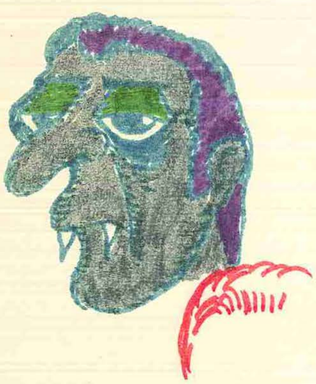
Electronics

R.J. Marks II Class Notes
Electronics
Rose-Hulman Institute of Technology
(1970-1971)

ELECRONICS I



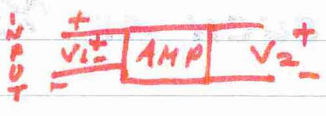
ELECTRON I

ELECTRONI

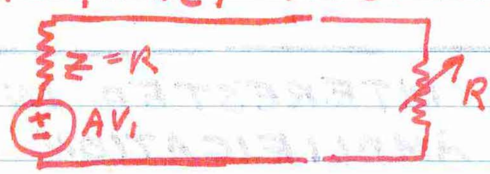
4-1-70 (LAB)

NEXT WEEK: MEASURE CHARACTERIST. OF AMPLIFIER.

1) GAIN: V_2/V_1

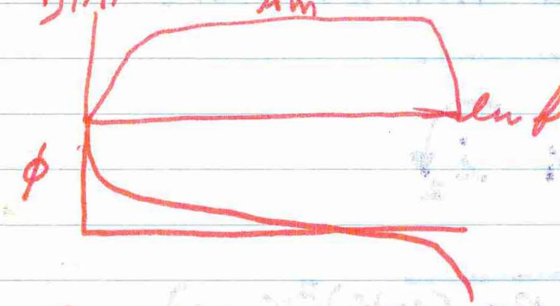


2) FREQUENCY RESPONSE

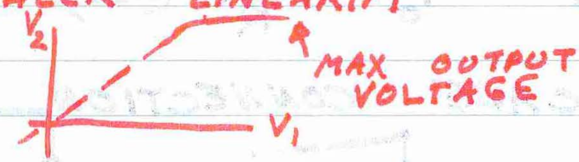


3) PHASE SHIFT BETWEEN V_1 & V_2

4) |A|



5) CHECK LINEARITY



6) TRANSIENT RESPONSE

7) INPUT AND OUTPUT IMPED. (ASUME RESISTIVE)

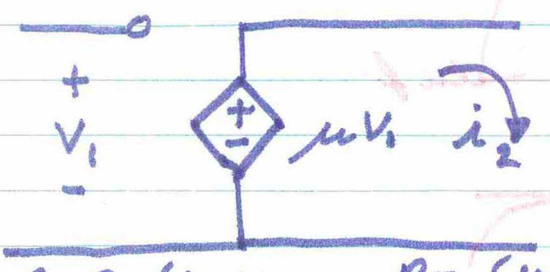
4-1-70

ANTENA SHOULD BE IN SAME DIMENSION (MAGNITUDE) OF TRANSMITED λ (SUCH AS $\lambda/2$)

$$\lambda = c/f$$

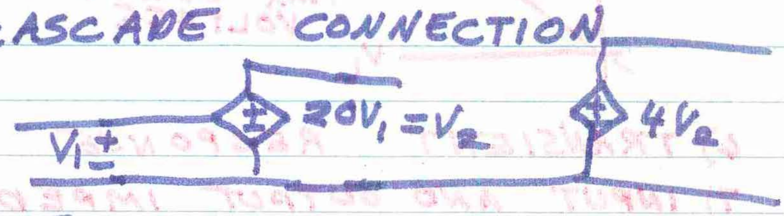
PRIMARILY INTERESTED IN POWER AMPLIFICATION

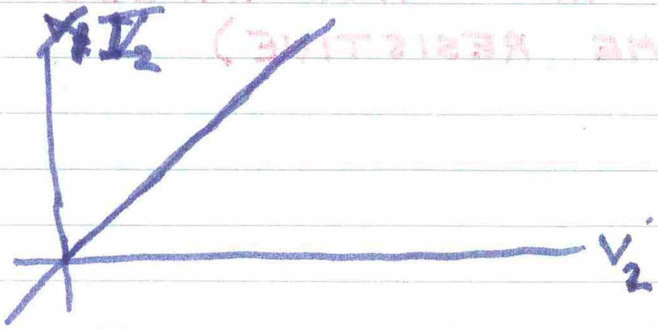
A) IDEAL VOLTAGE AMPLIFIER

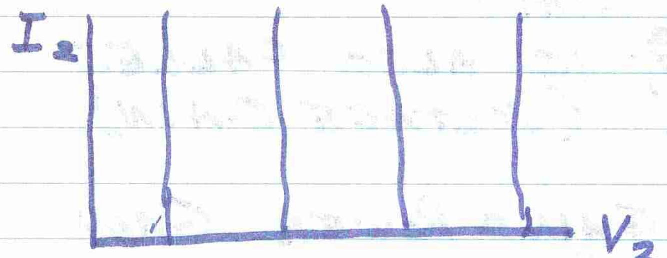


$P_i = 0$ $(i = 0)$ $P_o = \frac{(\mu V_1)^2}{R}$ $(= \infty)$

CASCADE CONNECTION

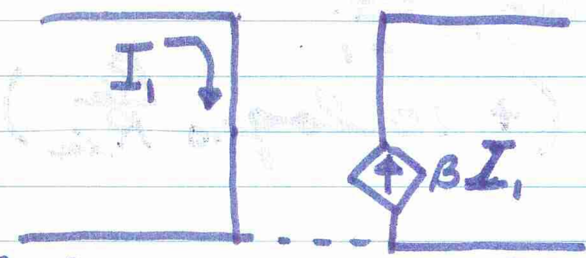






V INDEPENDENENT OF I

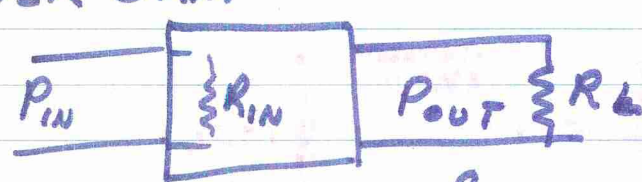
B) IDEAL CURRENT AMPLIFIER



$P_i = 0$ $\qquad$ $P_o = (\beta I_1)^2 R$

∞ POWER GAIN

C) POWER GAIN



$G_{dB} = 10\, ln_{10}\, P_o/P_1$

deciBel

$P_{IN} = V_1^2/R_{IN}$ $\qquad$ $P_o = V_2^2/R_L$

$\therefore G_{dB} = 10 \log_{10} \frac{V_2^2 R_n}{V_1^2 R_1^2} = 20 \log_{10} \frac{V_2}{V_1}$

$+ 10 \log_{10} \frac{R_{IN}}{R_{OUT}}$

D) VOLTAGE GAIN

$20 \log_{10} \frac{V_2}{V_1}$ IS ALSO CALLED DECIBEL (VOLTAGE GAIN)

VOLTAGE GAIN = POWER GAIN IFF $R_{IN} = R_{OUT}$

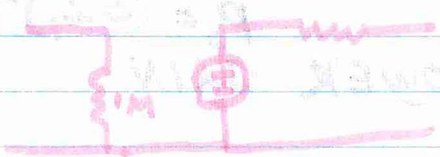
E) CURRENT GAIN (dB)

$G_{dB} = 20 \log_{10} \frac{I_2}{I_1}$

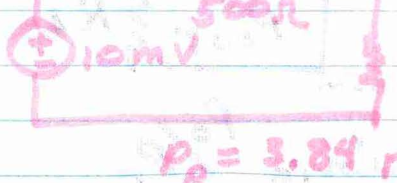
$\left(+ 10 \log_{10} \frac{R_L}{R_{in}}\right)$

4-3-70

2-6)

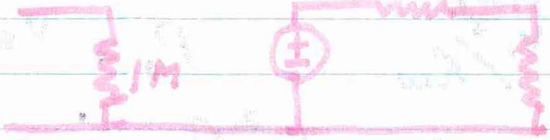


a)



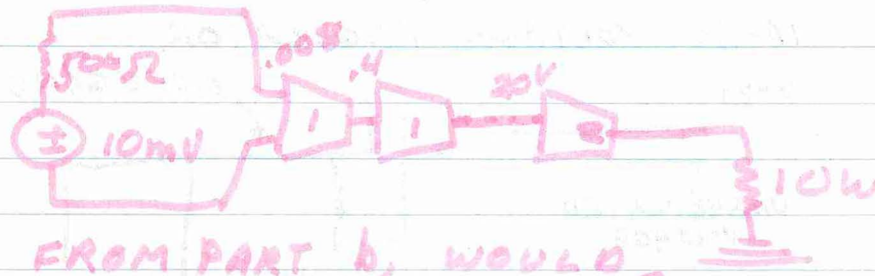
$P_R = 3.84$ nW

b) WITH ONE AMP



$1 = A_V \Rightarrow 20$ V FOR 10 WATTS

c)



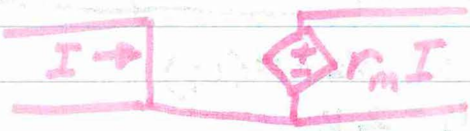
FROM PART b, WOULD WANT TO USE SECOND ?

$\frac{1000}{1000+5}$

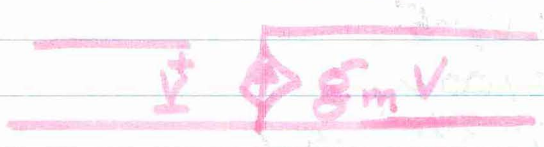
VOLTAGE GAIN ≅ 50

OTHER IDEAL AMPLIFIERS

1) TRANS RESISTANCE AMP



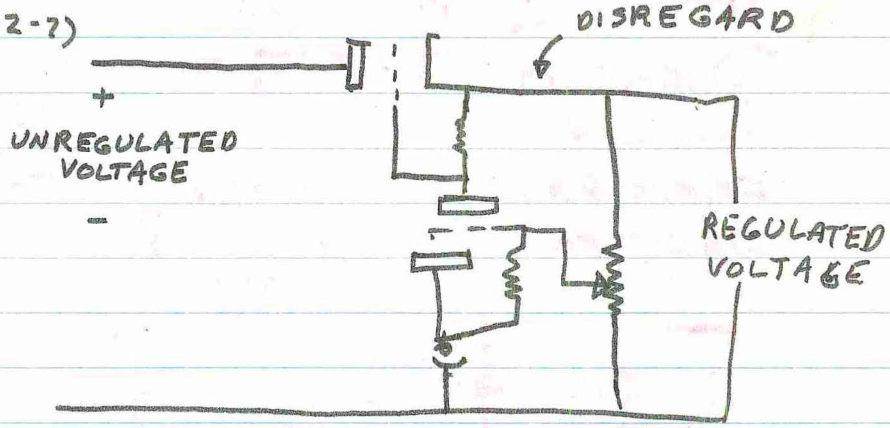
2) TRANS CONDUCTANCE

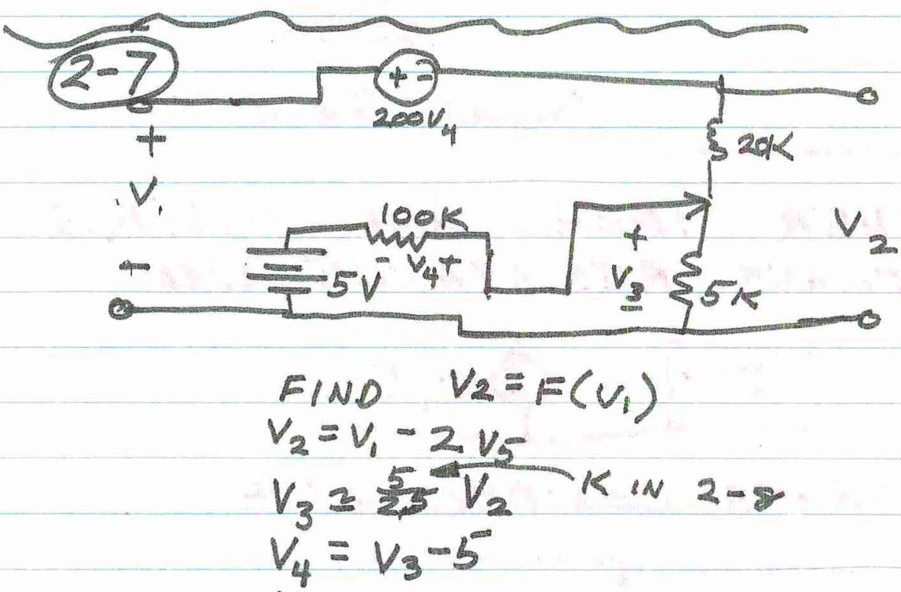


4-6-70

IDEAL VOLTAGE REGULATOR

2-7)





FIND $V_2 = F(V_1)$

$V_2 = V_1 - 2V_5$

$V_3 = \frac{5}{25} V_2$ ← K IN 2-8

$V_4 = V_3 - 5$

$V_5 = 100 V_4$

$V_5 = 100\left(\frac{5}{25}(V_1 - 2V_5) - 5\right)$

$= 20V_1 - 40V_5 - 500$

$V_5 = \frac{20}{41} V_1 - \frac{500}{41}$

$V_2 = V_1 - 2\left(\frac{20}{41} V_1 - \frac{500}{41}\right)$

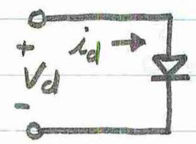
$= \frac{V_1}{41} + \frac{1000}{41}$

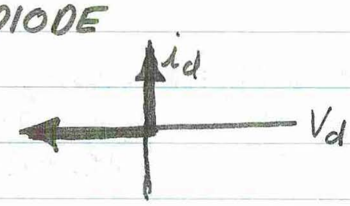
FOR $V_1 = 35$; $V_2 = 1035/41$

$V_1 = 40$; $V_2 = 1040/51$

$\frac{dV_2}{dV_1} = \frac{1}{41}$

THE IDEAL DIODE



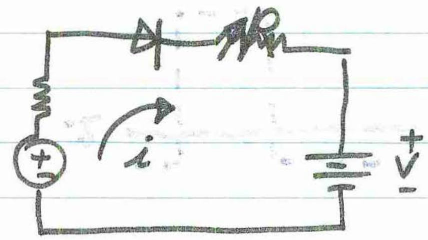


FORWARD BIAS; $V_d = 0$ FOR $i_d > 0$

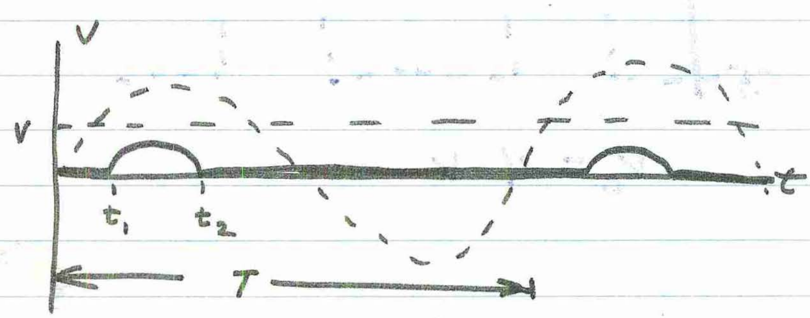
REVERSE BIAS; $i_d = 0$ FOR $V_d < 0$

HALF WAVE RECTIFIER'S ARE NEAT

BATTERY CHARGERS ARE ALSO NEAT



$$i = \begin{cases} \dfrac{V_s - V}{R_s + R} & \text{FOR } V_s > V \\ 0 & \text{FOR } V_s < V \end{cases}$$



$$I_{AV} = I_{dc} = \frac{1}{T}\int_{t_1}^{t_2} \frac{V_s \sin \omega t - V}{R_s + R}\, dt$$

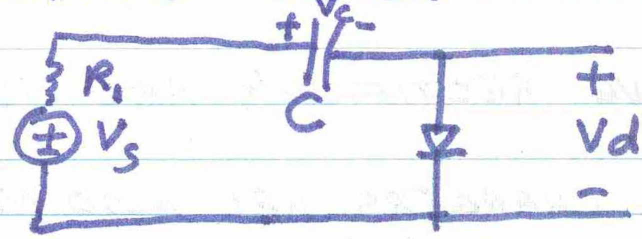
$$= \frac{1}{\omega T}\int_{\omega t_1}^{\omega t_2} \frac{V_s \sin(\omega t) - V}{R_s + R}\, d(\omega t)$$

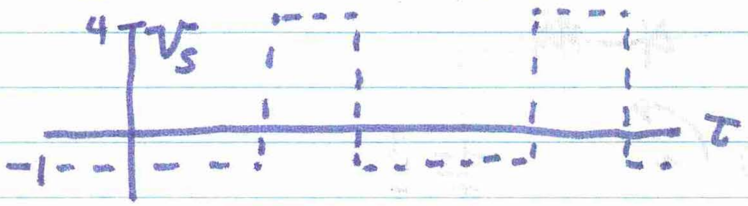
WHERE $\sin \omega t_1 = \sin \omega t_2 = \frac{v}{V_S}$

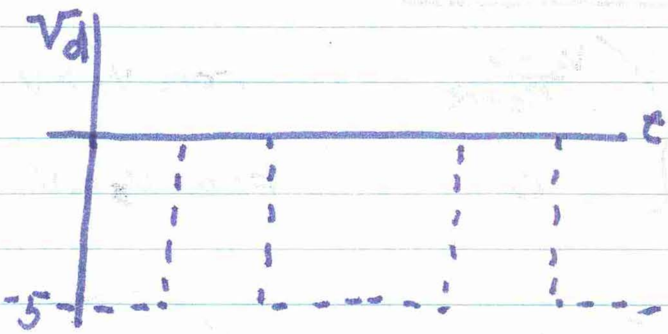
$$I_{AVE} = \frac{1}{2\pi} \int_{\theta_1}^{\theta_2} \frac{V_2 \sin\theta - v}{R_L + R_S} \, d\theta$$

4-8-70

CLAMPING CIRCUIT

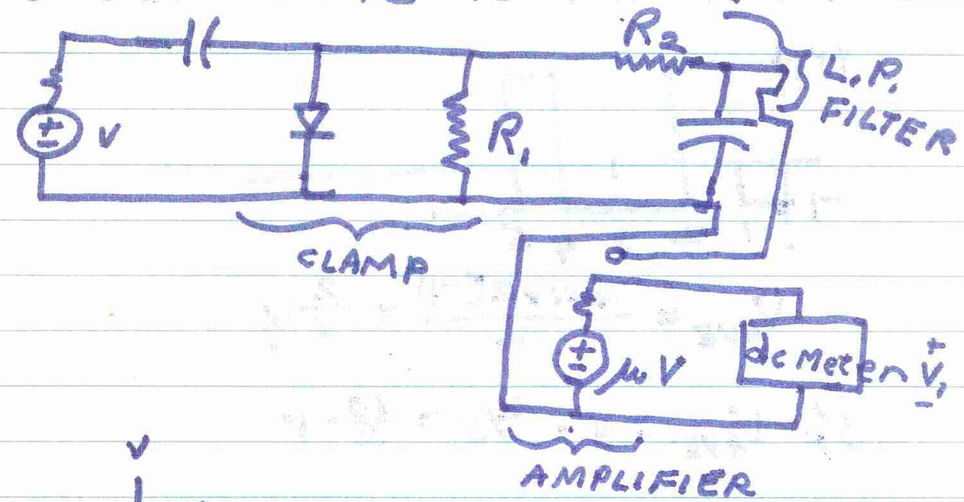


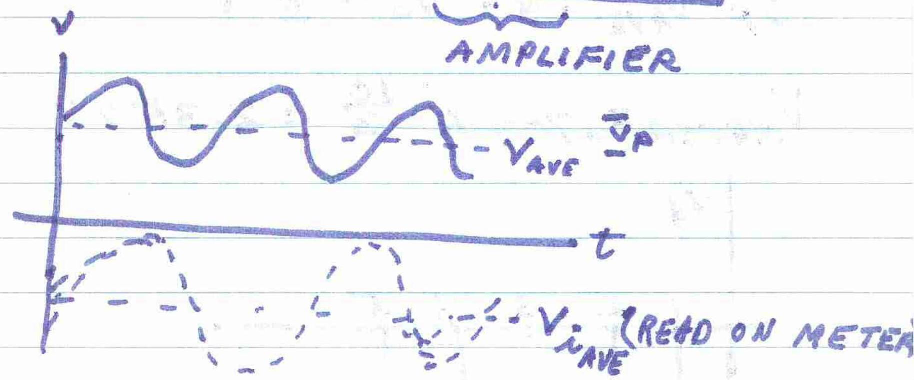




$V_c = 4$ V

A-C ELECTRONIC VOLTMEER





$V_{METER} = K|V_1| = K(V_p - V_{AVE})$

K IS SELECTED SO THAT

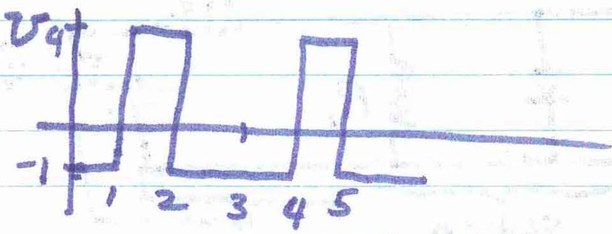
V_{METER} = RMS VALUE OF THE a-c PART OF v

FOR $v = V_s \sin \omega t + V_{AVE}$

$V_{RMS_{AC}} = \frac{V_s}{\sqrt{2}} = .707 V_s$

$\therefore K = .707$ SINCE $V_p - V_{AVE} = V_s$

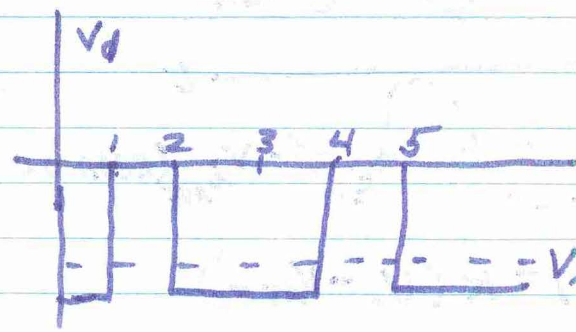
FOR NON-SIN WAVE INPUT



$$V_{AVE} = \frac{4 \times 1 + 2(-1)}{2} = \frac{2}{3} V_1$$

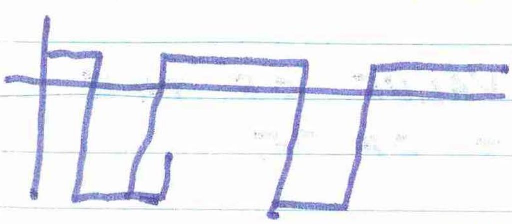
$$V_P - V_{AVE} = 4 - 2/3 = \frac{10}{3}\ V$$

$$V_{METER} = .707 \times \frac{10}{3} = 2.357\ V$$



$$V_i = \frac{-2 \cdot 5}{3} = \frac{-10}{3}$$

IF WAVE IS TURNED OVER

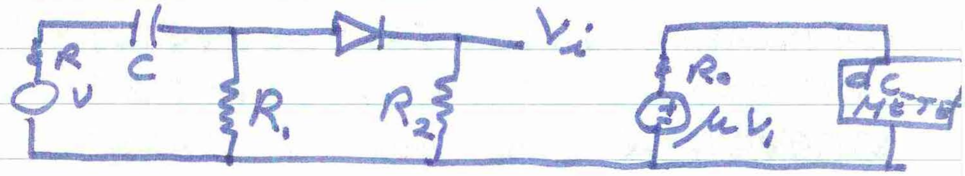


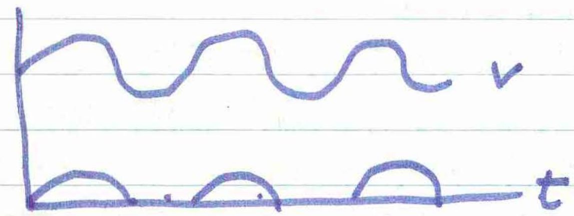
$$V_{AVE} = -2/3$$
$$V_p - V_{AVE} = 1 + 2/3 = 5/3$$

$$V_{METER} = .707 \times \frac{5}{3} = 1.178\ V$$

A PEAK ABOVE AVERAGE METER

AVERAGE METER

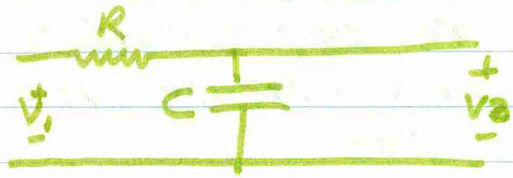




PEAK TO PEAK VALUE METER ARE FASCINATING

4-13-70

TRANSFER RATIO



$$\frac{V_2}{V_1} = \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R} = \frac{1}{1 + j\omega RC}$$

A SYSTEM FUNCTION

7) $\omega = 0 \Rightarrow$ d-c CASE

$$\left.\frac{V_2}{V_1}\right|_{dc} = 1$$

$$\left.\frac{V_2}{V}\right|_{\omega = 10^5} = 10^{-4}$$

NEW TERMS IN CHAPTER 3

1) FORWARD BIAS - EASY DIRECTION OF CURRENT (AS IN DIODE)

2) REVERSE BIAS - AS VOLTAGE IN A DIODE

3) HALF WAVE RECTIFIER - 

4) P.I.V. → PEAK INVERSE VOLTAGE (DIODE BREAKDOWN VOLTAGE

5) DIODE LIMITER - LIMITS OUTPUT VOLTAGE

6) PEAK RECTIFIER - KEEP CONSTANT VOLTAGE OUTPUT, BY USE OF A CAPACITOR

7) DIODE DEMODULATOR - SPECIAL RECTIFIER TO GET ENVELOPE

8) DIODE CLAMP - MOVE MAX OR MIN TO V=0

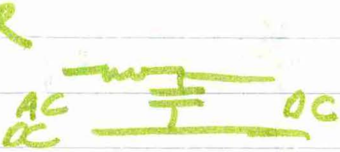
9) VOLTAGE DOUBLER - CLAMPER WITH A PEAK RECTIFIER

10) FULL WAVE RECTIFIER - TWO HALF STEP RECTIFIER

11) BRIDGE RECTIFIER - FULL WAVE RECTIFIER

12) FILTER CAPACITOR

13) BLOCKING CAPACITOR



3-14)

(SEE SCEMATIC)

a) $V_2 = V_1 - 2V_5$

$V_5 = 100 V_4$

$V_4 = V_3 - 5$

$V_3 \simeq 5/25 V_2$ (ASSUMING MINIMAL CURRENT)

PLUG; CHUG

$V_2 = V_1 - 2[100(\frac{1}{5}V_2 - 5)]$

$= V_1 - 40V_2 + 1000$

$V_2 = 1/41\ V_1 + \frac{1000}{41}$

b) $\Delta V_2 = \frac{dV_2}{dV_1}\Delta V_1 = \frac{\Delta V_1}{41}$

c) $V_2/_{dc} = \frac{37.5 + 10^3}{41} =$

$V_2/_{ac} = \frac{2.5 \sin 2\pi 120t}{41}$

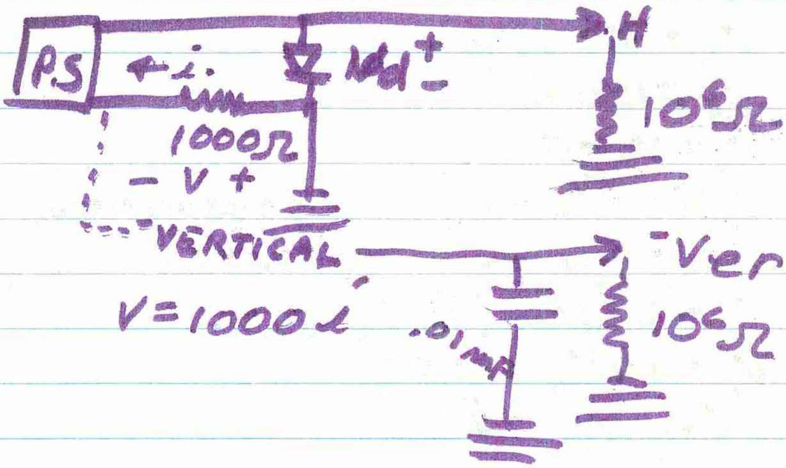
d) WILL FILTER AC COMPONENT

$V_2 = \frac{1}{200}V_1 + \frac{1000}{200} \rightarrow$ a.c.

$\Delta V_2 = \frac{\Delta V_1}{201}$

$V_2/_{a.c.} = \frac{2.5 \sin 2\pi 120t}{201}$

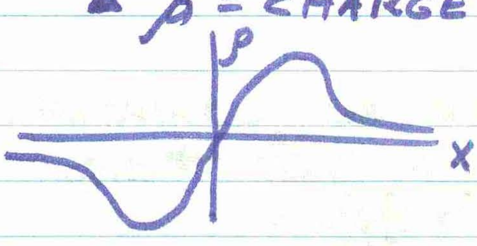
4-15-70 (LAB)



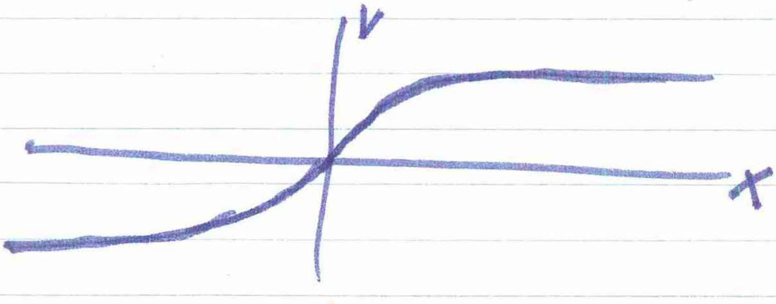
V = 1000 i

4-17-70
CH. 4
p. 78 PN JUNCTION WITH NO APPLIED VOLTAGE

ρ = CHARGE DENSITY

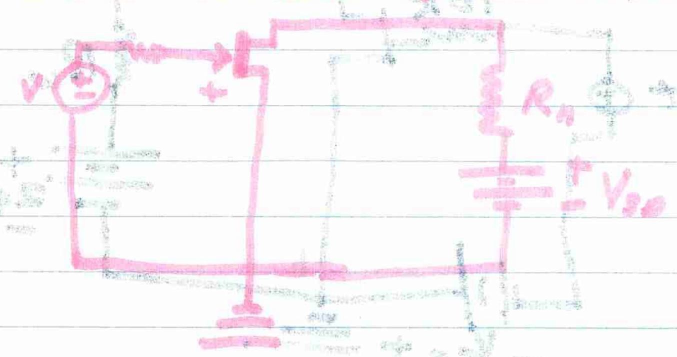


$$\frac{\partial^2 V}{dx^2} = \frac{-\rho}{\epsilon}$$



4-20-70

FET AMPLIFIER

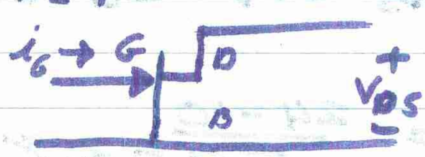


n-CHANNEL

MAJ CARRIER

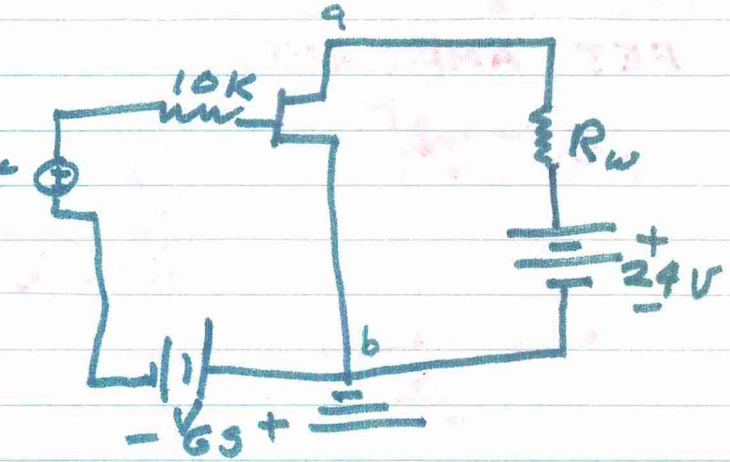
4-24-70

FET



V-i EQUATIONS
(IN TEXT)

4-27-70



$V_p = -5V$

$I_{DR_{SC}} = 10mA$

a) FIND R_d, SO DC OPERATING POINT IS $V_{DS} = 10V$ $I_d = 5ma$

$V_{ab} = 10V$

$$R_d = \frac{V_{DD} - V_{DS}}{I_D} = \frac{24 - 10}{5mA} = 2.8K$$

b) FIND V_{GG} VALUE AT THIS POINT

$$I_d = I_{DGS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$I_D = I_{DG}\left(1 + \frac{V_{GG}}{V_P}\right)^2$$

$$.5\,mA = 10\left(1 + \frac{V_{GG}}{-5}\right)^2$$

$$V_{GG} = 5(1 - .707) = 1.47V$$

c) FIND ac COMPONENTS OF V_{DS}

$$V_{DS} = V_{DD} - R_d i_d$$

$$= V_{DD} - R_d I_{DDS}\left(1 - \frac{V_i - V_{GG}}{V_P}\right)^2$$

$$= V_{DD} - R_d I_{DSS}\left[\left(1 - \frac{V_{GG}}{V_P}\right)^2 - 2\left(1 - \frac{V_{GG}}{V_P}\right)\frac{V_i}{V_P} + \left(\frac{V_i}{V_P}\right)^2\right]$$

$$= V_{DD} - R_d I_{DDS}\left(1 - \frac{V_{GG}}{V_P}\right)^2 \leftarrow DC$$

$$+ 2 R_d I_{DDS}\left(1 - \frac{V_{GG}}{V_P}\right)\frac{V_s}{V_P}$$

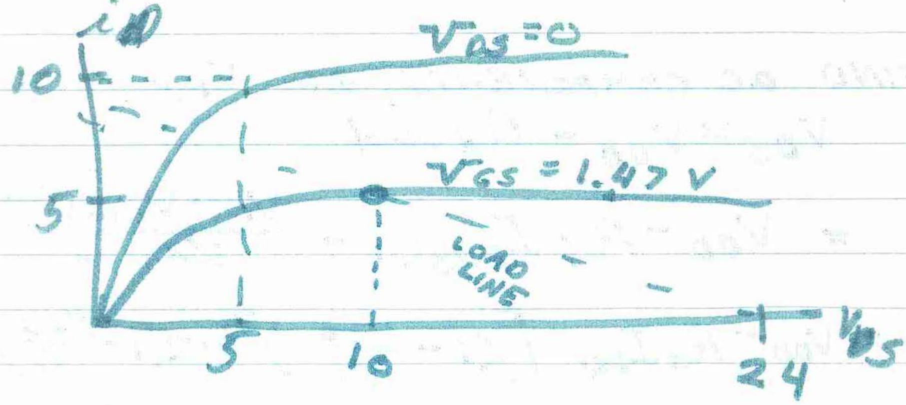
$$- R_d I_{DDS}\left(\frac{V_i}{V_P}\right)^2 \leftarrow \text{DISTORTION}$$

DC ↓

$$= 10 + 2 \times 2.8^k \, 10^{-3}\left(1 - \frac{1.47}{-5}\right)\frac{.1\cos\omega t}{-5} - 28\left(\frac{.1\cos\omega t}{-5}\right)^2$$

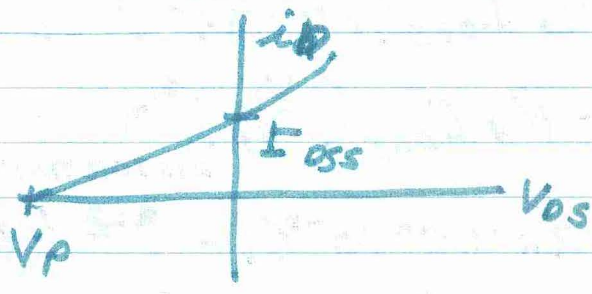
$$= 10 - .544\cos\omega t - .0112\left(\tfrac{1}{2} + \tfrac{1}{2}\cos 2\omega t\right)$$

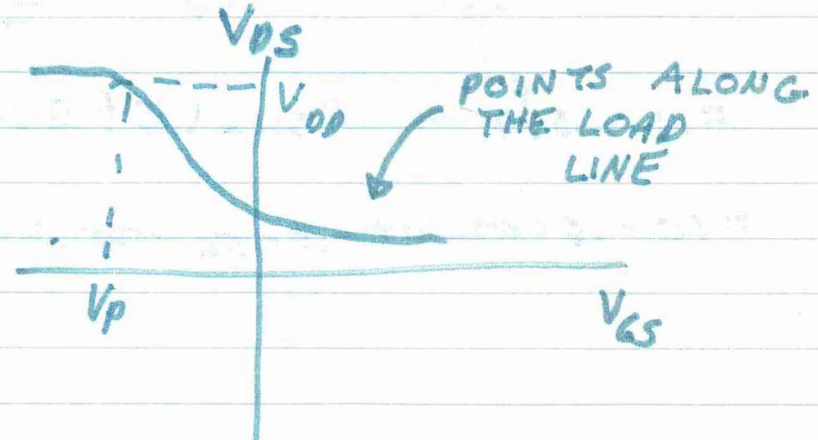
$$= 10 - .6\cos\omega t - .0056 - .0056\cos 2\omega t$$



$P_D = 10V \times 5mA = 50mW$
OF QUIESCENT PWR

TRANSFER CURVES





$V_{DS} = V_{DD} - i_D R_d$

5-1-70

$$-43 = 43\,e^{j\pi}$$

$$\ln_e y = \log_e 43 + \ln_e \varepsilon^{j\pi}$$

$$= \ln 43 + j\pi$$

HARMONIC DISTORTION

$$\text{FIRST HARMONIC} = \frac{2 R_d I_{DSS}}{-V_p}$$

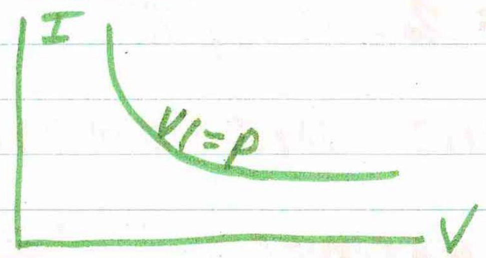
$$D = \frac{-V_1}{4(V_p + V_{GG})} = \text{DISTORTION}$$

INTERMODULATION DISTORTION

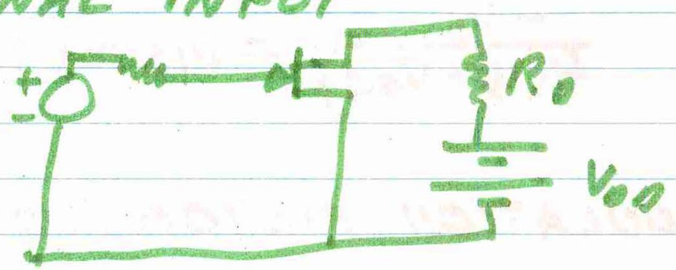
5-4-70

CONSTANT POWER HYPERBOLAS

$P = VI$



RELATION BETWEEN ~~OM~~ QUIECEST PWR. DISIPATION AND DISCIPATION WITH SIGNAL INPUT



$i_D = I_D + i_d$

$V_{DS} = V_{DS} + v_{ds}$

↑ D-C. BIAS   ↑ A.C. SIGNAL

FROM

$V_{DD} \Rightarrow P_{DD} = V_{DD}\, i_d = V_{DD}(I_D + i_d) =$

$= V_{DD}\, I_D = P_{DD}$

↑ IF i_d HAS 0 AVERAGE VALUE

IN R_d

$$P_R = R_d i_D^2 = R_d (I_D + i_d)^2$$

$$= R_d I_D^2 + 2 R_d I_D i_d + R_d i_d^2$$

($\leftarrow$ 0 AVE. VALUE)

AVER PWR IN R_d } $$P_R = R_d I_D^2 + R_d (i_d)^2_{AVE}$$

($R_d I_D^2$: D.C; $R_d (i_d)^2_{AVE}$: A.C.)

DRAIN PWR IN FET

$$p_T = v_{DS} i_d = (V_{DD} - R_d i_D) i_D$$

$$= V_{DD} i_d - R_d i_D^2$$

$$= p_{DD} - p_R$$

AVER. PWR. TO THE DRAIN

$$P_T = P_{DD} - P_R$$

5-6-70

ELECTRONICS I

EE 262 Spring 1970

TEXT: Angelo, <u>Electronics</u>, BJT's FET's & Microcircuits

DATE	PAGES	TOPIC	PROBLEM ASSIGNMENT
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3	16-19	Special Amplifier Application	2-8
6	25-34	Diode Circuits	3-1,2
8	35-41	Clamping Circuits	3-5,8
10	41-48	Monopulse Circuit	3-7
13		Example Problems	3-13
15	scan Ch.4	Movie "Minority Carriers"	3-15
17	" Ch.5	P-N Junction	5-1,2
20	105-109	FET	
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18		Example Problems	
20	213-236	Physics of BJT	
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25	243-250	Power Relations	
27		Example Problems	
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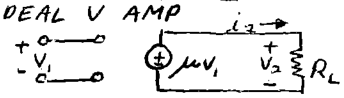
JUNE 1	269-280	Bias Stabilization	
3	281-292	Small Signal Models	
5	292-299	Hybrid- Model	
8		Example Problems	

[redacted]

• IDEAL V AMP

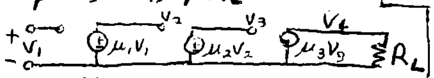


μ-VOLTAGE AMPLIFICATION FACTOR

$V_2 = \mu V_1$ (VOLTAGE CONTROLLED SOURCE)

OUTPUT IND. OF CURRENT

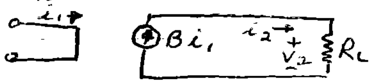
$p = (\mu V_1)^2 / R_L$



$V_4 = \mu_1 \mu_2 \mu_3 V_1$

$p = V_4^2 / R_L$

• IDEAL CURRENT AMP

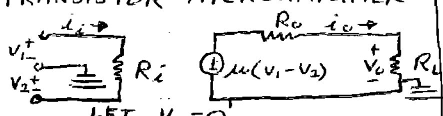


$i_2 = B i_2$

β-CURRENT AMPLIFICATION FACTOR

$p = (B i_1)^2 R_L$

• TRANSISTOR MICROAMPLIFIER



LET $V_2 = 0$

$V_o = \frac{R_L}{R_o + R_L} \mu V_1$

A_v = VOLTAGE GAIN $= \frac{R_L}{R_o + R_L} \mu$

A_c = CURRENT GAIN

$= \frac{i_o}{i_1} = \frac{V_o / R_L}{V_1 / R_i} = \frac{V_o R_i}{R_L V_1} = \frac{R_i}{R_L} A_v$

POWER DEL TO INPUT

$P_i = V_i^2 / R_i$

POWER DELIVERED $= P_o = V_o^2 / R_L$

POWER GAIN $= P_o / P_i$

$= \frac{V_o^2 R_i}{R_L V_1^2} = A_c A_v$

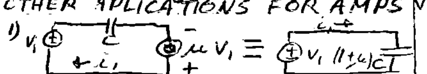
• GAIN IN DECIBELS

$G = 10 \log_{10} P_o / P_i$

$= 20 \log \frac{V_o}{V_1} + 10 \log \frac{R_i}{R_L}$

$A_v = 20 \log V_o / V_1$

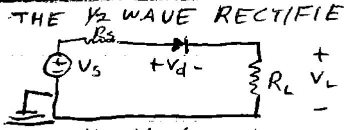
• OTHER APPLICATIONS FOR AMPS

1) 

$i_1 = C \frac{d}{dt}(V_1 + \mu V_1) = (1 + \mu) C \frac{dV_1}{dt}$

[redacted]

• THE ½ WAVE RECTIFIER

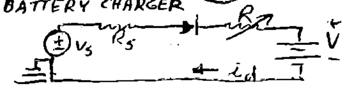


$V_s = V_s \sin \omega_s t$

$V_L = \frac{R_L}{R_s + R_L} V_s$; $V_s > 0$

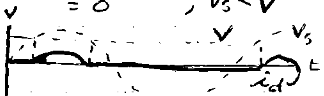
$= 0$; $V_s < 0$

BATTERY CHARGER

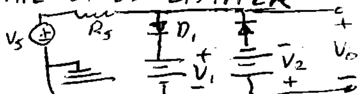


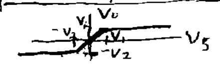
$i_d = \frac{V_s - V}{R_s + R}$, $V_s > V$

$= 0$; $V_s < V$

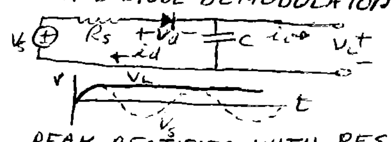


• THE DIODE LIMITER

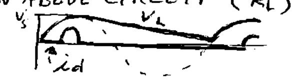




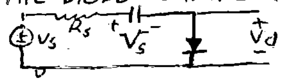
• THE PEAK RECTIFIER AND DIODE DEMODULATOR



PEAK RECTIFIER WITH RESISTIVE LOAD ACROSS V_L IN ABOVE CIRCUIT (R_L)



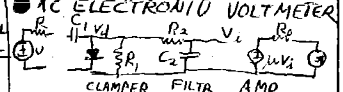
• THE DIODE CLAMPER

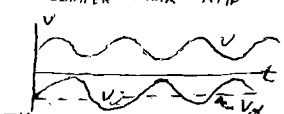


$V_d = V_s - V_s$

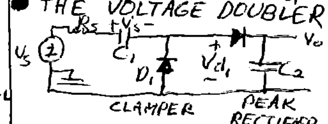
REVERSE DIODE & CAPAC POLARITY, CLAMPS BOTTOM TO T AXIS. MAY PUT BIG RES. ON V_d FOR DRAIN

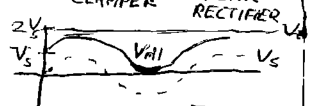
• AC ELECTRONIC VOLTMETER





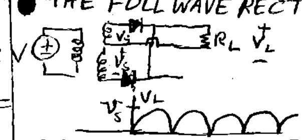
• THE VOLTAGE DOUBLER



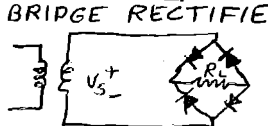


$V_{d11} = V_s + V$

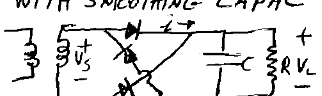
• THE FULL WAVE RECTIFIER



BRIDGE RECTIFIER



WITH SMOOTHING CAPAC



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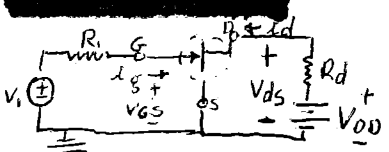


$V_{ds} = V_{DD} - R_d i_d$

$i_d = I_{dss} \left(1 - \frac{V_{GS}}{V_P}\right)^2$

$V_{DS} = V_{DD} - R_D I_{DDS} \left(1 - \frac{V_{GS}}{V_P}\right)^2$

$V_{GS} = V_1 - R_1 i_G \simeq V_1$

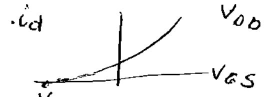
$V_{DS} = V_{DD} + 2 R_d I_{DDS} \frac{V_1}{V_P}$

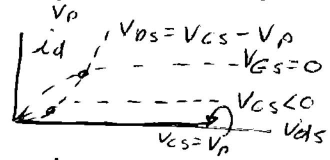
$- R_D I_{DSS} (V_1 / V_P)^2$

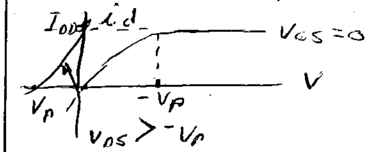
$V_{DS} = V_{DD} - R_d I_{DSS} + \frac{2 R_D I_{DSS}}{V_P} V_1$

$-K_V = 2 R_d I_{DSS} / V_P < 0$

$V_{DS} = V_{DD} - R_d I_{DSS} - K_V V_1$







$V_{DS} = V_{DS} - 2 K R_d (V_{GS} - V_T) V_1 \cos \omega t$

$- \frac{1}{2} K R_d V_1^2 - \frac{1}{2} K R_d V_1^2 \cos 2\omega t$

AT $i_D = 0$; $V_{GS} = V_T$

2) UNDISTORTED AMPLIFICATION

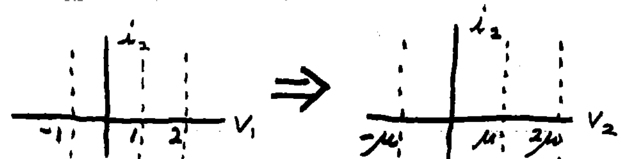
3) RELATED TO DISTORTION

4) SECOND HARMONIC

I) THE IDEAL AMPLIFIER

A) THE IDEAL VOLTAGE AMPLIFIER (VOLTAGE-CONTROLED SOURCE)

1)  $\Rightarrow V_2 = \mu V_1$

   a) 

   b) μ = VOLTAGE AMPLIFICATION FACTOR

2) OUTPUT VOLTAGE (V_2) IS INDEPENDENT OF OUTPUT CURRENT (i_2)

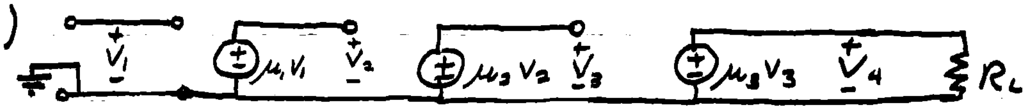
3) THE OUTPUT POWER FROM THE AMP:

   a) $P = [(\mu)(V_1)]^2 / R_L$

   b) R_L = LOAD RESISTANCE

   c) ANY AMOUNT OF POWER MAY BE DRAWN OUT OF AN IDEAL AMPLIFIER BY PROPERLY CHOOSING R_L

4) CASCADED VOLTAGE AMPLIFIERS

   1) 

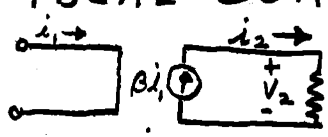
   2) OUTPUT VOLTAGE (V_4)

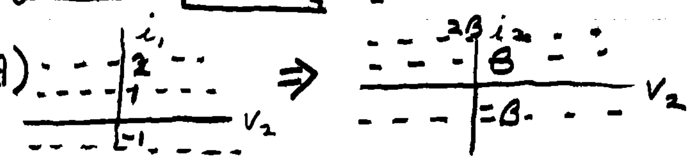
   $$V_4 = \mu_1 \mu_2 \mu_3 V_1$$

   3) POWER OUTPUT

   $$P = (\mu_1 \mu_2 \mu_3 V_1)^2 / R_L$$

B) THE IDEAL CURRENT AMPLIFIER (CURRENT CONTR. CURRENT SOURCE)

1)  $\Rightarrow i_2 = \beta i_1$

   a) 

   b) β = CURRENT AMPLIFICATION FACTOR

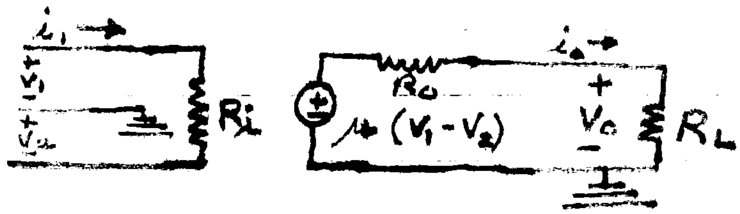
2) OUTPUT CURRENT (i_2) IS INDEPENDENT OF OUTPUT VOLTAGE (V_2)

3) OUTPUT POWER FROM AMP:

$$P = (\beta i_1)^2 R_L$$

C) A PRACTICAL TRANSISTOR MICROAMPLIFIER

1)



2) VOLTAGE & VOLTAGE GAIN (LET $V_2 = 0$)

a) $V_o = \frac{R_L}{R_o + R_L} \mu V_1$

b) $A_v = \frac{V_o}{V_1} = \frac{R_L}{R_o + R_L} \mu$

3) CURRENT & CURRENT GAIN (LET $V_2 = 0$)

a) $i_o = \frac{V_o}{R_L}$; $i_1 = \frac{V_1}{R_i}$

b) $A_c = \frac{i_o}{i_i} = \frac{V_o R_i}{R_L V_1} = \frac{R_i}{R_L} A_v$

4) POWER & POWER GAIN (LET $V_2 = 0$)

a) POWER DELIVERED TO INPUT (P_i)

$$P_i = V_1^2 / R_i$$

b) POWER DELIVERED BY AMP (P_o)

$$P_o = V_o^2 / R_L$$

c) POWER GAIN (G)

$$G = \frac{P_o}{P_1} = V_o^2 R_i / R_L V_1^2 = A_v A_c$$

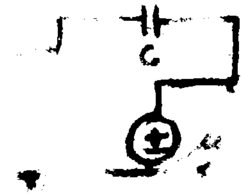
D) GAIN IN DECIBELS

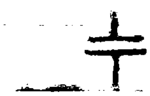
1) $G_p = 10 \log_{10} \frac{P_o}{P_1} = 20 \log_{10} \frac{V_o}{V_1} + 10 \log \frac{R_i}{R_L}$

$= 20 \log_{10} \frac{i_o}{i_1} + 10 \log_{10} \frac{R_L}{R_i}$

2) $A_v = 20 \log_{10} \frac{V_o}{V_1}$

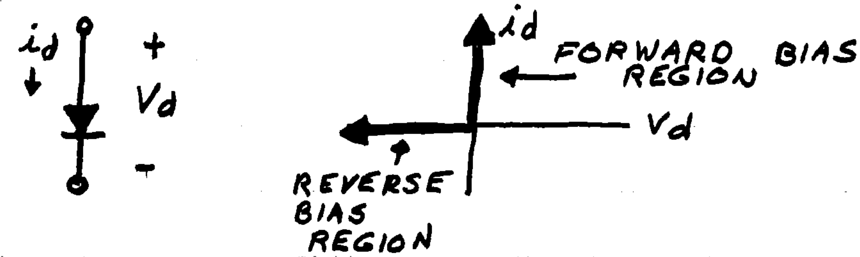
3) $A_c = 20 \log_{10} \frac{i_o}{i_1}$





II) THE IDEAL DIODE

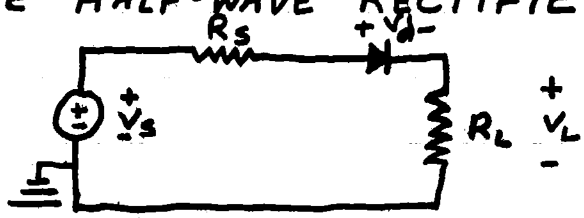
A) CHARACTERISTICS OF THE IDEAL DIODE



1) ACTS AS AN OPEN CIRCUIT WHEN $V<0$

2) ACTS AS SHORT CIRCUIT WHEN $i>0$

B) THE HALF-WAVE RECTIFIER

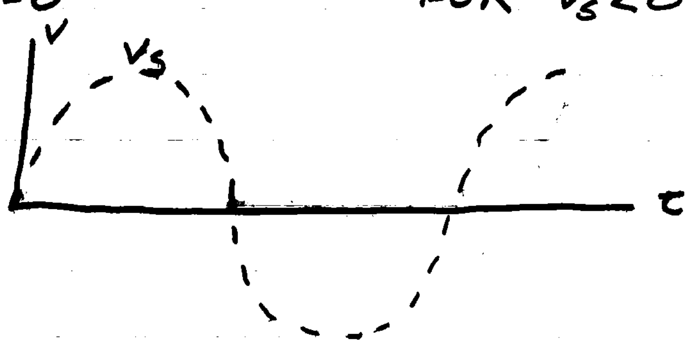


1) $V_s = \hat{V}_s \sin \omega_s t$

2) $V_L = \frac{R_L}{R_s + R_L} V_s$ FOR $V_s > 0$

$V_L = 0$ FOR $V_s < 0$

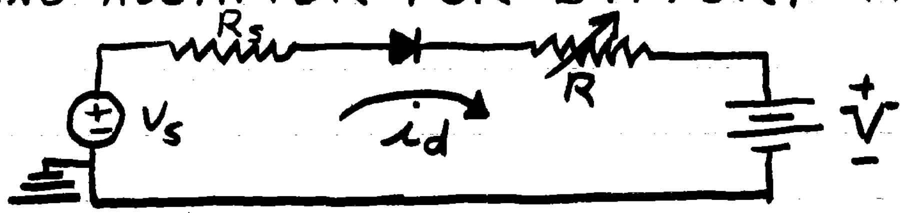
3)



4) RECTIFICATION - THE ACTION BY WHICH THE DIODE GENERATS DIRRECT VOLTAGE FROM AN ALTERNATING SOURSE

5) USING RECTIFIER FOR BATTERY RECHARGE

a)

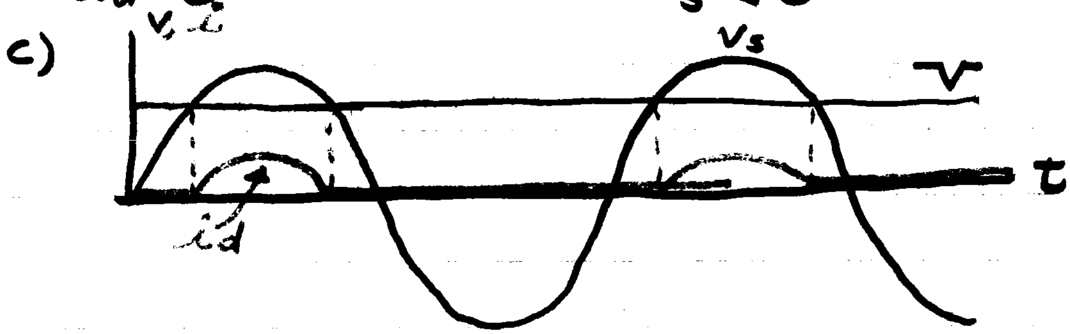


$v_s = V_s \sin \omega_s t$

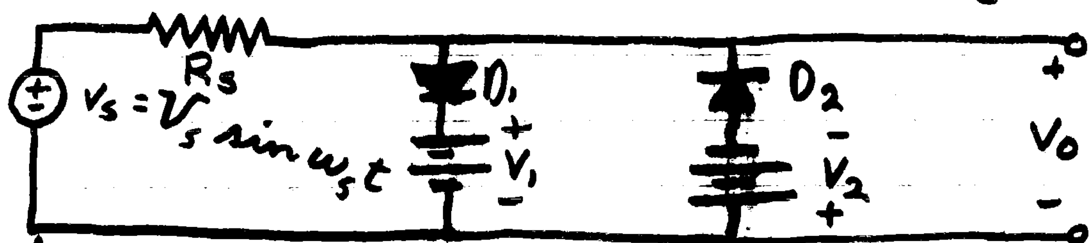
b) $i_d = \dfrac{v_s - \mathcal{V}}{R_s + R}$ FOR $v_s > \mathcal{V}$

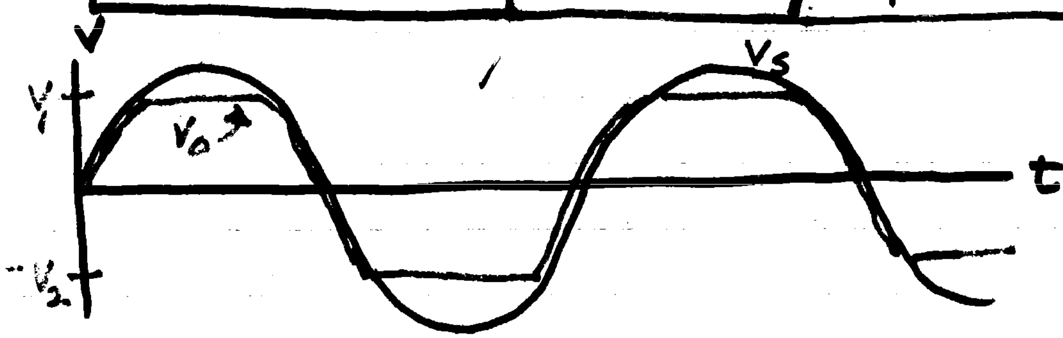
$i_d = 0$ FOR $v_s < \mathcal{V}$

c)



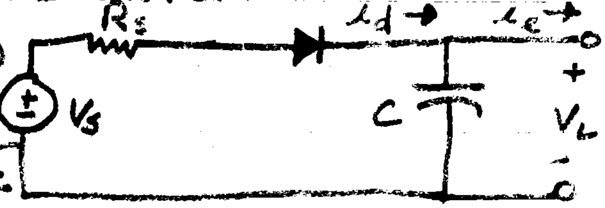
c) THE DIODE LIMITER - RESTRICTING OUTPUT V_o



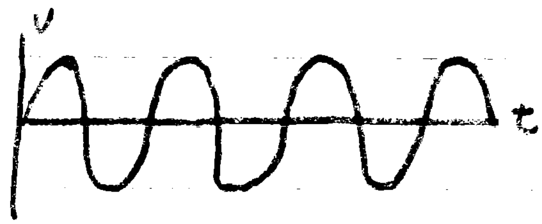


D) THE PEAK RECTIFIER AND DIODE DEMODULATOR

1) a)



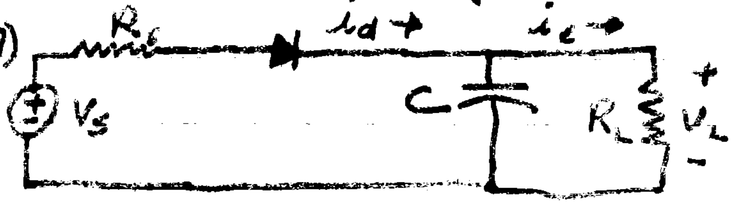
b)



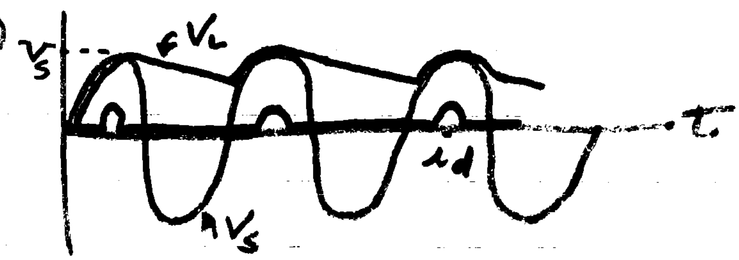
2) C CHARGES UP, & STAYS CHARGED

3) IF A RESISTER IS USED ON LOAD

a)

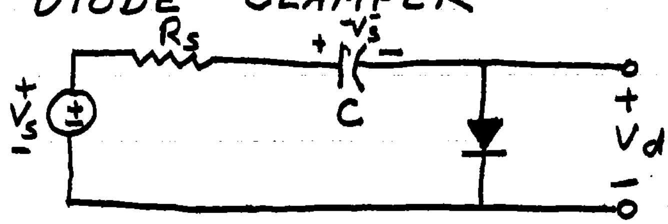


b)



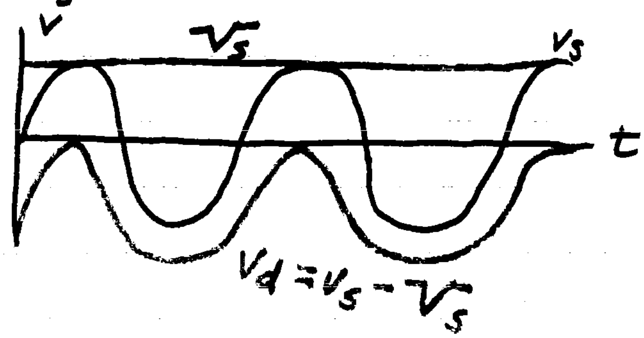
c) CAPACITOR DISCHARGES THRU RESISTOR.

E) THE DIODE CLAMPER



1) IDENTICAL WITH PEAK RECTIFIER, EXCEPT THE POSITIONS OF THE DIODE & CAPAC.

2) $V_d = V_s - V_S$

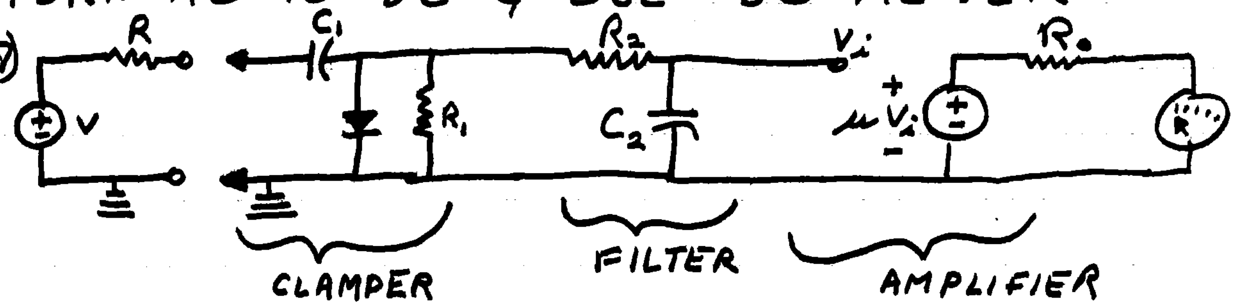


3) FOR CHANGES IN V_s, PUT SUITABLE RESISTANCE // WITH DIODE, SO CAPACITOR CHARGE MAY DRAIN OFF SLOWLY

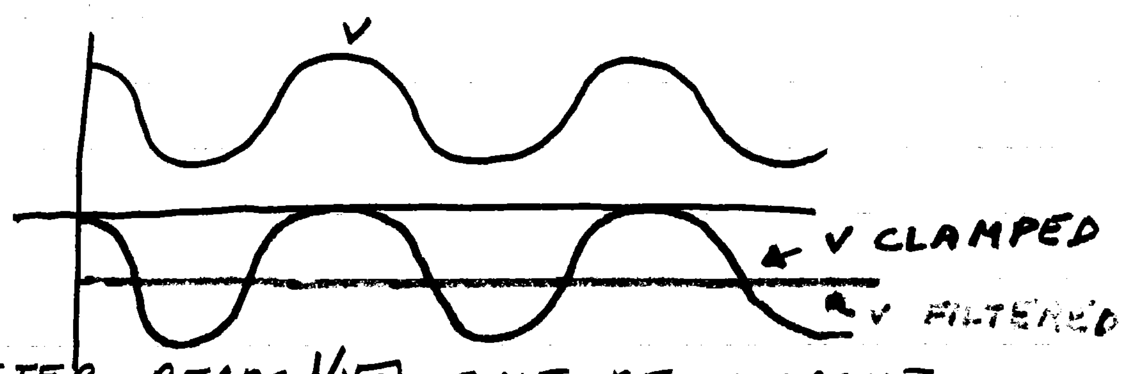
F) AN AC VOLTMETER

1) TURN AC TO DC & USE DC METER

2) a)



b)

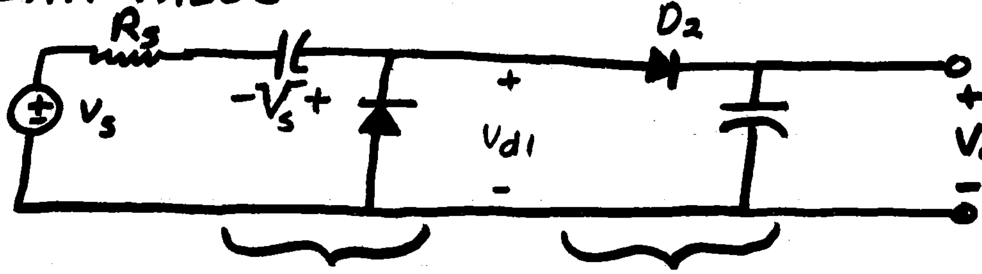


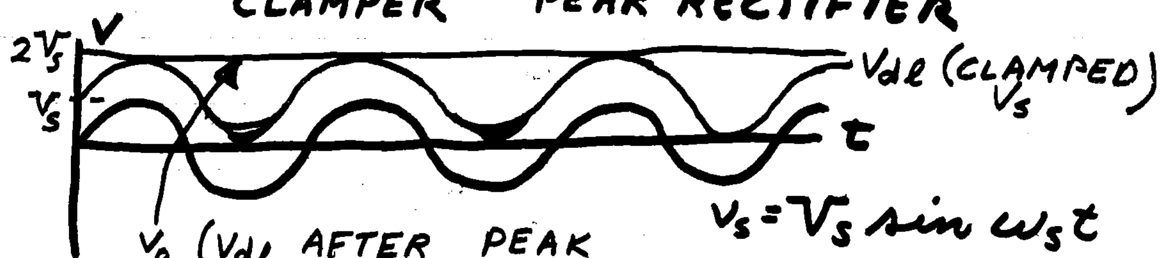
c) METER READS $1/\sqrt{2}$ TIME PEAK ABOVE AVERAGE READINGS (FILTERED V) GIVING RMS VALUE OF V AS A SINUSOID

G) THE VOLTAGE DOUBLER

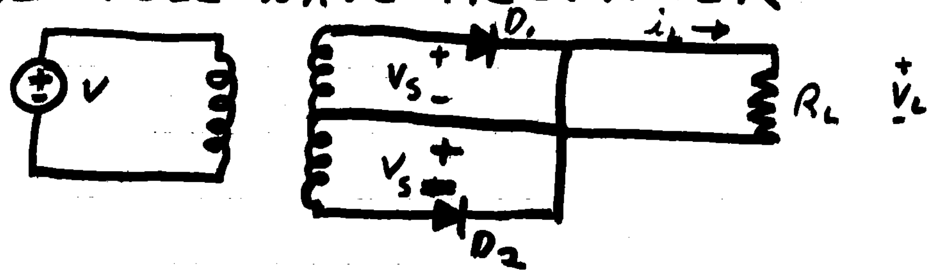
1) TAKES AC INPUT, & DOUBLES ITS PEAK VALUE

2)





H) THE FULL WAVE RECTIFIER



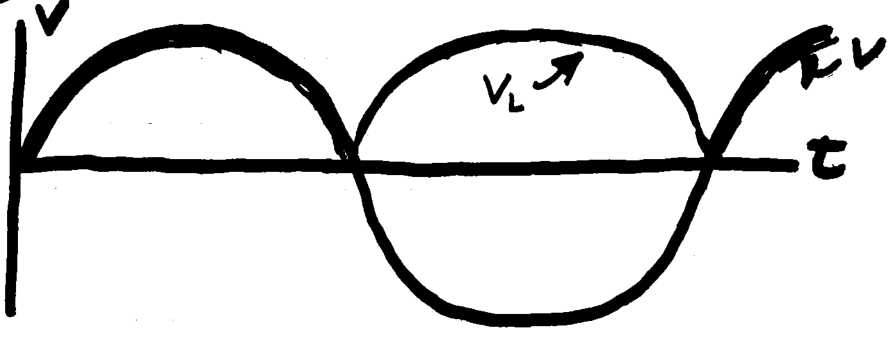
1) BASICALLY CONSISTS OF TWO HALF WAVE RECTIFIERS

2) WITH SINUSOID INPUT

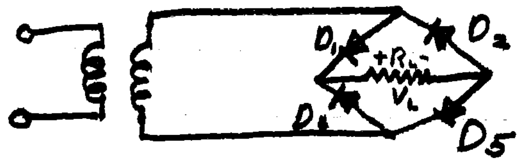
a) DURING + HALF OF CYCLE, D_1 ACTS AS SHORT CIRCUIT, D_2 OPEN

b) OPPOSITE ON NEGATIVE CYCLE

3)



4) THE BRIDGE RECTIFIER



a) WITH SINUSOID INPUT

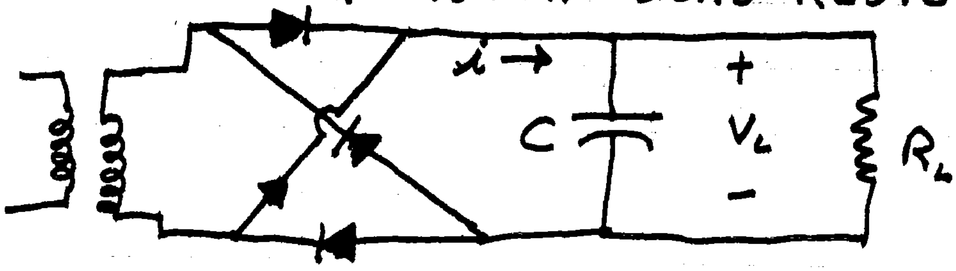
① FOR $V>0$, $R_L = V_{D_2} = V_{D_4}$

② OPPOSITE FOR $V<0$

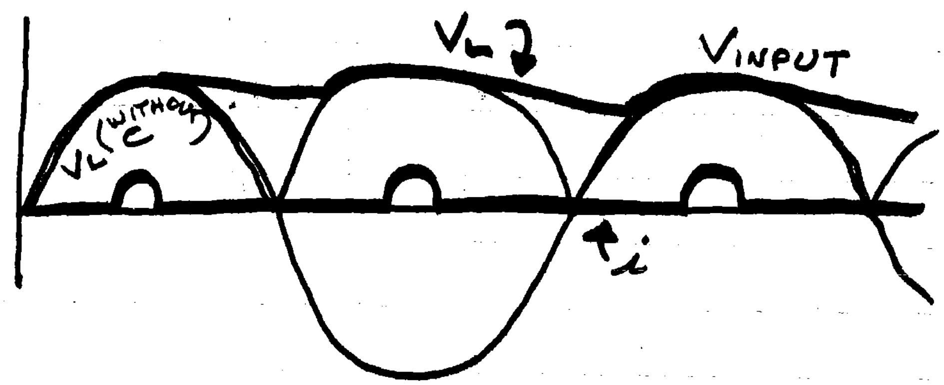
b) HAS SAME OUTPUT OF FULL-WAVE RECTIFIER

5) BRIDGE RECTIFIER WITH SMOOTHING CAPAC.

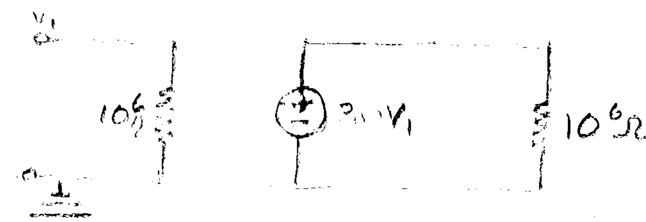
a) (PUT CAP ∥ WITH LOAD RESISTOR



b) SMOOTHS OUT v-t CURVE



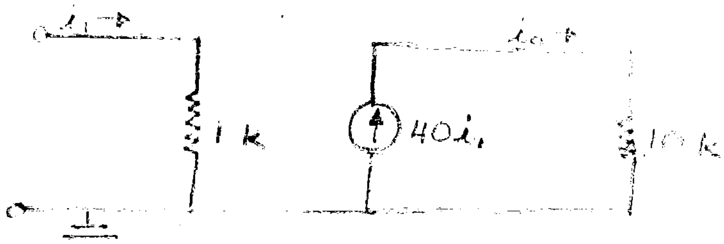
2-1) a)



$A_v = 20 \log_{10} 30 = 20(1.478) = 29.56$ dB

$R_i = R_o \Rightarrow G_p = A_v = 29.56$ dB

b)



$A_i = 20 \log_{10} 40 = 20(1.602) = 32.04$ dB

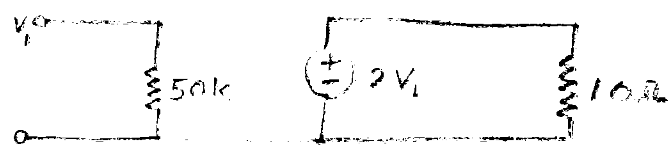
$G_p = 10 \log_{10} \frac{P_o}{P_i} = 10 \log_{10} \frac{i_o^2 R_o}{i_i^2 R_i}$

$= 20 \log_{10} \frac{i_o}{i_i} + 10 \log_{10} \frac{R_o}{R_i}$

$G_p = 20 \log_{10}(40) + 10 \log_{10} 10$

$= A_i + 10 = 42.04$ dB

c)



$A_v = 20 \log_{10} \frac{V_o}{V_i}$

$= 20 \log_{10} 2 = (20)(.301) = .602$ dB

$G_p = A_v + 10 \log_{10} \frac{R_i}{R_o} = .602 + 30 \log_{10} 5$

$= 21.6$ dB

d) $G_p = 10\log_{10}\frac{P_o}{P_i}$

$= 10\log_{10}\frac{V_o^2 R_i}{V_i^2 R_o}$

$= 20\log_{10}\frac{V_o}{V_i} + 10\log_{10}\frac{R_i}{R_o}$

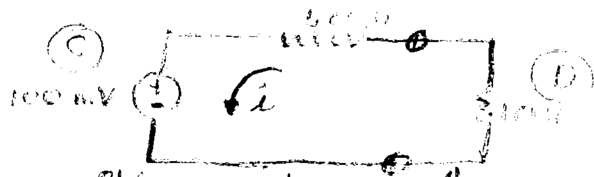
$= A_v + 10\log_{10}\frac{R_i}{R_o}$

$A_v = G_p + 10\log_{10}\frac{R_o}{R_i}$

$= 42.04 + 10\log_{10}10$

$= 52.04\,dB$

2-2) a)

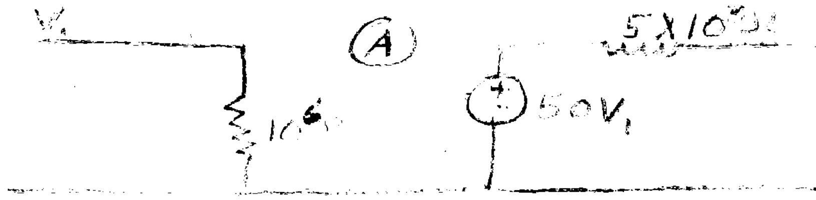


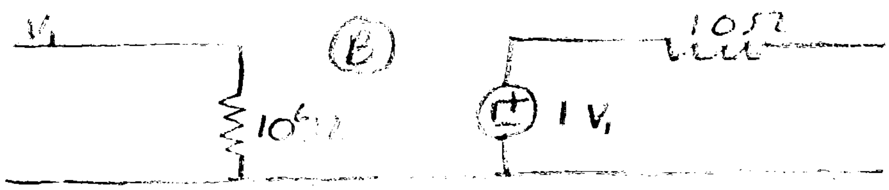
$i = .01/510 = \frac{1}{5.1} \times 10^{-4} = .196 \times 10^{-4}$

$P = i^2 R = (1.96)^2 \times 10^{-7}$

$= 3.84 \times 10^{-7}$ WATTS

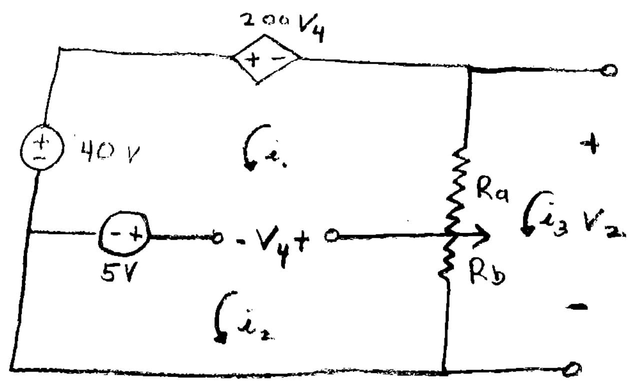
b)





$\Sigma V_i = 1.01$ V ?

$i_0 = .1$



$$V_2 - 40 + 200V_4 = 0 \Rightarrow V_4 = \frac{4}{20} - \frac{V_2}{200}$$

$$40 - 5 - 201V_4 + R_a i_1 - R_a i_3 \Rightarrow V_4 = \frac{+35}{201} + \frac{R_a i_1}{201} - \frac{R_a i_3}{201}$$

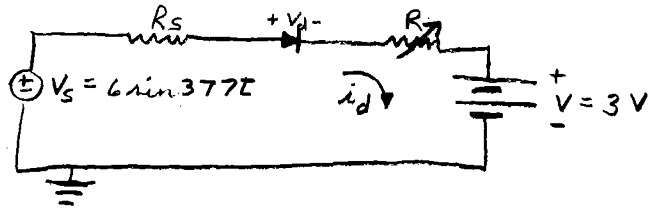
$$5 + V_4 + R_b i_1 - R_b i_3 = 0 \Rightarrow V_4 = R_b i_3 - R_b i_1 - 5$$

$$(R_a + R_b)(i_3 - i_1) = 0$$

$$R_a + R_b = 2.5 \times 10^4$$

$$\frac{4}{20} - \frac{V_2}{100} = \frac{35}{201} + \frac{R_a i_1}{201} - \frac{R_a i_3}{201} = R_b i_3 - R_b i_1 - 5$$

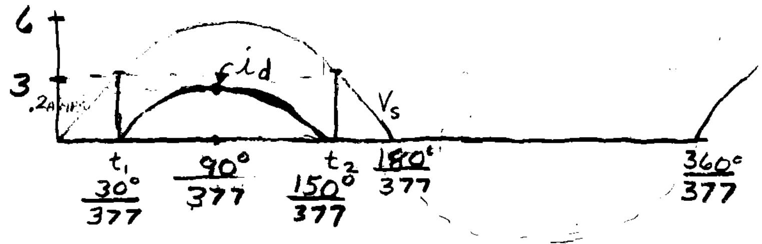
3-1)



a) $i_{d_{MAX}} = \frac{6-3}{R+R_s} = .2$

$R + R_s = \frac{3}{.2} = 15\,\Omega$

b)



$i_d = 0 \Rightarrow V_s = 6 \sin 377t = 3$

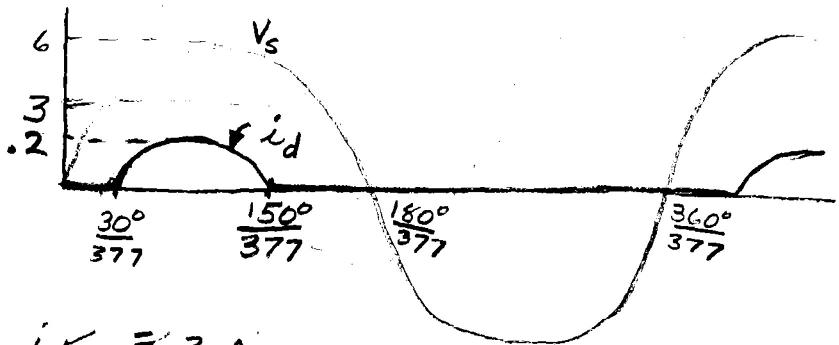
$\sin 377t = \frac{1}{2} \Rightarrow t = \frac{30°}{377}\ ; \ t = \frac{150°}{377}$

$\frac{120}{360} \times 100\% = \frac{1}{3} \times 100\% = 33\frac{1}{3}\%$

c) $V_{s_{MIN}} = {}^{-}6$

$V_{d_{MAX}} = {}^{+}6 + 3 = 9\ V$

~~3~~ 2) .2 A 60SEC = 12 COULOMBS



~~$i_{d_{MAX}} = 3$ A~~

~~$T = \frac{240°}{377} \Rightarrow f = \frac{377}{240°} \Rightarrow \omega = \frac{2(377)\pi}{240°} \frac{180°}{\pi}$~~

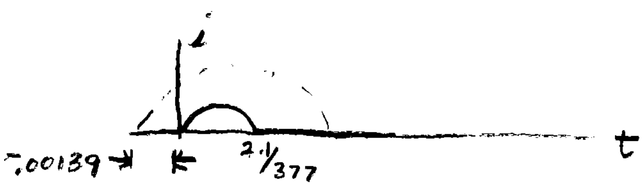
~~$i_d = 3 \sin 566t$~~

$240° = 4.19$ sec

$T = \frac{4.19}{377} = .0111$ sec

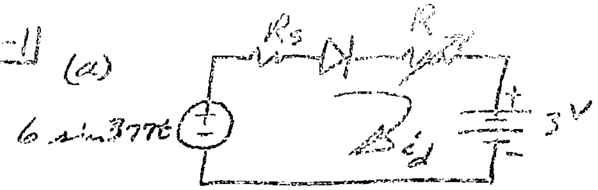
$f = 90 \Rightarrow \omega = 566$

$\therefore\ i_d = .2 \sin 566t\ (+.00139)\quad 0 < t < 120°$



$Q = .2 \int_0^{2.1}$

3-1 (a)

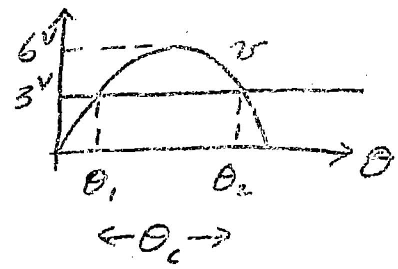


$$i_{d\,MAX} = \frac{V_s - V}{R + R_s}$$

$$0.2 = \frac{6-3}{R+R_s}$$

$$R + R_s = \frac{3}{0.2} = \underline{\underline{15\ \Omega}}$$

(b)



$$\sin\theta_1 = \sin\theta_2 = \frac{3}{6} = 0.5$$

$$\theta_1 = -\theta_2 + 180^\circ = 30^\circ$$

$$\theta_2 = 150^\circ$$

$$\theta_c = 150^\circ - 30^\circ = 120^\circ$$

the diode conducts $\frac{\theta_c}{360} = \frac{120}{360} = \underline{\underline{33.3\%}}$ of the time.

(c) The peak-inverse voltage appears across the diode when $v = -6$, Then $v_d = -6 - 3 = -9\ V$

$P.I.V. = \underline{\underline{9\ \text{Volts}}}$

3-2 The charge removed from the battery is

$$Q = I\,t = 0.2^A \times 60^{sec} = 12 \text{ coulombs}.$$

The diode current is $i_d = \frac{6\sin\theta - 3}{15}$ for $30^\circ < \theta < 150^\circ$.

The average charging current is

$$I_{d\,Ave} = \frac{1}{2\pi}\int_{\pi/6}^{5\pi/6} \frac{6\sin\theta - 3}{15}\,d\theta = \frac{1}{10\pi}\Big[-2\cos\theta - \theta\Big]_{\pi/6}^{5\pi/6}$$

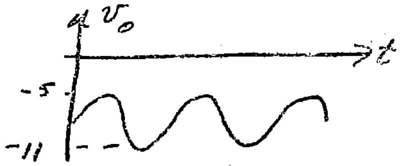
$$= \frac{1}{10\pi}\left[2\frac{\sqrt{3}}{2} - \frac{5\pi}{6} + 2\frac{\sqrt{3}}{2} + \frac{\pi}{6}\right] = \frac{2\sqrt{3} - \frac{2}{3}\pi}{10\pi} = 43.6\ mA$$

$\therefore$ the recharging time is $T = \frac{Q}{I_{d,Ave}} = \frac{12}{.0436} = 275$ sec

$T = 4$ min, 35 sec

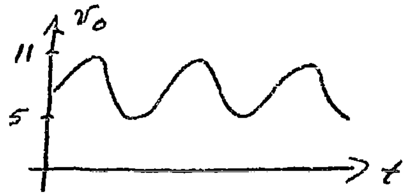
3-5

A (a) The most positive point is clamped to −5 volts



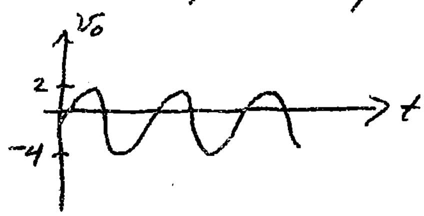
v_c = 8 volts

(b) The most negative point is clamped to +5 volts



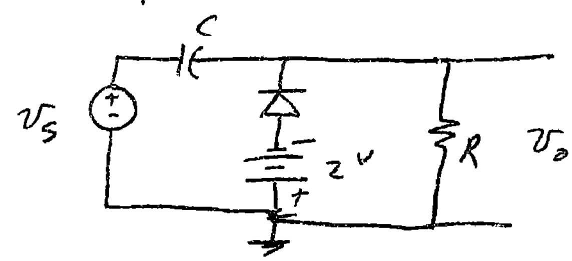
v_c = −8 volts

(c) The most positive point is clamped to +2 volts

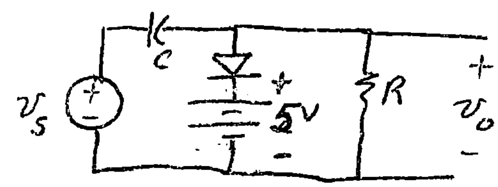


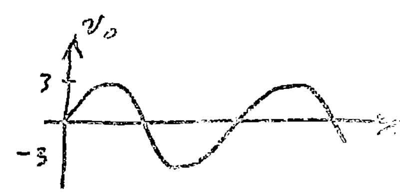
v_c = 1 volt

B



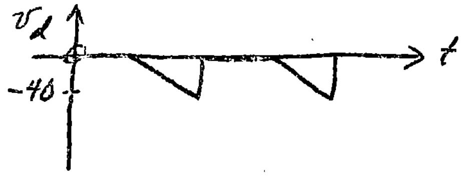
C





The diode never conducts!

3-8



$V_{meter} = 0.707\,(V_p - V_{Ave})$

$= 0.707\,(80 - 70) = \underline{7.07 \text{ volts}}$

$V_p = 80^v$

$V_{Ave} = \dfrac{70T + 40T + \frac{40T}{2}}{2T} = 70$

or $\left|V_p - V_{Ave}\right| = \left|\dfrac{-40\,T}{2 \times 2T}\right| = 10 = V_i$, $V_{meter} = 0.707\,V_i = 7.07$ volts

[illegible]

Experiment No. 3 Ap[illegible] 1970

FET CHARACTERISTICS

The purpose of this experiment is to measure the three parameters V_p, I_{DSS} and N for your junction field effect transistor.

The approximate relation between drain current i_D and gate to source voltage v_{GS} is

$$i_D = I_{DSS}\left(1 - \frac{v_{GS}}{V_P}\right)^N \qquad |v_{DS}| > |V_P|$$

where I_{DSS} is the drain current with the gate shorted to the source and V_P is the pinch-off voltage. In this equation it is assumed that the drain-to-source voltage is numerically larger than the pinch-off voltage.

Approximate Measurement of V_P and I_{DSS}

Set up the circuit of Figure 1 and obtain data to give the curve as shown.

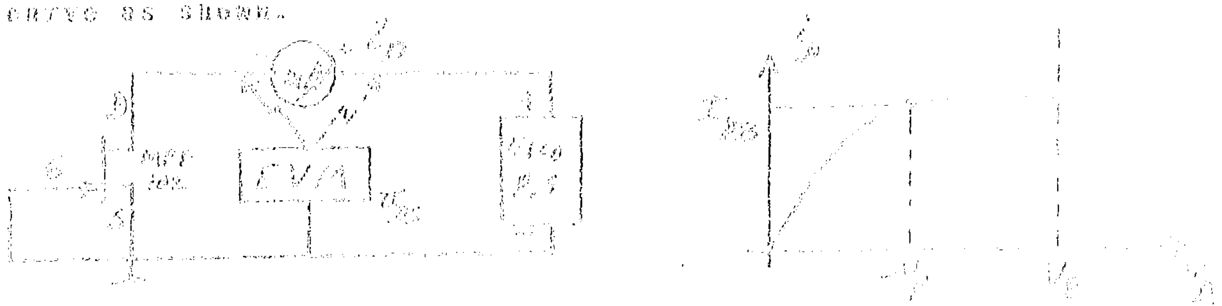


Figure 1

V_P and I_{DSS} can be estimated from the point shown on the curve.

More exact measurement

Set up the circuit of Figure 2 and obtain data to plot the curve as shown. This corresponds to fixing the drain-to-source voltage $v_{DS} = V_B$ as shown in Figure 1 and varying the gate-to-source voltage v_{GS} to vary the drain current i_D. The pinch-off voltage V_p is defined as the v_{GS} value when i_D is reduced to zero. (More practically to some value such as i_D = 1 micro A.)

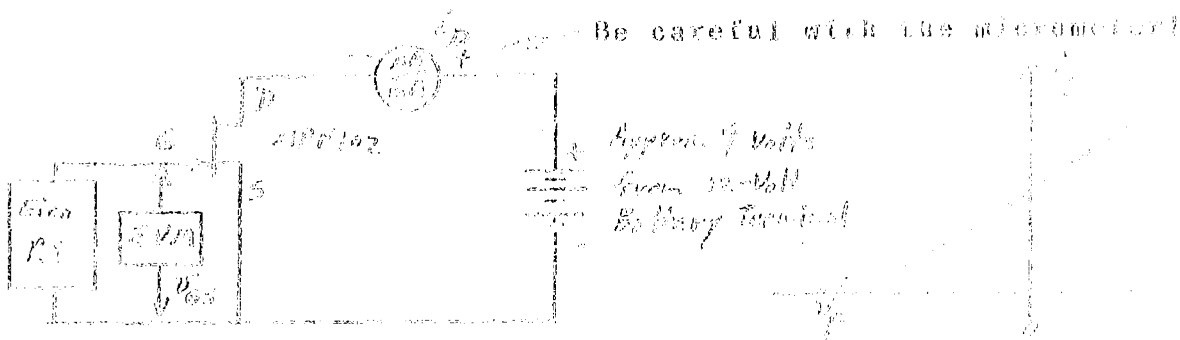


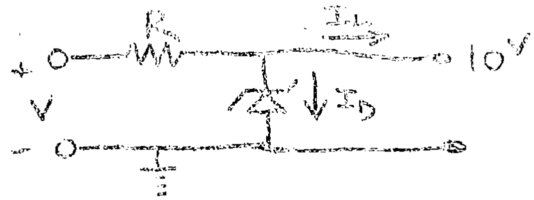
Figure 2

After you have determined the pinch-off voltage V_p in this manner, use the same i_D, v_{GS} data to plot log i_D vs log $(1 - \frac{v_{GS}}{V_p})$ by using log-log paper. If N is a constant, this curve will be a straight line whose slope is N. I_{DSS} can also be obtained from this curve.

EQUIPMENT

MPF102	FET	Electrical Science Kit
HP 410	EVM	On bench

Pico P.S.)
19-75-300 mA) check out
100 μA)
Lead box

5-1) 

$20 \le V \le 25$

$V_D = 10^V$

$I_D > 1$ ma

$P_D < 250$ mw

a) I_d is max when P_D is max

$\therefore$ max $I_D = \frac{250 \text{ mw}}{10^V} = \underline{25 \text{ ma}}$

b) when $V = 25^V$ and $I_L = 0$, the drop across R will equal $V_R = RI_D$

$\therefore R = \frac{V_R}{I_D} = \frac{25-10}{25} = \frac{15}{25} = \underline{.6K = 600\Omega}$

c) from circuit: $I_L + I_D = \frac{V_R}{R}$

$= \frac{20-10}{.6} = \frac{10}{.6} = 16.7$ ma

$\therefore I_L = 16.7 - 1.0 = \underline{15.7 \text{ ma}}$

5-2) output at 10^V = 30 ma (see previous circuit)

a) from circuit: $I_L + I_D = V_R/R = 30 + 1 = 31$ ma

31 ma $= \frac{20-10}{R} = \frac{10}{R}$; $R = \frac{10}{31} = \underline{.322 K}$

$R = \underline{322\Omega}$

b) the worst case is when $I_L = 0$ and $V = 25^V$

$P = V_D I_D = (10)\left(\frac{25-10}{.322K}\right) = \underline{465 \text{ mw}}$

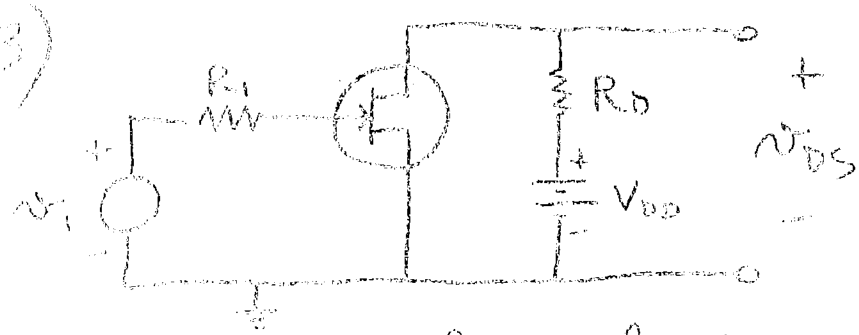
(6-2) for a n-channel FET [illegible]
and so the following relation holds

$$v_{DG} = v_{DS} - v_{GS} = 30^{V}$$

or $v_{DS} = 30 + v_{GS}$

$\therefore$ $v_{DS} = 30$ for $v_{GS} = 0$
$= 28$ " " " -2
$= 26$ " " " -4

(6-3)



n channel FET

$I_{DSS} = 5$ ma
$V_P = -4$ volts
$v_{DS} = 8$ volts
for $v_i = v_{GS}$
$V_{DD} = 25$ volts

a.) the drop across R_D will be $V_{DD} - v_{DS}$, and the current flowing through R_D is $I_{DSS} = 5$ ma

$\therefore$ $R_D = \frac{25-8}{5} = \frac{17}{5} = \underline{3.4\ K}$

b) in section 6-3 it was shown that the voltage amplification equaled [illegible]

$\therefore$ $K_v = \frac{(2)(5)(3.4)}{4} = \underline{8.5}$

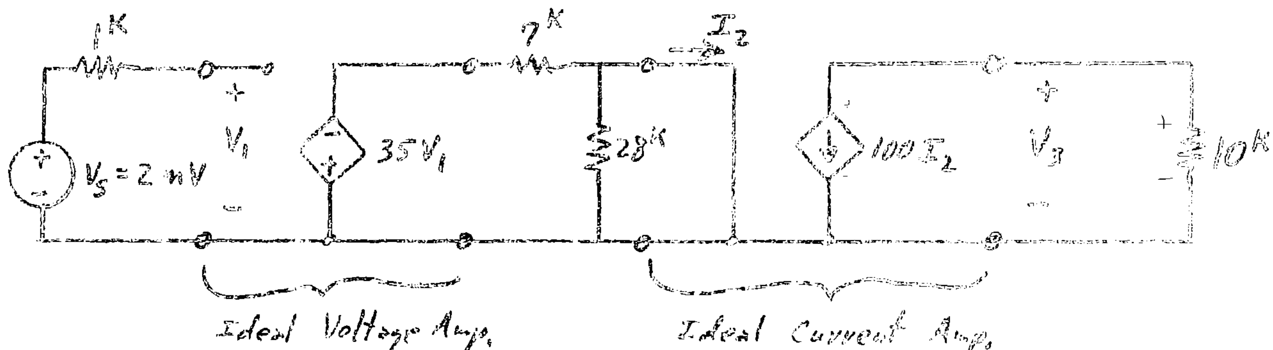
ROBERT MARKS

EE 262 Electronics I — April 3, 1990

Pop-Quiz No. 1

a) What is the magnitude and sign of V_3?

b) What is the over-all voltage gain in dB?



$I_2 = \frac{35 V_1}{~~28\times10^3~~} = \frac{35(2\times10^{-3})}{28\times10^3}$

$V_3 = I_2(10^4) = \frac{70}{28}\times10^{-6}\times10^4 = \frac{70}{28}\times 10^{-2}$ V

$= 2.5\times10^{-2}$ V

MAG = ~~2.5~~ V SIGN IS ~~NEG~~

$A_{V_1} = 20 \log_{10} \frac{V_{OUT}}{V_{IN}}$

~~$= 20 \log_{10} 35$~~

$I_2 = \frac{35 V_1}{7000}$

~~$V_3 = -100 \frac{35 V_1}{7000} = -\frac{1}{2} V_1$~~

$A_V = 20$ ~~log~~ $V_3 = (-\frac{1}{2}V_1)(10^3) = (.5\times10^3)V$

$A_V = 20 \log_{10} 5\times10^2$

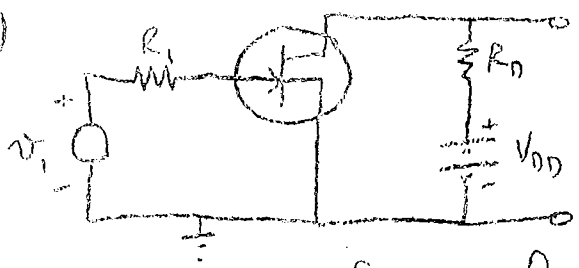
$= 400 \log_{10} 5$

$= 280$ dB

6

4 (3)

6-5)



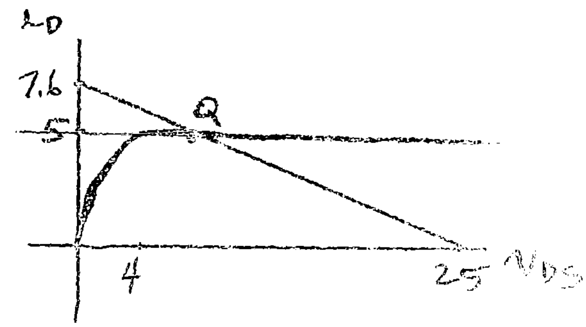
n-channel FET

$I_{DSS} = 5\,ma$
$V_p = -4^V$
$R_D = 3.3K$
$R_1 = 5K$
$V_{DD} = 25^V$

a) for $v_{GS} = 0$, $i_D = I_{DSS} = KV_P^2$

$$K = \frac{5\,ma}{16} = 3.12 \times 10^{-4}$$

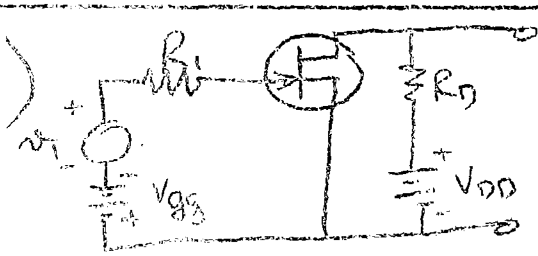
i_D	v_{DS}
0	0
.312 ma	1
1.25	2
2.81	3
5.0	> 4



b) for load line: x-intercept = $V_{DD} = 25^V$
: y-intercept = $\frac{V_{DD}}{R_D} = \frac{25}{3.3} = 7.6\,ma$

c) at Q: $I_D = 5\,ma$
$v_{DS} = V_{DD} - R_D I_D = 25 - (3.3K)(5\,ma) = 8.5^V$

6-6)



$R_D = 3.3\,K$
$R_1 = 50\,K$
$V_{gg} = 1.75^V$
$V_{DD} = 25^V$

$I_{DSS} = 12\,ma$
$V_p = -5^V$

a) $I_D = I_{DSS}\left(1 - \frac{V_{gg}}{V_p}\right)^2 = 12(.65)^2 = \underline{5.07\,ma}$

$V_{DS} = V_{DD} - R_D I_D = 25 - (5.07)(3.3) = \underline{8.3\text{ volts}}$

b) $K_v = \frac{2 I_{DSS} R_D}{-V_p}\left(1 - \frac{V_{gg}}{V_p}\right) = \frac{(2)(12)(3.3)(.65)}{5} = \underline{10.3}$

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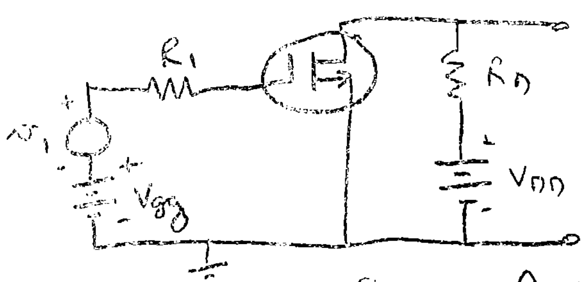
6-10)



$v_{DS} = V_{DS} - 2KR_D(V_{GS} - V_T)\,v_1 - KR_D v_1^2$

n-channel MOS

a.) for $|v_1| \leq |V_{GS} - V_T|$, ~~the voltage~~ gain will be the coefficient of the v_1 ~~term~~

$\therefore\ K_v = 2KR_D(V_{gs} - V_T)$ (positive)

b.) $K = .3\ ma/v^2$, $V_T = 3^V$, $V_{DD} = 25^V$

$V_{DS} = 6^V$, $I_D = 2.7\,ma$

$I_D = K(V_{GS} - V_T)^2$; $V_{GS} = \sqrt{9} + 3 = \underline{6^V}$

$R_D = \dfrac{V_{DD} - V_{DS}}{I_D} = \dfrac{25-6}{2.7} = \dfrac{19}{2.7} \simeq \underline{7K}$

c.) $K_v = 2 \times K \times R_D \times (V_{gs} - V_T)$

$= (2)(.3)(7)(6-3) = \underline{12.6}$

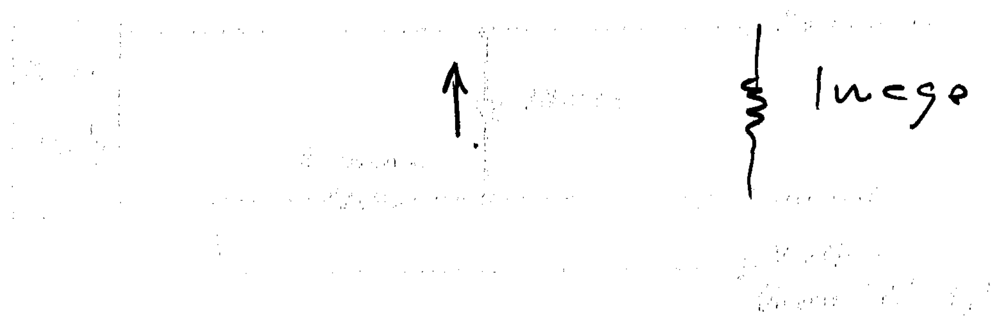


Figure 2

Report:

1. Plot the forward characteristic I vs V on semi-log paper (I - log, V - linear).

2. If the current does not increase exponentially for large values of voltage, can the difference be explained on the existence of linear resistance in the diode in addition to the junction characteristic $I = I_0 (e^{qV/kT} - 1)$? Explain.

Equipment:

Bias supply
1N 2069 Diode
R - 1000 ohms, 1 watt } in kit
Transformer
Variac
CRO, type 503 on bench
R - 1000 ohms, 10 watt
Load box

[illegible]

Experiment No. 4 [illegible]

JFET AMPLIFIER

The purpose of this experiment is to use the junction field effect transistor (JFET) in a simple amplifier circuit.

Selection of V_{GG} and R_d

Use your transistor data from the previous experiment to select V_{GG} so that $I_D = 2$ mA when no v_i signal is present.

Select R_d so that V_{DS} is approximately 5 volts.

Set up the circuit of Figure 1 and verify that $I_D = 2$ mA and $V_{DS} = 5$ volts.

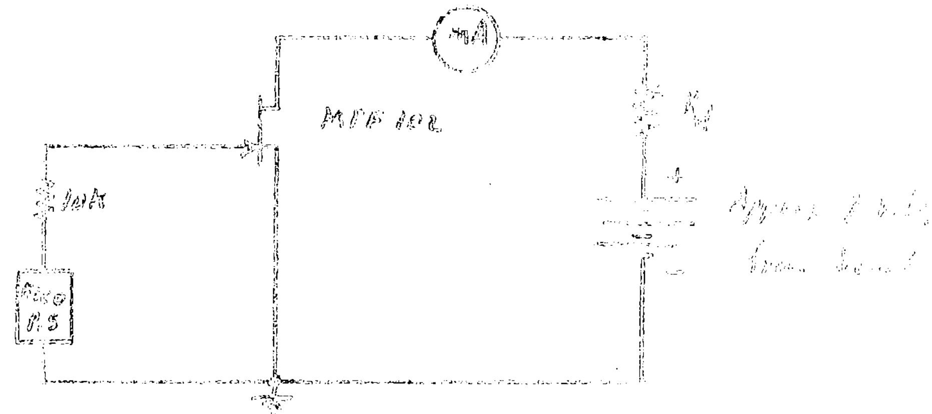


Figure 1

Small-Signal Voltage Gain

Set the output of your H.P. 200 audio oscillator to 1000 Hz 0.1 volt, peak as indicated on the CRO and (with the ground side of the oscillator connected to your circuit ground) connect the oscillator through an 8-microfarad capacitor to the gate of the transistor.

Measure the a-c component of the gate-to-source voltage (which should be 0.1 volt) and the a-c component of the drain-to-source voltage. Then the small-signal voltage gain is

$$K_v = \frac{V_{ds}}{V_{gs}}$$

This value can be compared with the theoretical value. However, since your transistor does not behave as a square-law device the K_v formula from the text is not correct. In order to account for the value of N which you measured for your transistor, consider the following analysis.

$$v_{DS} = V_{DD} - R_d\, I_{DSS}\, (1 - \frac{v_{GS}}{V_p})^N$$

where

$$v_{GS} = v_I - V_{GG}$$

then

$$v_{DS} = V_{DD} - R_d\, I_{DSS}\, (1 - \frac{v_I - V_{GG}}{V_p})^N$$

The small-signal voltage gain can be defined as

$$A_v = \left.\frac{\partial v_{DS}}{\partial v_I}\right|_{v_I=0} = - R_d\, I_{DSS} N\, (1 - \frac{v_I - V_{GG}}{V_p})^{N-1} \left.(-\frac{1}{V_p})\right|_{v_I=0}$$

$$= \frac{NR_d I_{DSS}}{V_p}\, (1 + \frac{V_{GG}}{V_p})^{N-1}$$

which agrees with the text when $N = 2$.

Distortion

Increase the oscillator voltage V_I until a "clipped" voltage wave is observed on the CRO for the v_{DS} waveform. Is this clipping caused by "cut-off" or "saturation" of the transistor current?

Also observe the change in ammeter current I_D as V_I is varied. Does any change in I_D occur before clipping of v_{DS} occur?

Change the quiescent operating point by varying the values of V_{GG} and/or R_d and observe the effect of the new operating point on the clipping of the waveform. Can you find a point where the onset of clipping occurs simultaneously for both the positive and the negative voltage peaks? A load-line analysis would be helpful here.

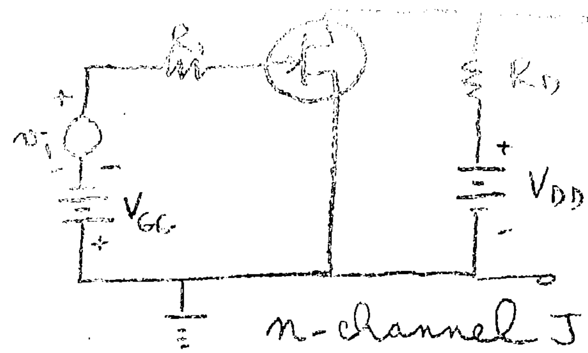
Equipment:

MPF 102)Electrical Science Kit
10K Resistor)

HP 410 EVM }
HP 200 Oscillator } on bench
CRO

Gico P S. 15-75-300 mA } check out
Load Box - Resistance Subst. Box }

6-12)



n-channel JFET

$I_{DSS} = 10$ ma
$V_P = -4^V$
$V_{GG} = 2.25^V$
$V_{DD} = 25^V$
$R_1 = 1K$
$R_D = 6.8K$

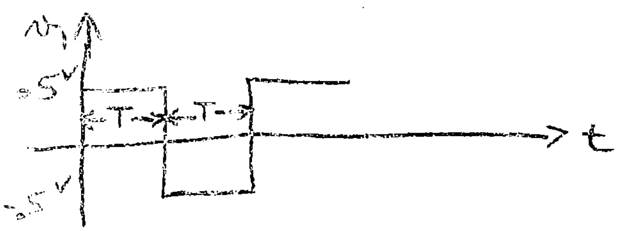
a) $P_{TQ} = V_{DS} I_D$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 10\left(1 - \frac{2.25}{4}\right)^2 = 1.91 \text{ ma}$$

$$V_{DS} = V_{DD} - R_D I_D = 25 - (6.8)(1.91) = 12^V$$

$$P_{TQ} = (12)(1.91) = \underline{23 \text{ mw}}$$

b)



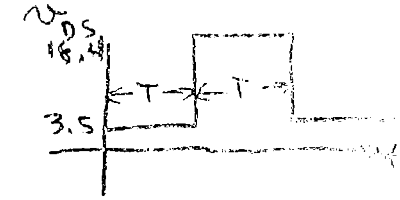
$$i_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P} - \frac{v_i}{V_P}\right)^2 = 10\left(1 - \frac{9}{16} + \frac{v_i}{4}\right)^2$$
$$= \frac{10}{16}\left(\frac{7}{4} + v_i\right)^2$$

v_i is either +.5 or −.5

$\therefore i_D = \underline{3.16 \text{ ma}}$ and $\underline{.975 \text{ ma}}$

$$v_{DS} = V_{DD} - R_D I_D$$

$\therefore v_{DS} = \underline{3.5^V}$ and $\underline{18.4^V}$



c) $P_T = \frac{1}{2}(p_{T1} + p_{T2}) = \frac{1}{2}\left[(v_{DS})(i_D) + (v_{DS})(i_D)\right]$
$= \underline{14.5 \text{ mW}}$ $(< P_{TQ} = 23 \text{ mw})$

b) same circuit and values as 6-1 ...

$v_1 = V_1 \cos \omega t$

$V_1 = \frac{V_{GS} - V_P}{I_{DD}} D$ where D is the dist...

$V_1 = \frac{-2.25 + 4}{25} 2 = .14^V$

a) $K_V = \frac{2 I_{DSS} R_D}{-V_P}\left(1 - \frac{V_{GS}}{V_P}\right) = \frac{(2)(10)(6.8)}{4}(1 - ...)$

$= 14.9$

c) $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 10\left(\frac{7}{16}\right)^2 = 1.91 ma$

$V_{DS} = V_{DD} - R_D I_D = 25 - (6.8)(1.91) = 12^V$

$P_{DD} = V_{DD} I_D = (25)(1.91) = 47.8 mw$

$P_R = R_D I_D^2 = (6.8)(1.91)^2 = 24.8 mw$

$P_T = V_{DS} I_D = (12)(1.91) = 22.9 mw$

d) $v_1 = .14 \cos \omega t$

neglect 2% distortion

$V_{DS} = K_V V_1 = I_D R_D$; $I_D = \frac{K_V V_1}{R_D} = \frac{(14.9)(.14)}{6.8} = .306$

$I_{D\,rms} = \frac{.302}{\sqrt{2}} = .214$

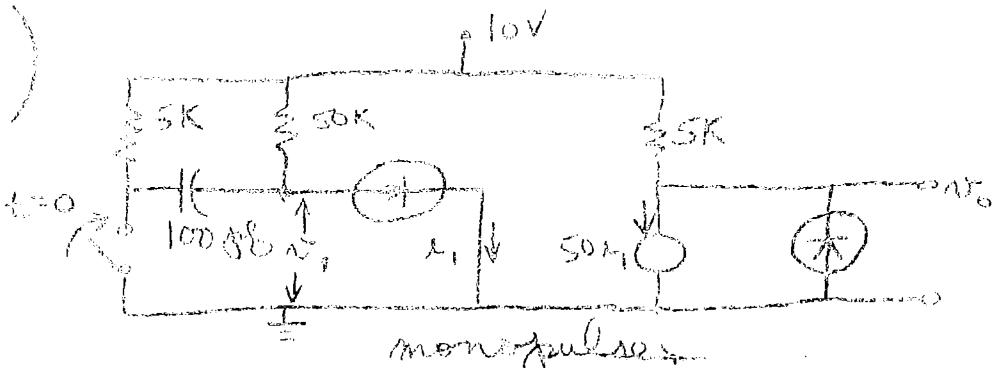
$P_{R\,rms} = (6.8)(.214)^2 = .31 mw$

$P_{DD} = V_{DD} I_D = (25)(1.91) = 47.8 mw$ (same as ...)

$P_R = R_D I_D^2 + R_D I_{D\,rms}^2 = 24.8 + .31 = 25.1 mw$

$P_T = P_{DD} - P_R \approx 22.7 mw$

-10)



$V_0 = .7v$
$v_0 = 0$

the switch is closed at $t=0$

for $t<0$, the voltage $v_1 = +.7 = V_0$
" " $v_0' = -.7 = -V_0$

at $t=0$ the capacitor will charge instantaneously and $v_1 = -(10^V - .7^V) = -9.3$

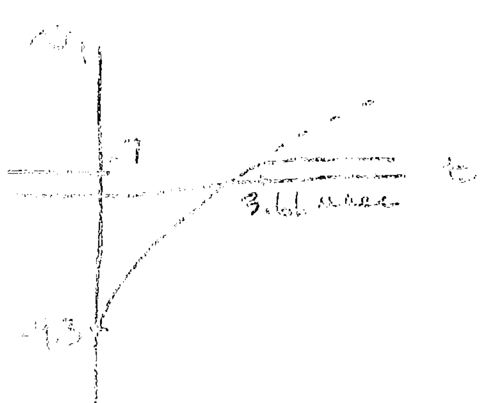
$v_0(t=0)$ will be $+10^V$

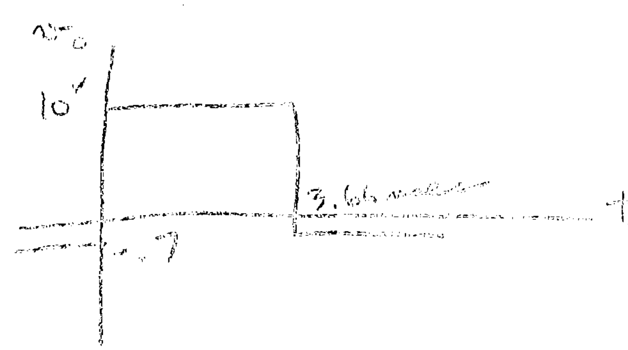
τ (time constant) $= RC = (50)(100) = 5000$ nsec

$t_x = \tau \ln \frac{10 - v_1}{10 - V_0} = 5 \ln \frac{10+9.3}{9.3}$

$= 5 \ln 2.08 = 3.66$ usec

∴ after 3.66 usec the capacitor will discharge to ground and again $v_1 = .7v$ and $v_0 = -.7v$

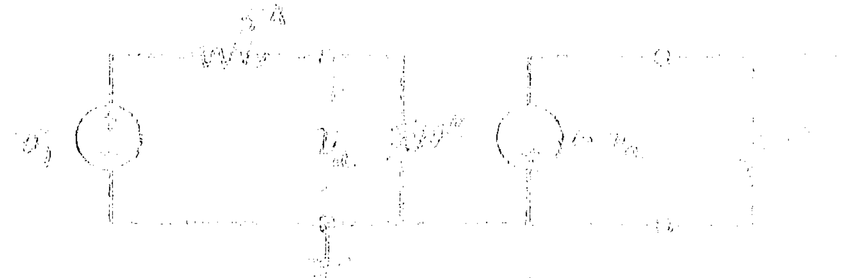




(one page of notes allowed)

a) What is the voltage gain of the amplifier, v_2/v_a?

b) What is the power gain of the amplifier in dB, where Power Gain = (power in 2k)/(power in 10k)?



a) $20 \log_{10} 15 = \underline{\underline{23.52 \text{ dB}}}$

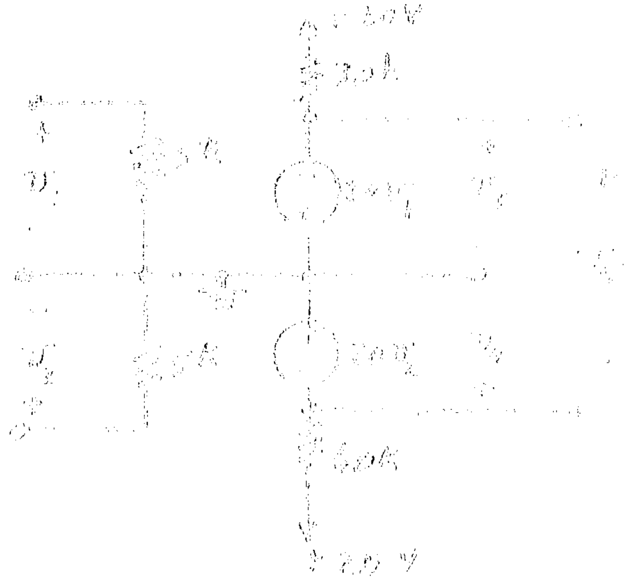
b) $10 \log_{10} \frac{(15 v_a)^2 / 2k}{v_a^2 / 10k} = 10 \log \frac{15^2 \times 10}{2} = 10 \log 1125 = \underline{\underline{30.51 \text{ dB}}}$

An approximate model for a differential amplifier is shown below.

a) What is the numerical value of v_5 when $v_1 = v_2 = +0.1$ volt?

b) What is the numerical value of v_5 when $v_1 = +0.1$ volt and $v_2 = -0.1$ volt?

$v_5 = v_3 - v_4$

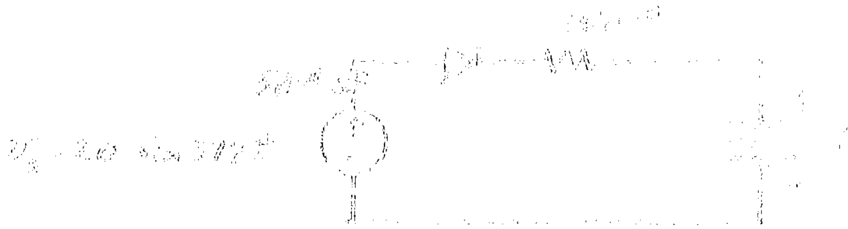


a) $v_5 = -2 - (-2) = \underline{\underline{0}}$

b) $v_5 = -2 - 2 = \underline{\underline{-4}}$

b) What is the peak [illegible]

c) What percentage of the time does the diode conduct?



a) $I_{peak} = \frac{20-6}{200} = \frac{14}{200} = \underline{70\ mA}$

b) $PIV = 20 + 6 = \underline{26\ Volts}$

c) $6 = 20 \sin\theta \qquad \theta = \arcsin 0.3 = 17.5°$

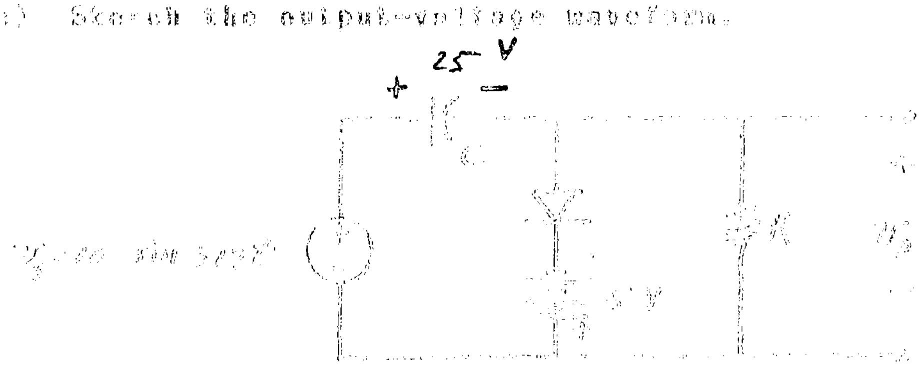
$\%\ Conduction = \frac{180 - 2 \times 17.5}{360}\, 100 = \underline{40.2\ \%}$

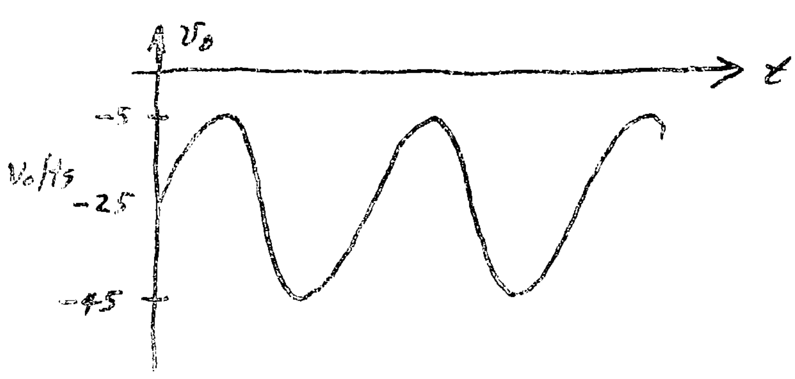
6. Assume that $\tau = RC \gg 1/60$ second and that v_s has been present for a long time.

a) What is the voltage across the capacitor? $20+5 = \underline{25\ Volts}$

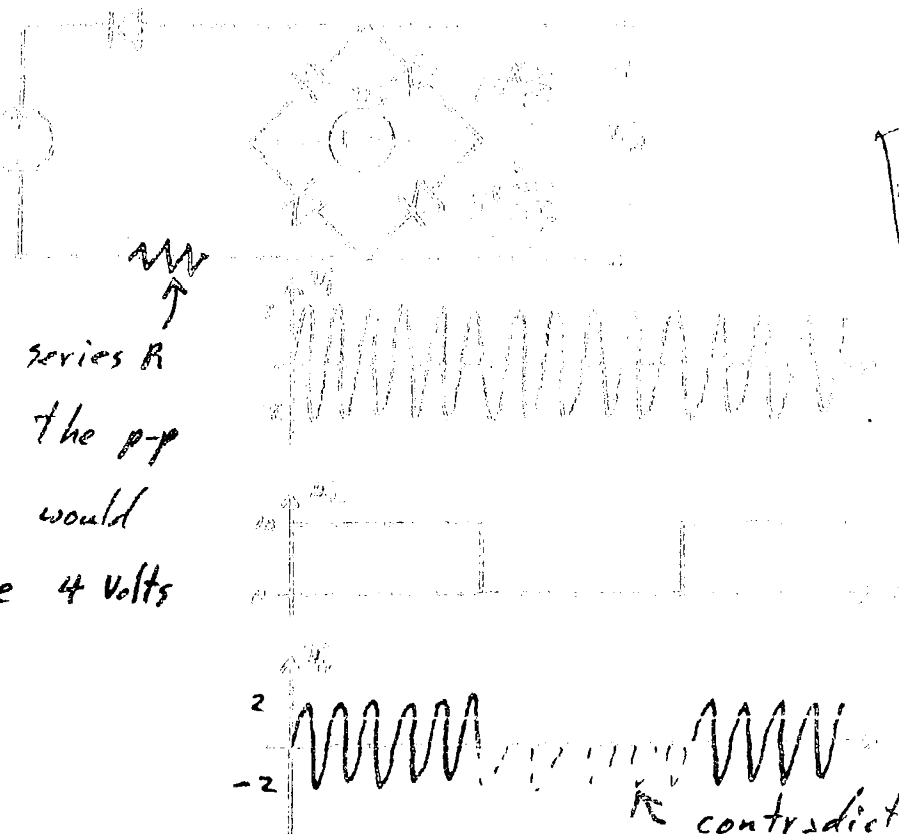
b) What is the PIV across the diode? $25+20-5 = \underline{40\ Volts}$

c) Sketch the output-voltage waveform.





waveforms shown.



Needs series R but then the p-p value of v_o would no longer be 4 Volts

contradiction with ideal diodes

Problem [illegible] counted

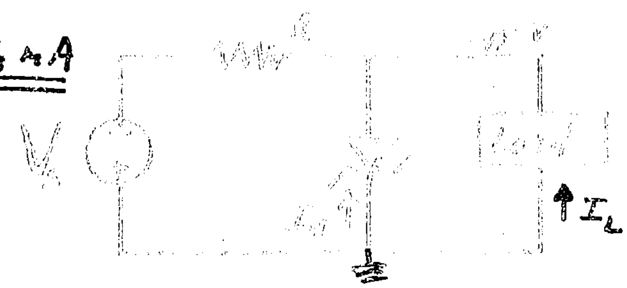
[illegible]. The d-c voltage V_S is expected to vary between 25 and 30 volts. The zener diode is used to regulate the output voltage at 15 volts. For good regulation the diode current should be greater than 1 mA and the power dissipated in the diode must not exceed 125 mW. Assume that the diode voltage remains constant at 15 volts.

a) What is the maximum permissible value of I_d?

b) What value of R should be used to assume proper circuit operation for "worst case" conditions?

c) What is the maximum load current I_L for "worst-case" conditions?

a) $I_{d_{max}} = \frac{125 \text{ mW}}{15 \text{ V}} = \underline{8\tfrac{1}{3} \text{ mA}}$



b) when $I_L = 0$

$V_s = 30$ Volts

$R = \frac{30-15}{8\tfrac{1}{3}} = \underline{1.8 \text{ k}\Omega}$

c) Poorly worded! The max I_L ~~[illegible]~~ which could be guaranteed for load was desired. "Worst case" when

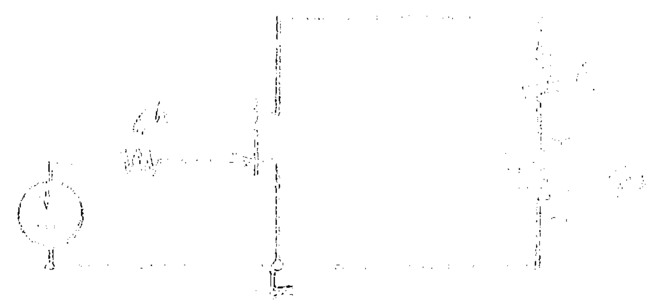
$V_s = 25$, 15 [illegible]

6. a) Determine the value of R_d [illegible]

b) What power is dissipated in the transistor under the conditions of part (a)?

$I_{DSS} = 6$ mA

$V_p = -6$ Volts



a) $i_D = I_{DSS}\left(1 - \frac{0}{V_p}\right)^2 = I_{DSS}$

$$R_d = \frac{V_{DD} - v_{DS}}{i_D} = \frac{48-12}{6\ mA} = \underline{\underline{6\ K\Omega}}$$

b) $$P_T = 12 \times 6\ mA = \underline{\underline{72\ mW}}$$

d. What is the small signal voltage gain $\frac{v_{ds}}{v_i}$ of the amplifier when $|v_i| << |V_p|$?

$I_{DSS} = 6$ mA

$V_p = -6$ Volts

Note: v_{ds} is the signal component of the drain-source voltage

$$v_{DS} = V_{DD} - R_d I_{DSS}\left(1 - \frac{v_i - V_{GG}}{V_p}\right)^2 = V_{DD} - R_d I_{DSS}\left[\left(1 + \frac{V_{GG}}{V_p}\right) - \frac{v_i}{V_p}\right]^2$$

$$v_{ds} = -R_d I_{DSS}\left(1 + \frac{V_{GG}}{V_p}\right) 2 \frac{v_i}{V_p}$$

$$\left|\frac{V_{ds}}{V_i}\right| = -\frac{2 R_d I_{DSS}}{V_p}\left(1 + \frac{V_{GG}}{V_p}\right) = \frac{2 \times 10^K \times 6\ mA}{6}\left(1 - \frac{2}{6}\right) = \underline{\underline{13.3}}$$

100-39
MED-83 (56)

BOB MARKS

Mid-Term Exam.

April 29, 1970

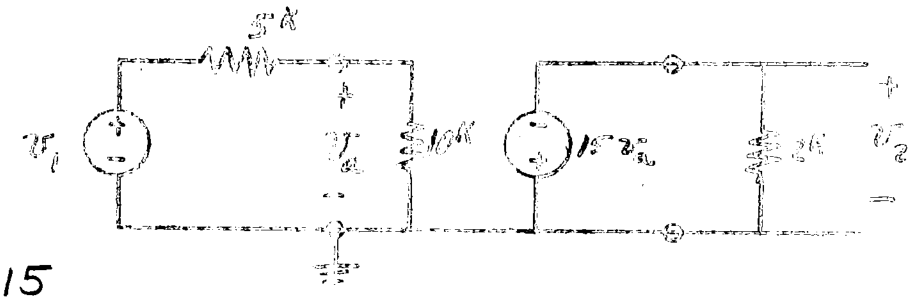
(one page of notes allowed)

39/70

3 Periods

1. a) What is the voltage-gain of the amplifier, v_2/v_a, in dB?

b) What is the power gain of the amplifier in dB, where Power Gain = (power in 2k)/(power in 10k) ?



$V_A = \frac{10}{15} V_1$

$\frac{V_2}{V_a} = \frac{15 V_A}{V_A} = 15$

$A_V = 20 \log_{10} 15$

$= 20\,(1.176)$

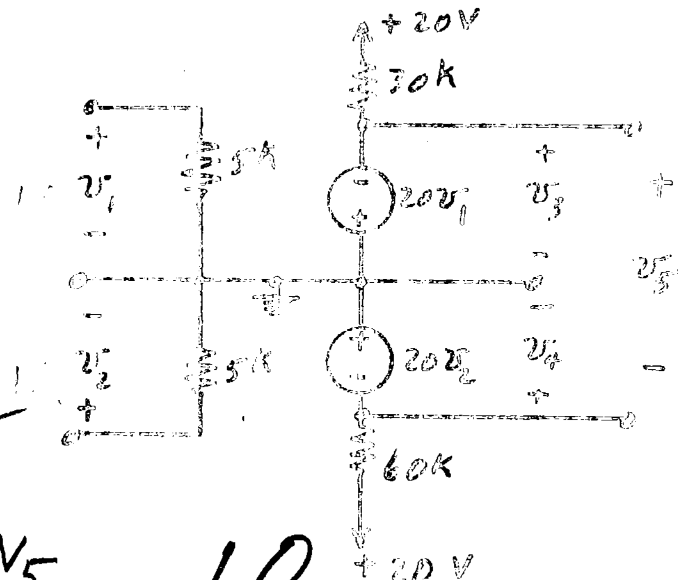
$= 23.52\ dB$ ✓

5

2. An approximate model for a differential amplifier is shown below.

a) What is the numerical value of v_5 when $v_1 = v_2 = +0.1$ volt?

b) What is the numerical value of v_5 when $v_1 = +0.1$ volt and $v_2 = -0.1$ volt?



$V_5 = V_3 - V_4$

$= (-20V_1) - (-20V_2)$

$= -20V_1 + 20V_2$

a) $V_1 = V_2 = .1$ VOLTS

$V_5 = (-20)(.1) + 20(.1)$

$V_5 = 0$ VOLTS ✓

b) $(-20)(.1) + 20(-.1) = V_5$

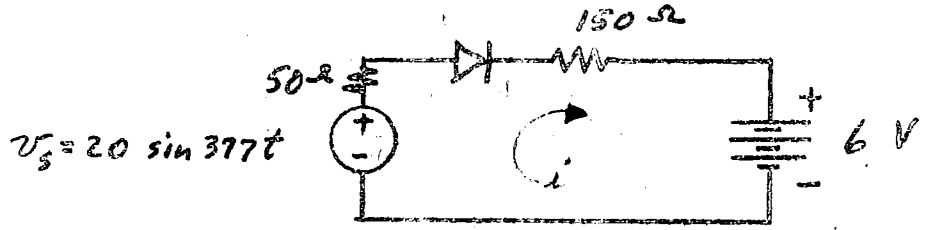
$V_5 = -2 - 2 = -4$ VOLTS ✓

10

a) What is the peak current in the battery-charger circuit shown?

b) What is the peak-inverse-voltage (PIV) across the diode?

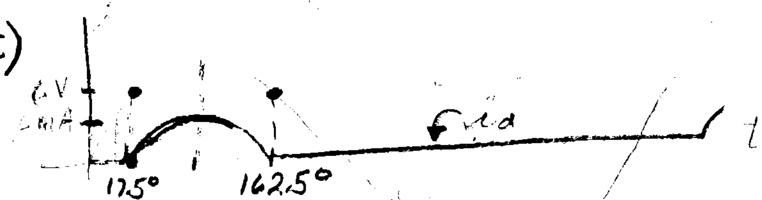
c) What percentage of the time does the diode conduct?



a) $i = \frac{14}{200} = \frac{6}{100} = 6\times10^{-3} = 70\,mA$

b) −26 VOLTS

c)



t = 17.5°

$\frac{162.5-17.5}{360} \times 100\% = \frac{145.0}{360} = 40.3\%$

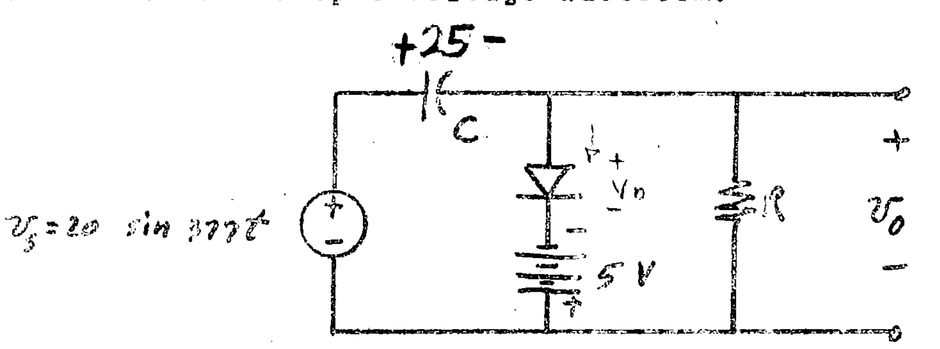
9

4. Assume that τ = RC ≫ 1/60 second and that v_s has been present for a long time.

a) What is the voltage across the capacitor? 25 VOLTS

b) What is the PIV across the diode? −40 VOLTS

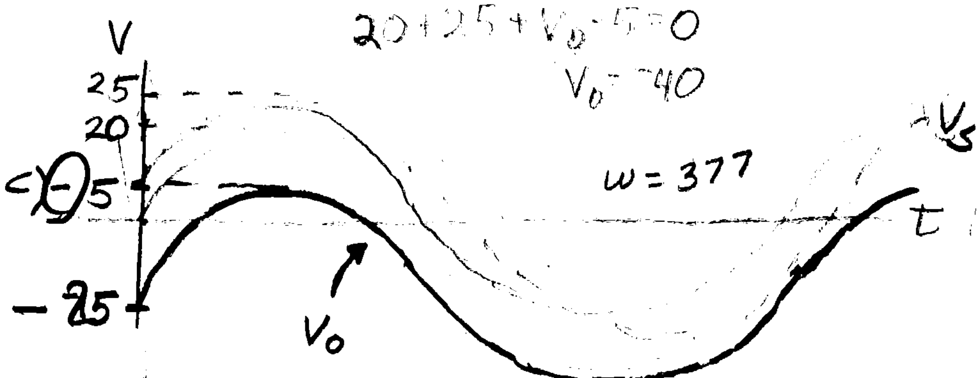
c) Sketch the output-voltage waveform.



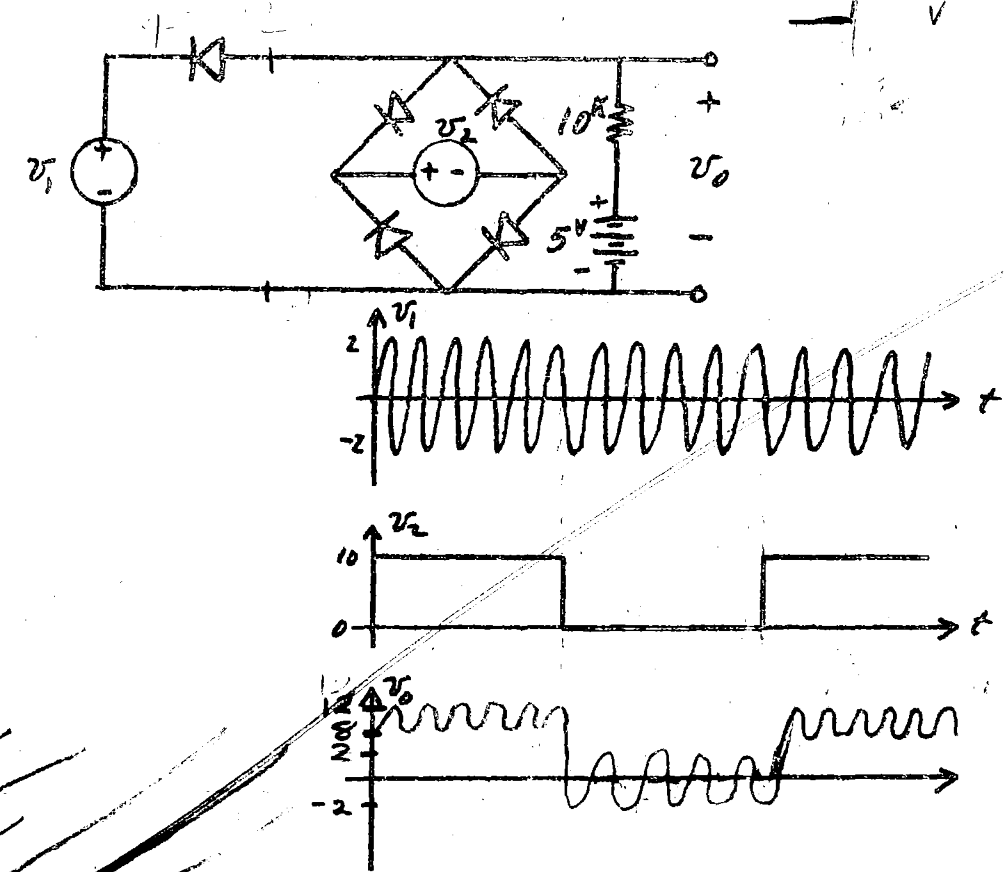
8

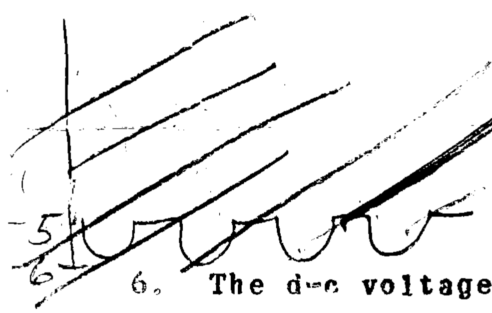
20+25+V_D−5=0

V_D=−40



5. Sketch and dimension the waveform of v_o when v_1 and v_2 have the waveforms shown.



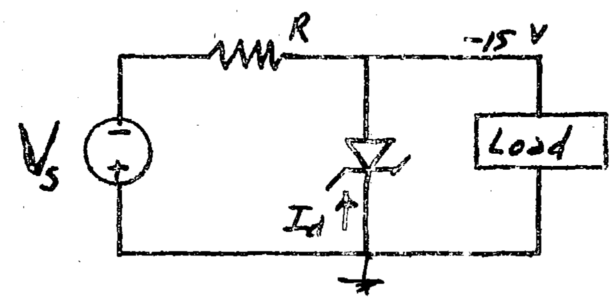


6. The d-c voltage V_s is expected to vary between 25 and 30 volts. The zener diode is used to regulate the output voltage at -15 volts. For good regulation the diode current should be greater than 1 mA and the power dissipated in the diode must not exceed 125 mW. Assume that the diode voltage remains constant at 15 volts.

a) What is the maximum permissible value of I_d?

b) What value of R should be used to assume proper circuit operation for "worst case" conditions?

c) What is the maximum load current I_L for "worst-case" conditions?



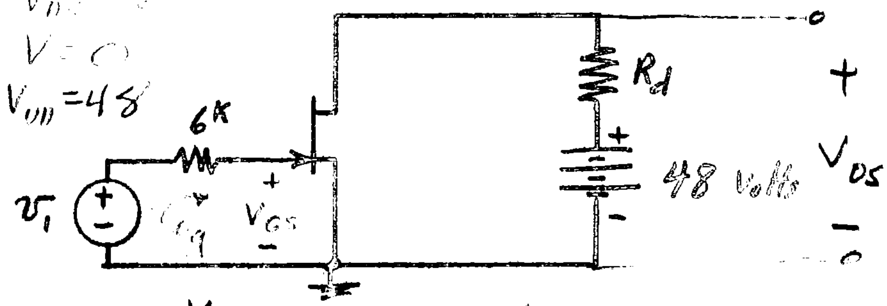
7. a) Determine the value of R_d so that v_{DS} = 12 volts when v_1 = 0.

b) What power is delivered to the transistor under the conditions of part (a)?

$I_{DSS} = 6$ mA

$V_p = -6$ Volts

V_{DS} = ?
$V_1 = 0$
$V_{DD} = 48$



~~$V_{DS} = V_{DD} + 2R_D I_{DSS} \frac{V_1}{V_p} - R_D I_{DSS} (V_1/V_p)^2$~~

a) $V_{DS} = V_{DD} - R_D I_{DSS} + \frac{2R_D I_{DSS}}{V_p} V_1$

$12 = 48 - R_D(6\times10^{-3}) + 0$

$R_D = \frac{48-12}{6\times10^{-3}} = 6$ K

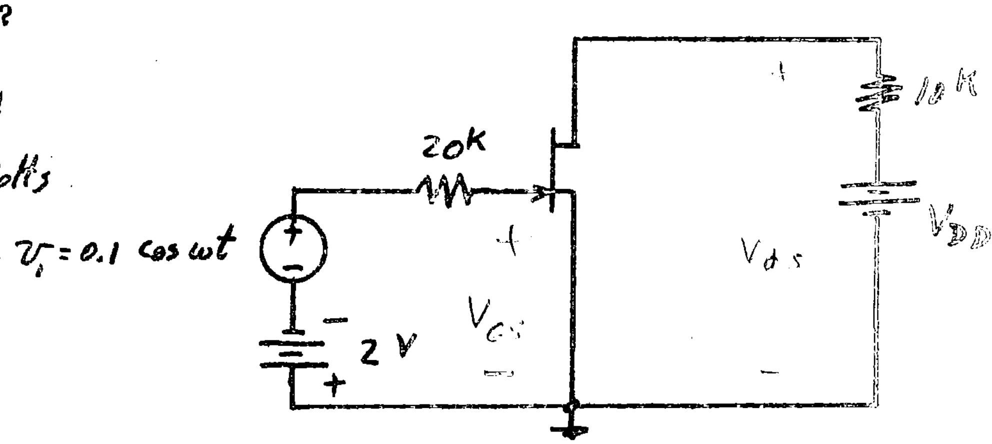
b) PWR DELIVER = POWER AB = $\frac{(12)^2}{6\times10^3}$

5

8. What is the small signal voltage gain $\frac{v_{ds}}{v_1}$ of the amplifier when $|v_1| << |v_p|$?

$I_{DSS} = 6$ mA

$V_p = -6$ Volts



Note: v_{ds} is the signal component of the drain-source voltage.

$V_{DS} = V_{DD} - R_D I_{DSS} \left(1 - \frac{V_{GS}}{V_P}\right)^2$

$V_{DS} = V_{DD} - 10^4 (6\times10^{-3})\left(1 - \frac{2}{+6}\right)$

$V_{DS} = V_{DD} - 40$

$V_1 = .1$

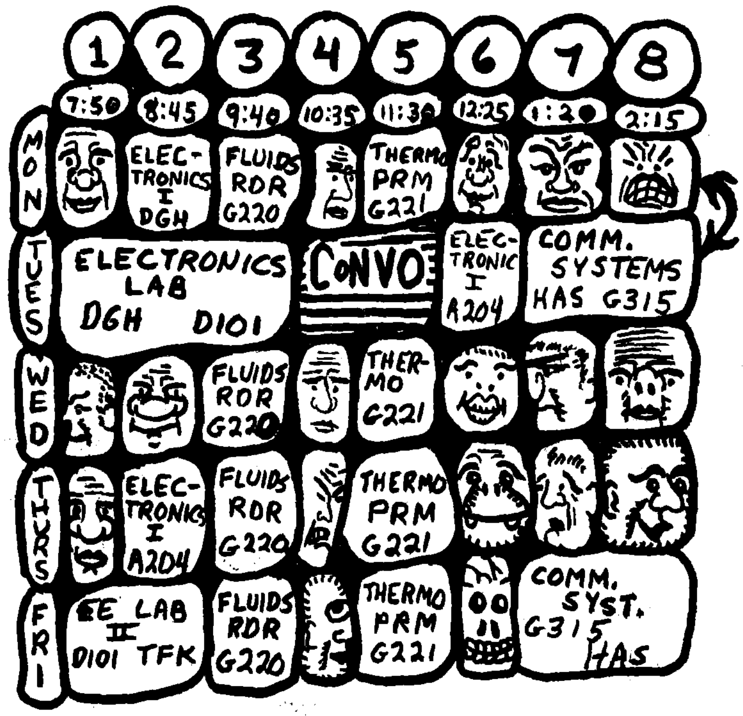
$V_{DS} = V_{DD} - 40$

2

7

1

.1


1
2
3
4
5
6
7
8
7:50
8:45
9:40
10:35
11:30
12:25
1:20
2:15
MON
ELEC-TRONICS I DGH
FLUIDS RDR G220
THERMO PRM G221
TUES
ELECTRONICS LAB DGH D101
CONVO
ELEC-TRONIC I A204
COMM. SYSTEMS HAS G315
WED
FLUIDS RDR G220
THER-MO G221
THURS
ELEC-TRONICS I A204
FLUIDS RDR G220
THERMO PRM G221
FRI
EE LAB II D101 TFK
FLUIDS RDR G220
THERMO PRM G221
COMM. SYST. G315 HAS

[illegible]

[illegible] 1963

[illegible]

[illegible] ENGINEERING

1) PROCESSING [illegible]

2) PROCESSING [illegible]

USE OF ELECTRONICS

APPROACH [illegible]

GENERAL TREATMENT OF SEMI-CONDUCTOR [illegible]

A) B. T. & FET

B) NO [illegible] IN COURSE

C) SPECIAL ELECTRONIC DEVICES [illegible]

1) [illegible]

2) [illegible]

3) SCR'S & SCS & ETC

D) INTEGRATED CIRCUITS

1) DIGITAL

2) LINEAR

ANALYSIS & DESIGN MUST INCLUDE

1) D.C. OPERATION - BIAS REQUIREMENTS

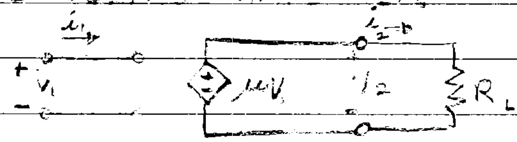
2) A.C. " - SIGNAL "

a) SMALL SIGNAL (LINEAR)

b) LARGE SIGNAL (NONLINEAR)

IDEAL AMPLIFIER

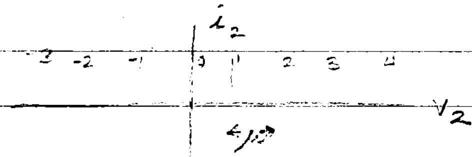
A) IDEAL VOLTAGE AMPLIFIER



$V_2 = \mu V_1$

INPUT IMPEDENCE = ∞

OUTPUT IMPEDENCE = 0

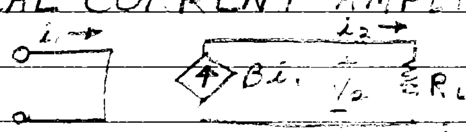


VOLTAGE GAIN = $\frac{V_2}{V_1} = A_V = \mu$

POWER GAIN = $\frac{P_{out}}{P_{in}} = \frac{P_{RL}}{0} = \infty$ $(R_L \neq \infty)$

CURRENT GAIN = $\frac{i_2}{i_1} = \infty$

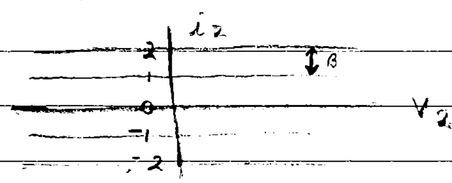
B) IDEAL CURRENT AMPLIFIER



CURRENT GAIN = $\frac{i_2}{i_1} = i_2 = \beta$

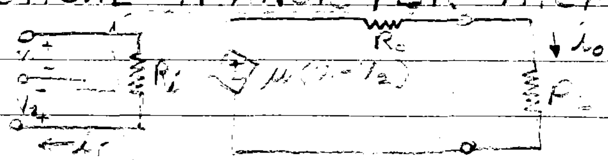
POWER GAIN = $\frac{P_{out}}{P_{in}} = \infty$

VOLTAGE GAIN = ∞ $(R_L \neq 0)$



(3)

PRACTICAL TRANSISTOR MICRO-AMPLIFIER



$\mu = 1000$; $R_i = 5\ k\Omega$; $R_o = 100\,\Omega$

$v_o = i_o R_L$

$i_o = \frac{\mu (v_1 - v_2)}{R_L + R_o}$

$\therefore v_o = \frac{\mu R_L}{R_L + R_o}(v_1 - v_2)$

$v_2 = 0 \Rightarrow A_v = \frac{v_o}{v_1} = \frac{\mu R_L}{R_L + R_o}$

$v_1 = 0 \Rightarrow A_v = \frac{v_o}{v_2} = \frac{-\mu R_L}{R_o + R_L}$

$A_i = \frac{i_o}{i_i} = \frac{v_o / R_L}{v_i / R_i} = A_v \frac{R_i}{R_L}$ (CURRENT GAIN)

$A_p = \frac{P_o}{P_{in}} = (v_o^2/R_L) / (v_i^2/R_i) = A_v^2 \frac{R_i}{R_L}$

$= A_v A_i$ (PWR GAIN)

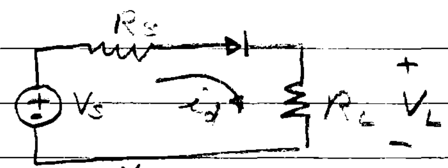
INPUT IMPEDANCE = $Z_{in} = R_i$

OUTPUT IMPEDANCE = $Z_{out} = R_o$

3-18-71

FOR MONDAY: pp. 37-48 PROBS: 50.3.7 ; 53.3.13 ; 53.3.14

LECTURE: $\frac{1}{2}$ WAVE RECTIFIER



$i_o = \frac{V_s}{R_s + R_L}$

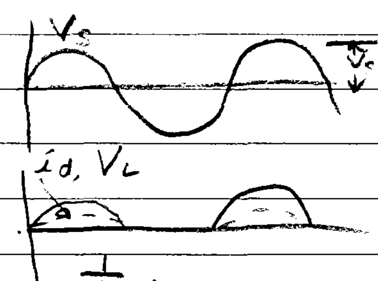
$V_L = \frac{R_L}{R_L + R_s} V_s$ } $V_s > 0$

$V_D = 0$

$i_D = 0$

$V_L = 0$ } $V_s < 0$

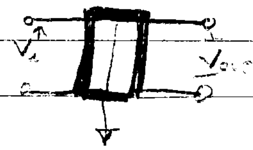
$V_D = V_s$

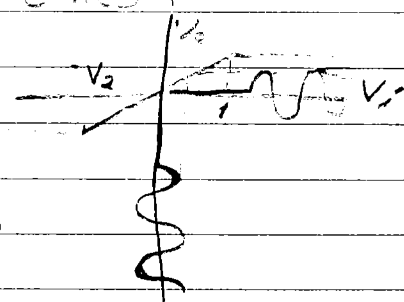


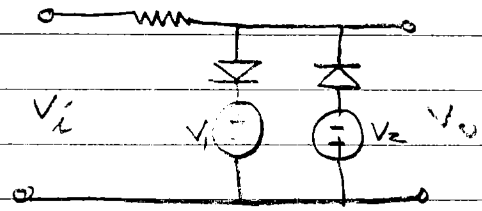
$\bar{i}_d = \frac{1}{\pi} i_{o\,MAX}$

$= \frac{1}{\pi} \frac{V_s}{(R_L + R_s)}$

CLIPPER OR LIMITER CIRCUIT



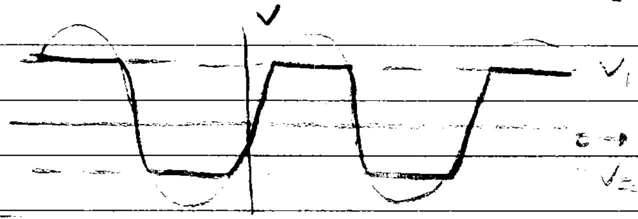


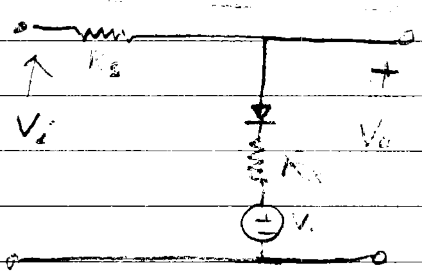


$-V_2 < V_i < V_1 \Rightarrow V_o = V_i$

$V_i > V_1$, D_1 CONDUCTS $\Rightarrow V_o = V_1$

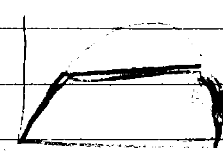
$V_i < -V_2$, D_2 CONDUCTS $\Rightarrow V_o = -V_2$



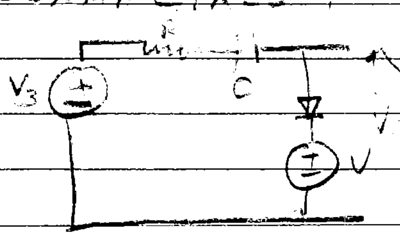


$V_o = \frac{V_i + V_1}{R_s + R_1} R_1 + V_1$

$= \frac{R_1}{R_1 + R_s} V_i + \frac{R_s}{R_s + R_1} V_1$



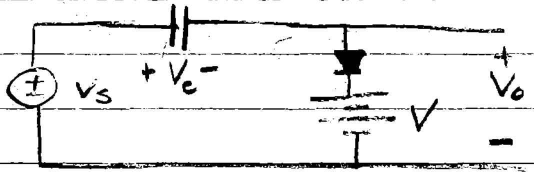
CLAMP CIRCUIT



3-22-71

READ 57-83 3:8; 3.13; 3:15

LECTURE: CLAMP CIRCUIT

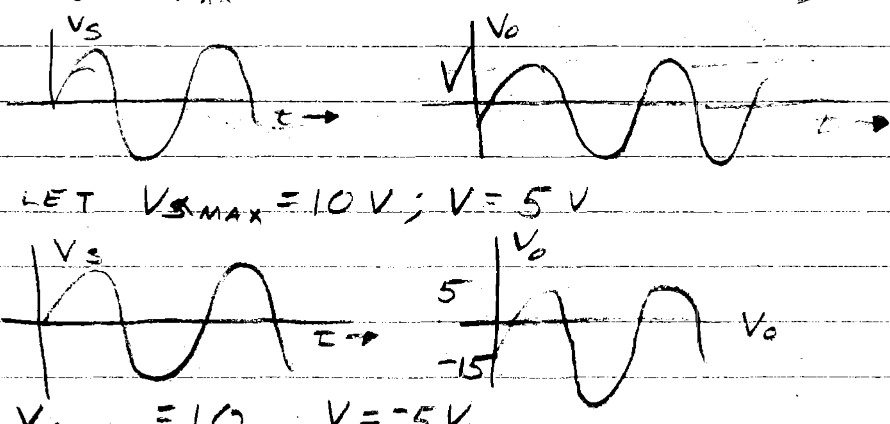


$V_o \leq V \Rightarrow$ POSITIVELY CLAMPTED TO V

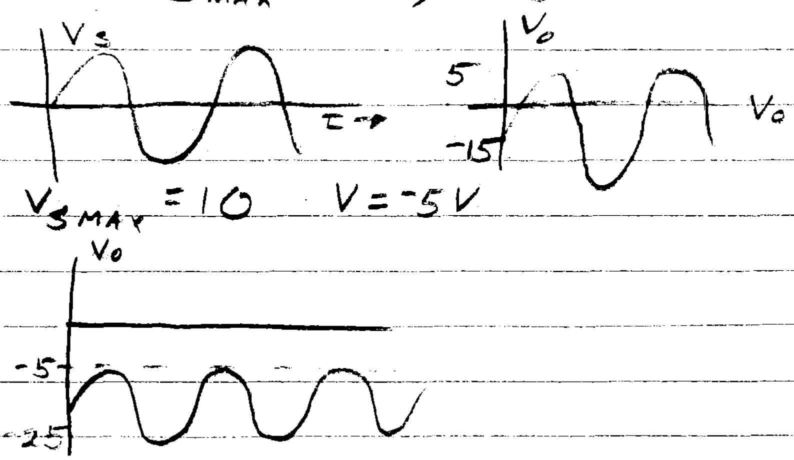
SHAPE OF WAVEFORM DOESN'T CHANGE

$V_o = V_s - V_C$; $V_{XMAX} \geq V$

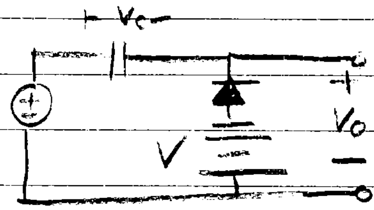
$V_c = V_{SMAX} - V$ (DIODE CONDUCTS)



LET $V_{SMAX} = 10V$; $V = 5V$

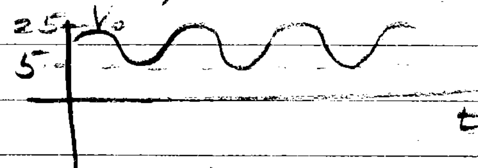


$V_{SMAX} = 10$ $V = -5V$



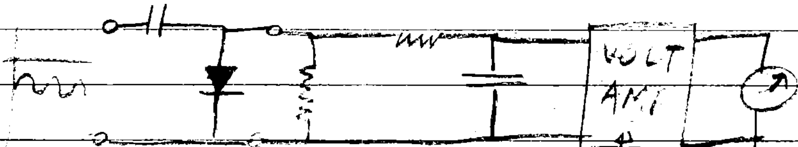
TURNING AROUND
DIODE CLAMPS TO
THE BOTTOM
(NEGATIVELY CLAMPS TO V)

$V_s = 10V$; $V = 5\ V$



$V_c = +(V_{MIN} - V) = -13\ V$

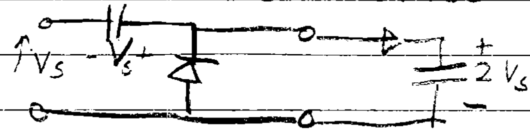
AC VTVM CIRCUIT



ASSUME GAIN OF 1

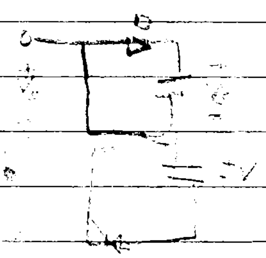
LET $V_s = V_m \sin \omega t + D.C.$

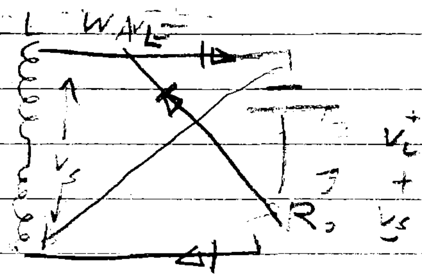
$\frac{1}{2}$ WAVE VOLTAGE DOUBLER



V_s A SINUSOID

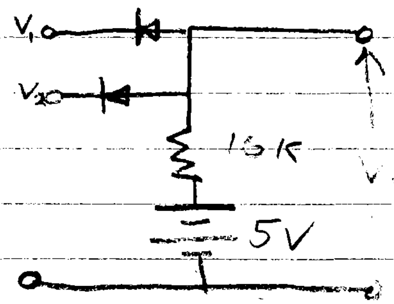
FULL WAVE VOLTAGE DOUBLER





3-23-71

3-13)

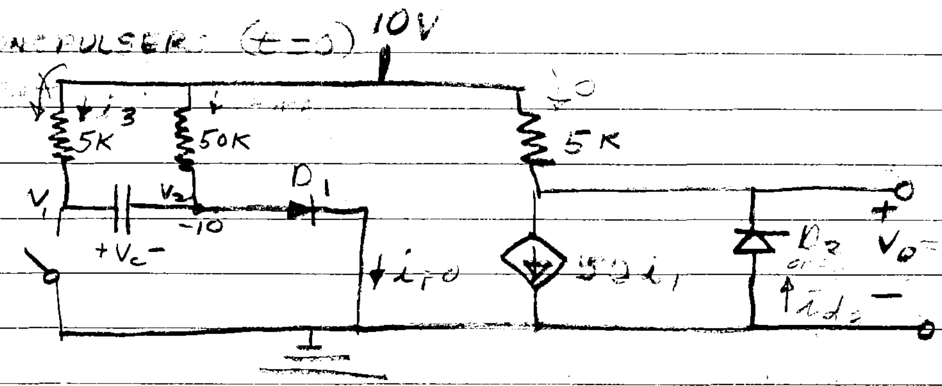


V_1	V_2	V_0
-1	0	-1
	0	0
0		
3	4	3
4	3	3

$V_0 = $ [illegible] $(V_1, V_2) \quad \forall \; V_1, V_2 < 5$

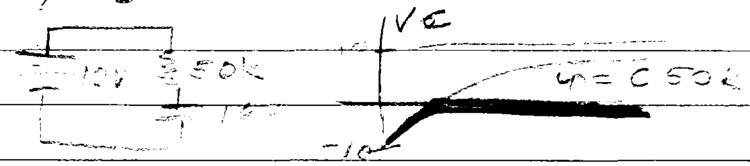
$\Rightarrow V_0 = \min(V_1, V_2, 5V)$

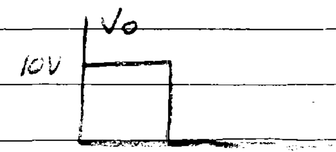
MONOPULSER: (t=0)



t<0, D_1 CONDUCTS, $i_3=0$, $V_1=10$, $V_2=0$
($\Rightarrow V_c=10V$), $i_1=.2\,mA$ ($\Rightarrow 50 i_1 = ...$)
$V_o=0$, $i_4=2\,mA$, $i_{D_2}=8\,mA$

t=0, $V_c=10\,V$





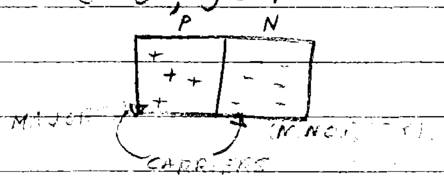
3-25-71)

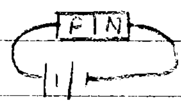
LAB REPT. 5

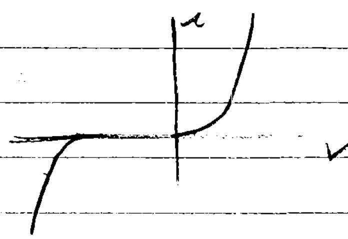
(SELF HAND OUT)

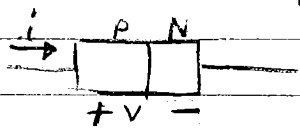
3-29-71

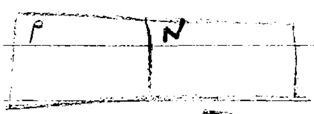
5-3 ; 5-4









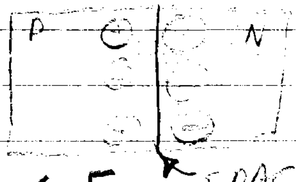


→ $I_{DIFFUSION}$

← $I_{SATURATION}$

I_d FROM MAJORITY CHARGE CARRIER

I_S " MINORITY " "



SPACE CHARGE LAYER

CHARGE & DEPLETION REGION

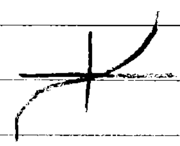
VOLTAGE VARIABLE CAPACITORS (VERICA[illegible]

APPLICATIONS VERY COMMON

1) AFC - AUTOMATIC FREQ CONT.

2) FM MODULATOR

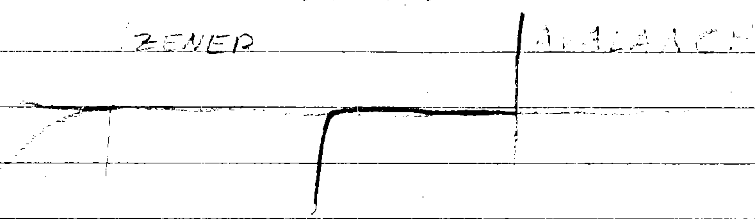
3) REMOTE CONTROL



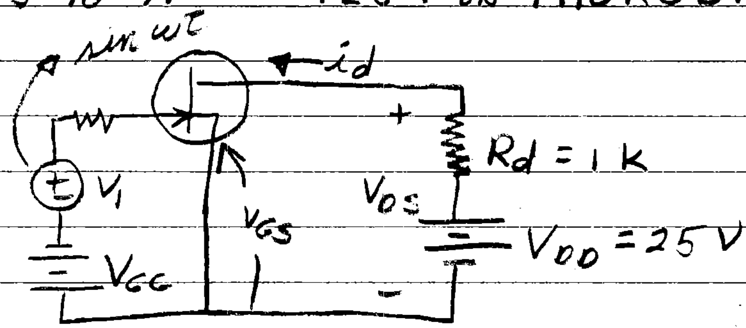
BREAKDOWN

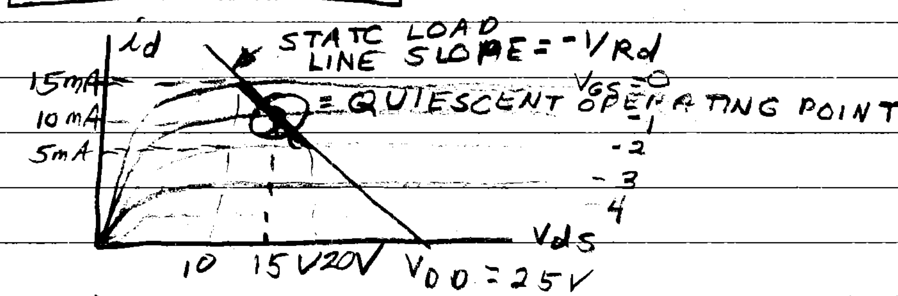
ZENER < 5V

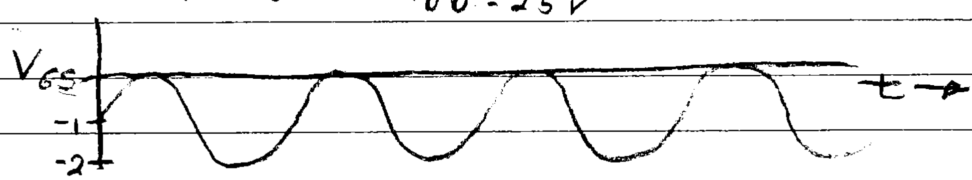
AVALANCHE > 5V



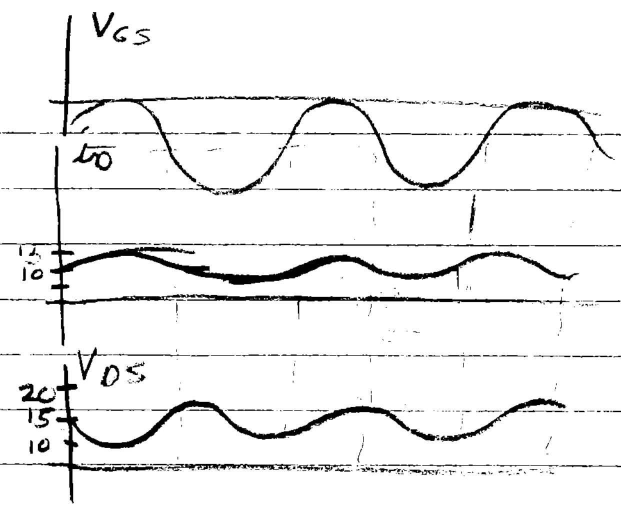
5-10-71 TEST ON THURSDAY







(11)



GAIN(VOLTAGE) = $5 \angle 180° = -5$

QUIESCENT CONDITIONS

P_{DD} = PWR. FROM DRAIN SUPPLY

$= (25)(10) = 250\ mW$

$P_T = (15)(10) = 150\ mW$

$P_{R_D} = (10^3)(.01)^2 = 100\ mW$

UNDER SIGNAL CONDITIONS

$P_{DD} = 250\ mW$

$P_{RD} = (10^3)(.01 + .005 \sin \omega t)^2$

$= 112.5\ mW$ (A.C. + D.C.)

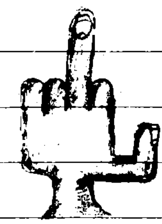
$P_T = 137.5\ mW$

4-7-71 DUE THURSDAY

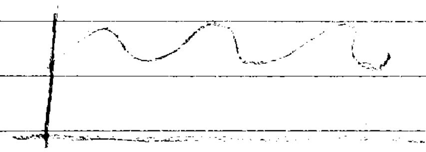
$i = I_{DSS}(1 - V_{GS}/V_P)^2$

$V_{DS} = V_{DC} - R_d I_d$

$V_{GS} = V_i - V_{GG}$

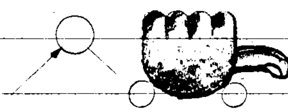


4-8-71



$i = I_{DQ} + I$ [illegible] ω [illegible] 2

RMS [illegible] 2



$V_{GS} = 0$

MOST

I) DEPLETION MODE — LITTLE [illegible]

LIKE JFET EXCEPT $I_G = 0$

II) ENHANCEMENT ([illegible] N 133) — VERY LITTLE

TEST

LOOK AT OLD HOMEWORK

NO QUANTITATIVE PN PROBLEMS

IDEAL AMPS - DIODES - FET'S

DISTORTION = $\left(\frac{V_H}{V_o}\right)$ [illegible]

4-13-71

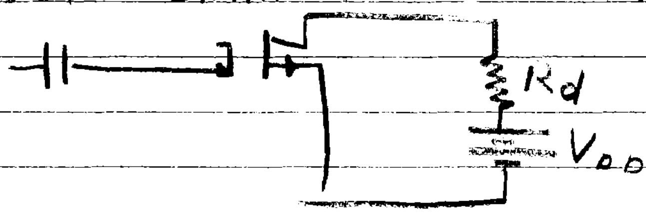
DUE THURS. 146.6.13

USE EXPONENT OF 1.5

182.7.2 ; 183.7.4

CHAPT. 7

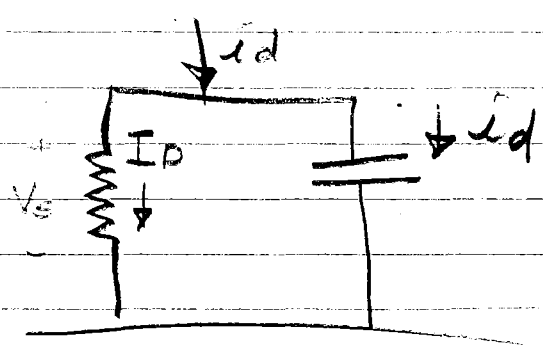
MOST - ENHANCEMENT MODE



4-15-71

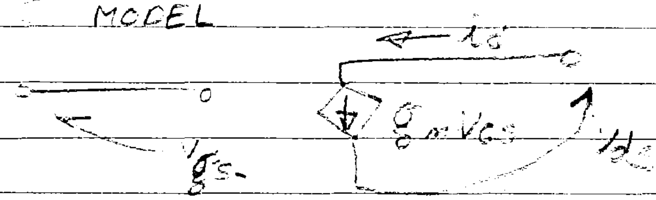
HAND IN MON

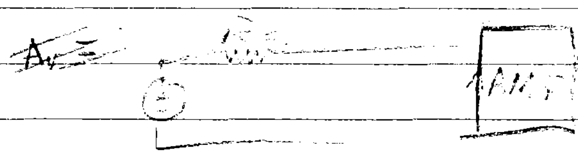
183.7.3   184.7.5   184.7.6



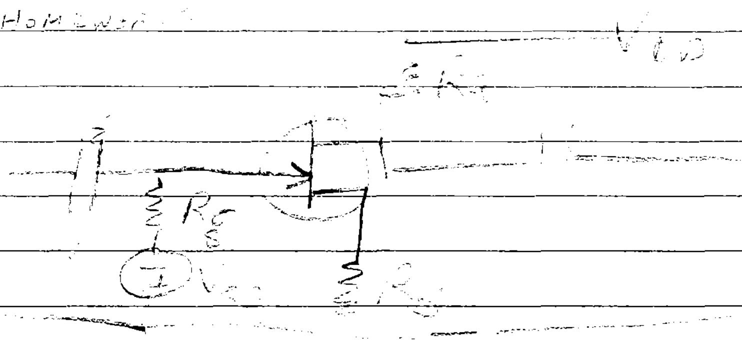
TUES

MODEL





HOMEWORK



$I_{DSS} = 10\ mA$, $V_P = -3V$

$V_{CC} = 25V$

$V_{DS} = 10V$, $I_D = ...$

FIND R_d, V_{GG}, R_s

[illegible] $ AEC [illegible] [illegible]

[illegible]

[illegible] (X) X = E (LISTS [illegible])

G NO LIST

7/3/9 PROGRAME NAME (INPUT, OUTPUT)

FCRT PROG

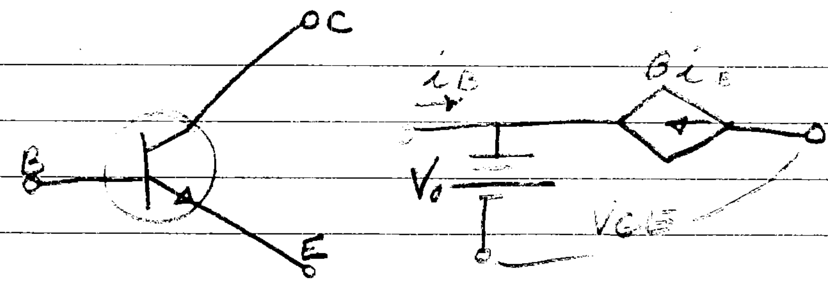
7/8/9

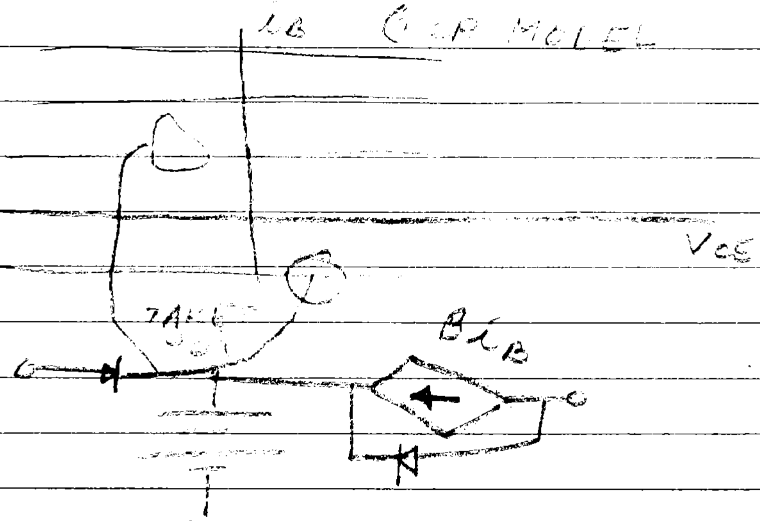
MATH

6/7/8/9

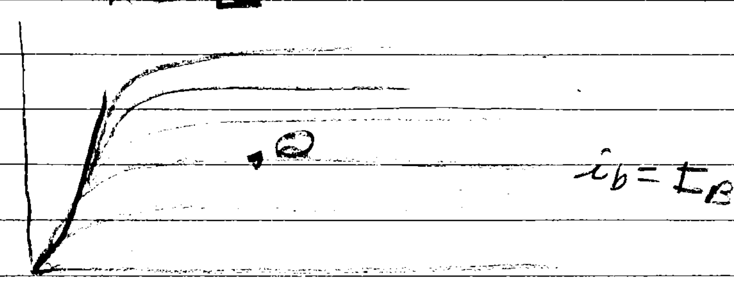
```
COMPLEX Z(100)
Z = CMPLX (R, X)
ZABS = CABS(Z)
R = REAL(Z)
X = AIMAG (Z)
PRINT 5, Z
[illegible] (2X, 2F10.3)
ANG = 57.3 x ATAN2(AIMAG(Z), REAL(Z))
```

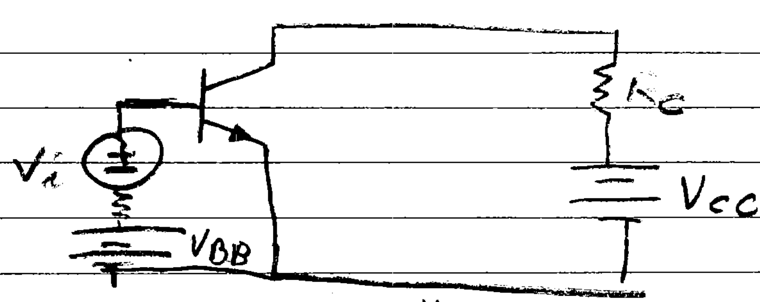
→ 180





FOR REAL





$$I_B = \frac{V_{BB} - V_0}{R_b}$$

6-3

READ TO 270

251 9.4 252 9.6 - 53.8

1.1

MON

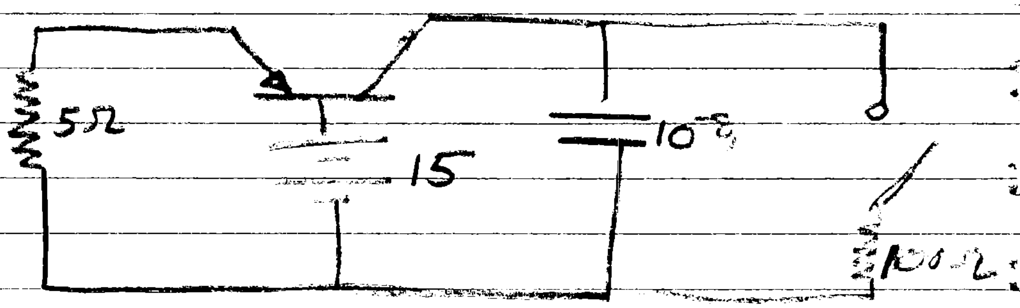
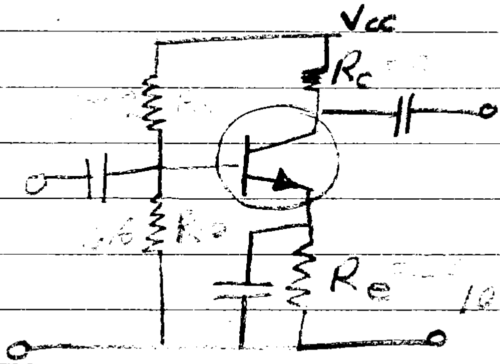
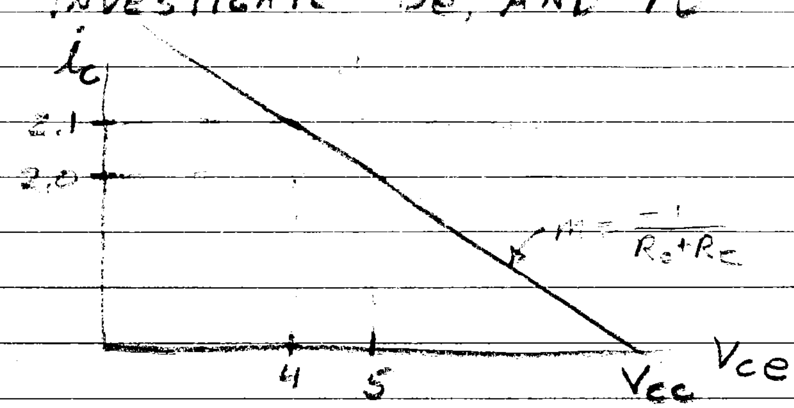


CHART. 10



$I_{C MAX} = 2.1\ mA = I_{C2}$
$I_{C MIN} = 2.0\ mA = I_{C1}$
$V_{CE(MIN)} = 4\ V$
$V_{CE(MAX)} = 5\ V$
$100 < \beta < 300$
$V_o = .65\ V$

NEGLECT I_{CEO}, BUT WILL INVESTIGATE S_e, AND η



$V_{cc} = 25\ V$ (SIMILAR TRIANGLES)

$R_e + R_c = \frac{1}{.1} = 10k$

ASSUME $R_e = .25\ R_c$

$\Rightarrow R_c = 8k$; $R_e = 2k$

$S_{e2} = \ldots R_e$ $\quad S_{e2} = \ldots I_c$

$= \frac{1 + R_e/R_b}{1 + \ldots R_e/R_b}$

$V_{BB} = \ldots \frac{\ldots}{200} \ldots + V_{BE} \ldots$

$V_{BB} = \frac{R_2}{R_1+R_2} V_{CC}$

$R_b = R_1 R_2 / (R_1+R_2)$

$R_1 = R_b / K = \frac{13.3}{...} = 67.. k$

$$S_{e2} = \frac{\Delta I_C / I_{C1}}{\Delta\beta / \beta_1}$$

$$\frac{R_e}{R_b} = \frac{1 - S_{e2}}{S_{e2}(1+\beta_2) - 1}$$

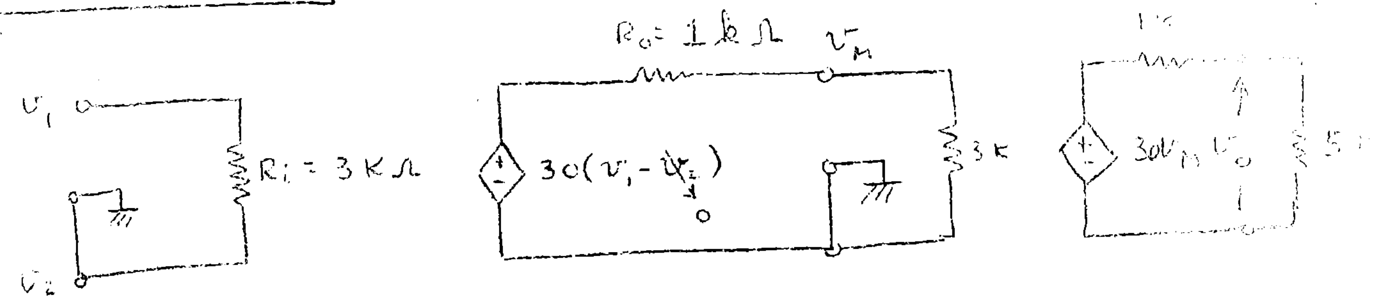
$$V_{BB} = \frac{I_{C1}[R_b + (1+\beta_2) R_e]}{\beta} + V_0$$

THURS.

$\beta_E = 76 \quad ... 7)$

HOMEWORK

Problem 21.2.5



$$V_o = \frac{5}{6} \cdot 30V_M, \quad V_M = \frac{3}{4.0} \times 30\, v_1$$

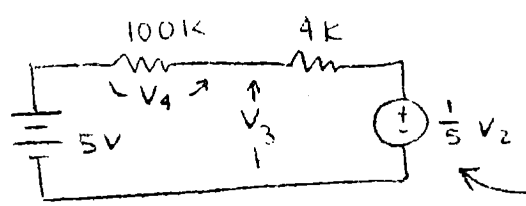
$$V_o = \frac{5}{6} \times 30 \times \frac{3}{4.0} \times 30 v_1 \quad \frac{5 \times 3 \times 30^2}{6 \times 4} \approx \boxed{563} = \frac{V_o}{V_m}$$

Overall voltage gain

PROBLEM 22.2.7

(a) $V_2 = V_1 - 2V_5 \qquad V_5 = 100V_4 \qquad V_4 = -5 + V_3$

$V_3 \stackrel{?}{=} \frac{1}{5} V_2$



EQUIVALENT CIRCUIT

$$V_4 = -5 + \frac{1}{5} V_2 - 4 \left(\frac{1/5 V_2 - 5}{104000} \right)$$

$$V_2 = V_1 - 2 \left[100 \left(-5 + .2V_2 - 4 \left(\frac{.2V_2 \cdot 5}{104} \right) \right) \right]$$

$$= V_1 - 200 \left[-5 + .2V_2 - \frac{.8V_2 - 20}{104} \right]$$

$$V_2 = V_1 + 1000 - 40V_2 + 1.925(.8V_2 - 20)$$

[illegible]

HOMEWORK

2.2.2.7 cont

$$V_2 \left(\frac{39.46}{\sout{40.46}}\right) = V_1 + 961.6$$

~~$V_2 = \frac{V_1}{\sout{40.46}\ 39.46} + 28.7$~~

$$\boxed{V_2 = \frac{V_1}{39.46} + 24.4}$$

← note that the output voltage is relatively independent of V_1

(b) $V_1 = 35$, $V_2 = \frac{35}{39.46} + 24.4 = .888 + 24.4 = \boxed{25.3\text{V}}$

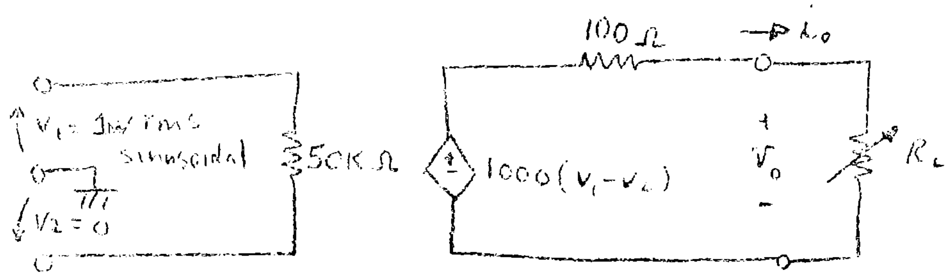
(c) $V_1 = 40\text{ V}$ $V_2 = \frac{40}{39.46} + 24.4 = \boxed{25.4\text{ V}}$

(d) From b and c $\Delta V_2 / \Delta V_1 = \frac{25.4 - 25.3}{40 - 35} = \frac{.1}{5} = \boxed{\frac{1}{50}}$

differentiating: $\frac{dV_2}{dV_1} = \boxed{\frac{1}{39.46}} = \boxed{.0253}$

HOMEWORK

PROBLEM 20.2.3



(a) $R_L = 100\,\Omega$ $\quad P_{max} = \dfrac{(1000 \times .001)^2}{4 \times 100} = \dfrac{1}{400} =$ **.025 W**

= **25 mW** ← output power from amplifier

(b) $P_{in} = \dfrac{(.001)^2}{5 \times 10^4} = \dfrac{10^{-6}}{5 \times 10^4} = \frac{1}{5} \times 10^{-10}$ W

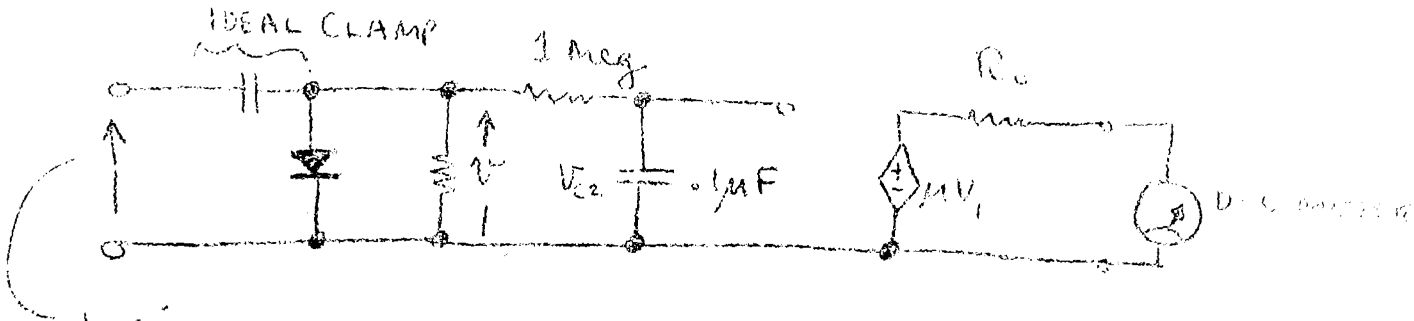
= **20 pW** $\quad A_p = \dfrac{25 \times 10^{-3}}{20 \times 10^{-12}} =$ **1.25 × 10**

(c) NO, OF COURSE NOT!

EE 262

SOLUTIONS

4.3.5



$10 \sin \underbrace{2\pi \times 16000}_{\omega} t$ V.

$v = -10 + 10 \sin \omega t$

$v_{C2,\,d\text{-}c} = -10$ V.

a-c component across C_2

$$= 10 \left| \frac{\frac{1}{j\omega C}}{10^6 + j\omega C} \right| = 10 \left| \frac{1}{1 + j\omega .1} \right|$$

$$\doteq \cancel{10}\ \frac{10^{-1}}{\cancel{.1} \times 2\pi \times 16 \times \cancel{10^3}} =$$

$$\doteq \frac{10^{-1}}{100} = \boxed{10^{-3} \text{ V. amplitude}}$$

(c) If frequency is 16 Hz, $\omega \doteq 100$ rad/sec

$$\text{a-c component} = 10 \left| \frac{1}{1 + j\,0.1\omega} \right| = \left| \frac{10}{1 + j10} \right|$$

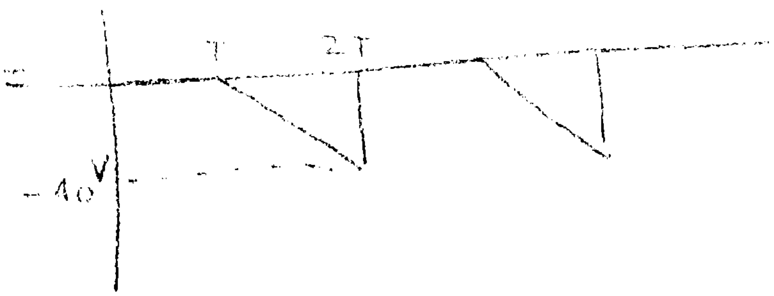
$$\simeq \boxed{1 \text{ VOLT AMP.}}$$

SOLUTIONS

53.3.13 WORKED IN CLASS!

50.3.8

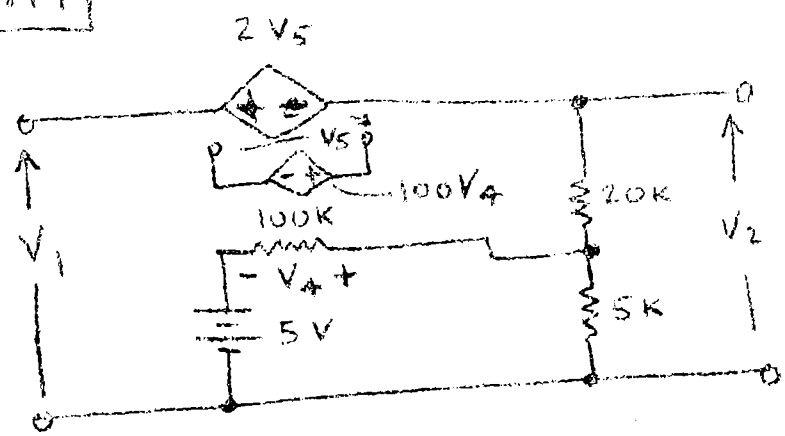
v_{FILTER} =



average value $= \left(\frac{-40 \times T}{2} \right) \div 2T = -10\,V$

meter reads $0.707 \times 10 =$ **7.07 VOLTS**

53.3.14



(a) $V_2 = V_1 - 2V_5$

$V_5 = 100\,V_4$

$V_4 = -5 + .2\,V_2$

$V_2 = V_1 - 2 \cdot 100(-5 + .2V_2) = V_1 + 1000 - 40V_2$

$41V_2 = V_1 + 1000$ $\quad V_2 = \boxed{\frac{1}{41} V_1 + 24.4}$

(b) $\frac{\partial V_2}{\partial V_1} = \boxed{\frac{1}{41}}$ $\quad$ (c) ripple in $V_2 = \frac{5}{41} = \boxed{.0122\,V\ p\text{-}p}$

53.3.14 cont.

(d) $V_2 = V_1 - 2A(-5 + .2V_2)$

$V_2 = V_1 + 10A - .4AV_2$

$V_2(1 + .4A) = V_1 + 10A$

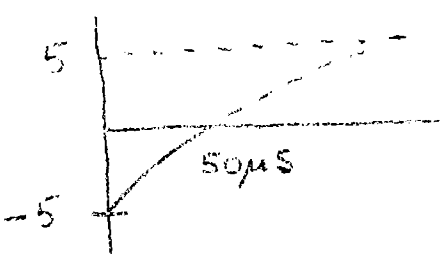
$$V_2 = \frac{1}{1+.4A}V_1 + \frac{10A}{1+.4A}$$

$$\frac{1}{1+.4A} = \frac{1}{1000} \qquad .4A = 999 \Rightarrow A = 2500$$

TWO AMPLIFIERS IN CASCADE EACH WITH GAIN 100 WOULD BE SATISFACTORY.

54.3.15

(a)



$v = 5 - 10e^{-\frac{t}{T}}$

$0 = 5 - 10e^{-\frac{5\times10^{-5}}{T}} \qquad .5 = e^{-\frac{5\times10^{-5}}{T}} \qquad \frac{-5\times10^{-5}}{T} = -.693$

$T = \frac{5\times10^{-5}}{.693} = 7.21\times10^{-5}$

$C = \frac{T}{R} = \frac{7.21\times10^{-5}}{5\times10^{4}} = 1.44\times10^{-9} = \boxed{1.44\ nF}$

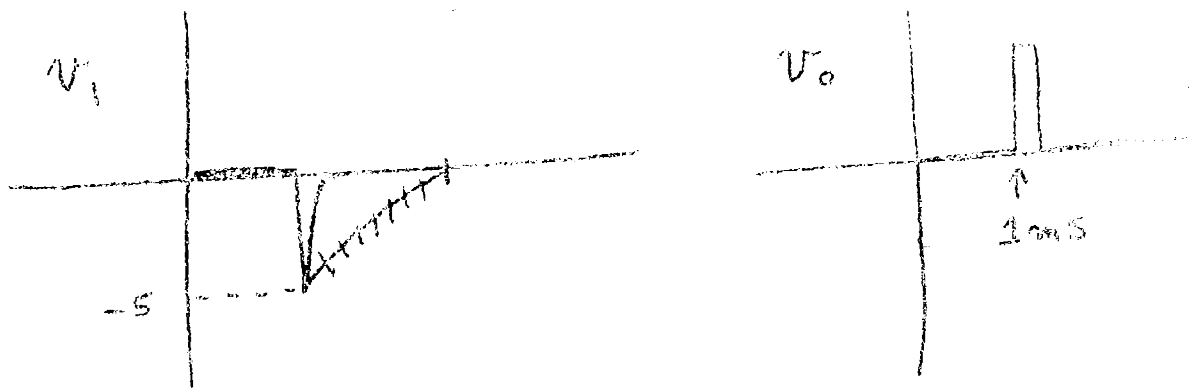
EE 262
SOLUTIONS

54.3.15 CONT

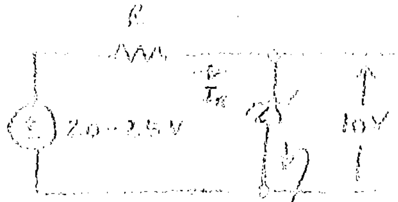
(b) 1, 3, 5, ... ms.

(c) NO!

(d)



101.5.1



$I_d \geq 10\,mA$

$P_D \leq 250\,mW$

(a) $I_{d,max} = \frac{250}{10} = \boxed{25\,mA}$

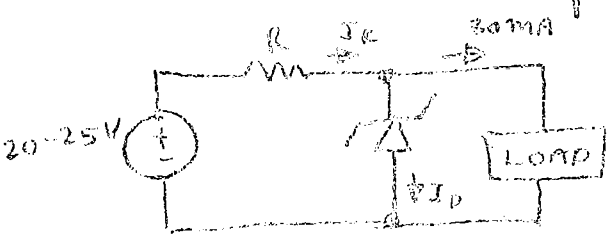
(b) $R = \frac{25-10}{25} = .6\,k\Omega = \boxed{600\,\Omega}$

(c) $V = 20\,V$

$I_R = \frac{10}{600} = \frac{1}{60} = .016\,A = 16\,mA$

$I_{L,max} = \boxed{15\,mA}$ (16−1)

102.5.2 Constant output $I_L = 30\,mA$



$R = \frac{20-10}{31} = \frac{10}{31} = .323\,k\Omega = \boxed{323\,\Omega}$

$P_{D,max} = 10 \times I_{D,max} = 10 \times \left(\frac{25-10}{.323} - 30 \right)$

$= 10 \times (46.5 - 30)$

$= 10 \times 16.5 = \boxed{165\,mW}$

BOB MARKS

Electrical Engineering Dept
Rose-Hulman Institute of Tech
Terre Haute, Indiana
March 22, 1971

EE262 - Electronics I
Quiz no. 1
Closed books - ten minutes

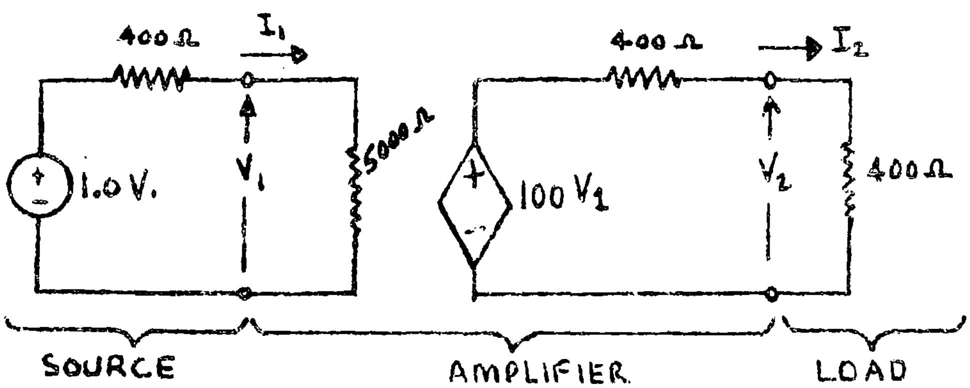
A somewhat less than ideal amplifier is shown below connected between a source and a load. For the circuit values shown, compute:

(a) the voltage gain, $A_v = V_o/V_{in}$

(b) the current gain, $A_i = I_o/I_{in}$

(c) the power gain, $A_p = P_{LOAD}/P_{from\ source}$

(d) value of R_L which would draw maximum power from the output of the amplifier.



a) $V_i = \frac{5000}{5400}$ $V_o = \frac{400}{800} 100 V_1$

$A_V = \frac{V_o}{V_i} = \frac{50 V_i}{V_i} = 50$

b) $I_i = \frac{V_i}{5400}$ $I_o = \frac{100 V_i}{800}$

$\frac{I_o}{I_i} = \frac{1 V_i 5400}{8 V_i}$

Solution

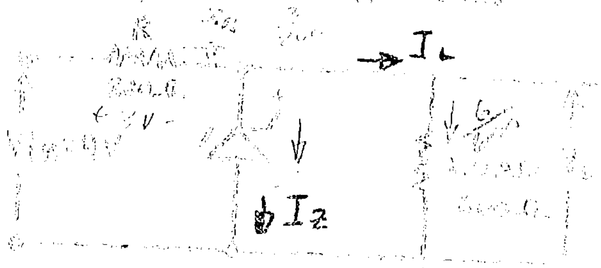
[illegible]
Rose-Hulman Institute [illegible]
Terre Haute, Indiana
April 5, [illegible]

EE262 - Electronics I
Quiz #2
Closed books - 50 minutes

In the circuit shown find

(A) V_L
(B) P_D
(C) I_R
(D) minimum value of V_{in} such that V_L remains regulated.

Zener diode: $V_Z = 6$ V.



(A) $V_L = \boxed{6\ V}$

(B) $I_Z = I_R - I_L = \frac{3}{200} - \frac{6}{600} = .015 - .010$

$= .005\ A \qquad P_Z = .005 \times 6 = \boxed{.03\ W}$

(C) $I_R = \frac{9-6}{200} = \boxed{15\ mA}$

(d) becomes unregulated when I_R falls to I_L

$\frac{V_{in} - 6}{200} = .01 \quad , V_{in} - 6 = 2 \qquad V_{in} = \boxed{8\ V}$

Solutions

102.6.3

$$C_j = \frac{K}{(\psi_0 + V)^m} \qquad m = 2, \quad \psi_0 = .85$$

$C_j = 200$ pF for $V = 2$

$$\frac{200 = \dfrac{K}{(2.85)^2}}{20 = \dfrac{K}{(V+.85)^2}} \;;\; 10 = \left(\frac{V+.85}{2.85}\right)^2$$

$$\frac{V+.85}{2.85} = 3.16$$

$$V = 2.85 \times 3.16 - .85$$

$$= 9 - .85 = \boxed{8.15\text{ V}}$$

102.6.4

$$C_j = \frac{K}{(\psi_0 + V)^2} \qquad f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

$$= \frac{1}{2\pi\sqrt{L}\sqrt{\dfrac{K}{(\psi_0+V)^2}}} = \boxed{\frac{\psi_0 + V}{2\pi\sqrt{LK}}}$$

P12.6.3

$I_{DSS} = 5.0\ mA$

$V_P = -4\ V$

$V_{DD} = 25\ V$

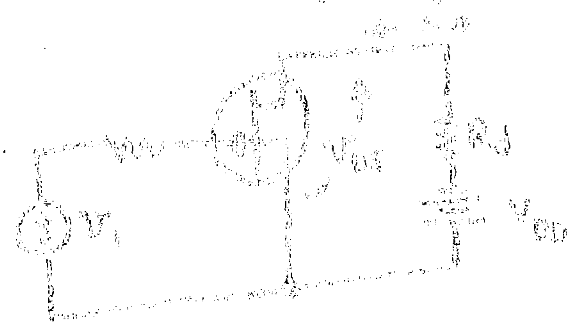
(a) $v_{DS} = 8\ V$ for $v_{GS} = 0$

$$i_D = 5\left(1 + \frac{0}{4}\right)^2 = 5\ mA$$

$$R_d = \frac{25 - 8}{5} = \frac{17}{5} = \boxed{3.4\ k\Omega}$$

(b) $$g_m = -\frac{2\ I_{DSS}}{V_P} = \frac{2 \times 5}{4} = \boxed{2.5}$$

P12.6.4



$I_{DSS} = -4\ mA$

$V_P = 4\ V$

$V_{DD} = 25\ V$

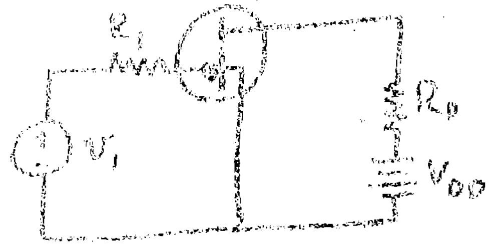
$v_{DS} = -V_{DD} - R_d\, i_D$ $\qquad -7 = -25 - R_d(-4)$

$i_D = -4\ mA$ $\qquad R_d = \frac{18}{4} = \boxed{4.5\ k\Omega}$

(b) $$g_m = \frac{2 \times 4}{4} = \boxed{2}$$

P 5.2 Solutions

143.6.5



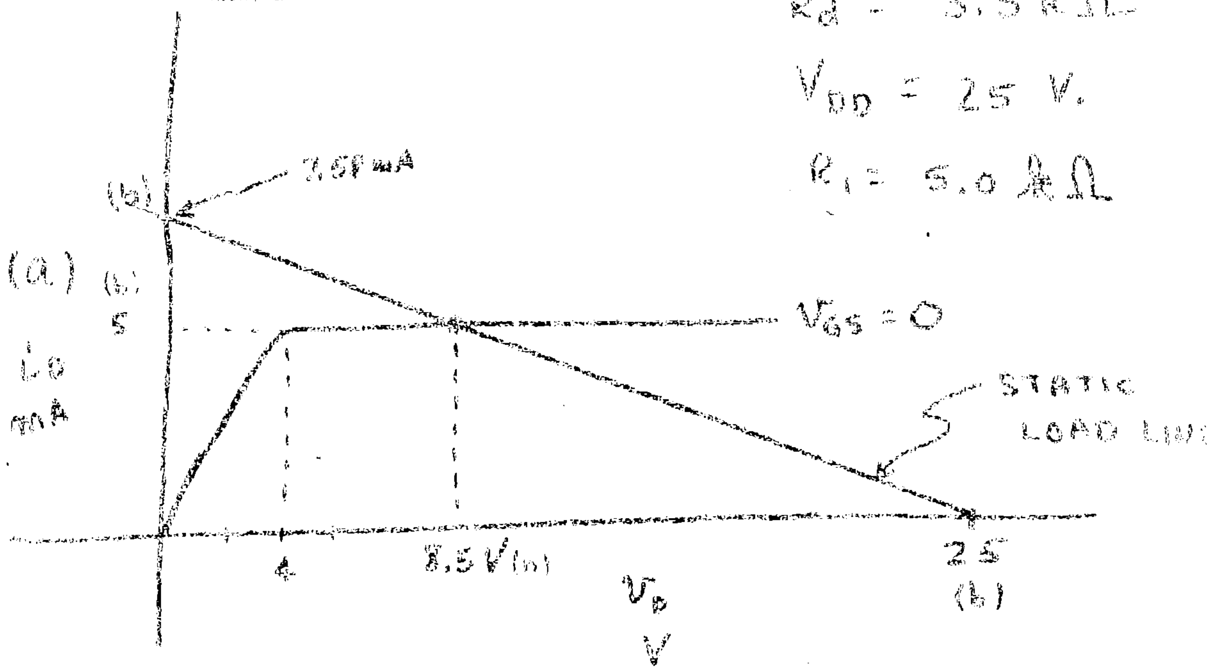
$I_{DSS} = 5$ mA

$V_P = -4$ V.

$R_d = 3.3$ kΩ

$V_{DD} = 25$ V.

$R_1 = 5.0$ kΩ



(c) $V_{DS} = 8.5$ V

$i_D = 5.0$ mA

143.6.6

$I_{DSS} = 12$ mA $\quad R_1 = 50$ kΩ

$V_P = -5$ V. $\quad V_{GG} = 1.75$ V.

$R_d = 3.3$ kΩ $\quad V_{DD} = 25$ V.

$$i_D = 12\left(1 - \frac{1.75}{5}\right)^2 = 12 \times .65^2 = \boxed{5.07 \text{ mA}}$$

$$V_{DS} = 25 - 3.3 \times 5.07 = 25 - 16.8 = \boxed{8.2 \text{ V}}$$

(b) $$g_m = \frac{2 \times 3.2 \times 12}{5} = \boxed{15.36}$$

[illegible]

[9.2.67]

$I_{DSS} = 10\,mA$

$V_p = -4\,V$

$V_{DD} = 25\,V$

$I_{DSS} \times R_d = 25 - 7 = 18 \qquad R_d = \frac{18}{10} = \boxed{1.8\,k\Omega}$

(b) $K_v = \frac{2 R_d I_{DSS}}{V_p} = \frac{2 \times 1.8 \times 10}{4} = \boxed{9}$

(c) $R_d = \frac{25 - 7}{2.5} = \frac{18}{2.5} = \boxed{7.2\,k\Omega}$

$2.5 = 10\left(1 + \frac{V_{GS}}{4}\right)^2 \qquad \sqrt{.25} = 1 + \frac{V_{GS}}{4} = .5$

$V_{GS} = 4 \times -.5 = \boxed{[illegible]}$

(d) $K_v = \frac{2 \times 7.2 \times 10}{4} = \boxed{36}$

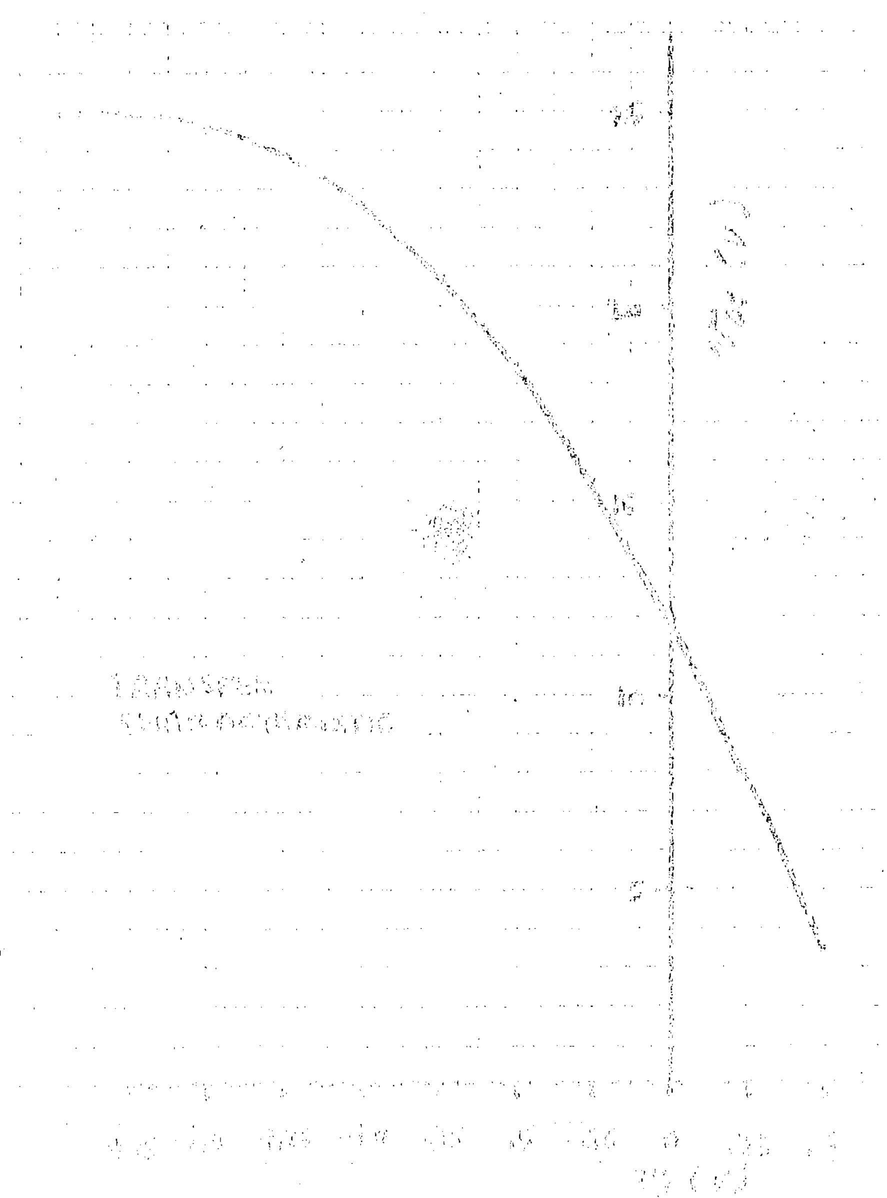
(e) Since the coefficient of the v_i^2 term is

$-\frac{R_d I_{DSS}}{V_p^2}$ The second design yields more distortion.

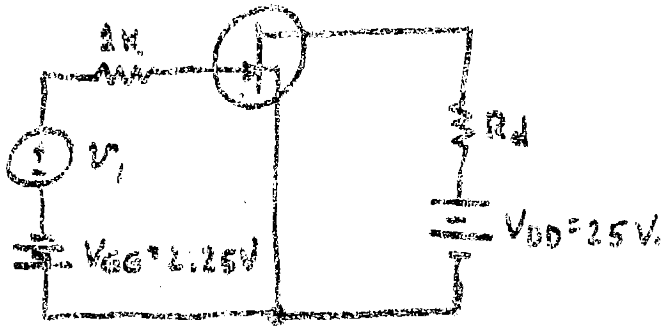
Equation 8-34

$$V_{BS} = V_{BP} - R_d I_{DSS}\left(1 - \frac{V_{BS} + V_t}{V_t}\right)^2$$ GOOD IN P.O. REGION ONLY

$$= 15 - 18\left(1 + \frac{V_1 - 2.25}{4}\right)^2$$



146.6.13



$I_{DSS} = 10\,mA$

$V_p = -4\,V$

$R_d = 6.8\,k\Omega$

(a) $V_{Rd} = \frac{1}{2} I_{DSS} R_d V_1^2$

distortion term is $\frac{R_d I_{DSS} V_1^2}{V_p^2}\left[\frac{1}{2}\left(1+\cos 2\omega t\right)\right]$

distortion (2nd h) $= \frac{V_1^2 R_d I_{DSS}}{2 V_p^2}$

signal term is $= \frac{2 R_d I_{DSS}}{V_p} V_1$

% dist $= \left|\left(4 V_1 / V_p\right)\right| \times 100$

$\frac{4 V_1}{V_p} = .02 \qquad V_1 = \frac{.02 V_p}{4} = \boxed{.02\ V}$

(b) $\frac{2 \times 6.8 \times 10}{4} = \boxed{34} = K_v$

(c) $P_{DD} = 25\, I_D \quad , \quad I_D = 10\left(1 - \frac{2.25}{4}\right)^2 = 1.914\,mA$

$P_{DD} = \boxed{47.8\ mW}$

146.6.13 cont

$V_{DS} = 25 - 6.8 \times 1.914 = 11.98\ V.$

$P_T = \boxed{22.44\ mW}$

$R_{Rd} = \boxed{24.9\ mW}$

Bob Marks

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana
April 5, 1971

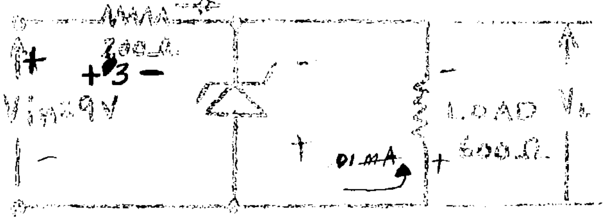
EE262 - Electronics I
Quiz #2
Closed books - 50 minutes

75

In the circuit shown find

(A) $V_L = 6V$
(B) P_D
(C) I_R
(D) minimum value of V_{in} such that V_L remains regulated.

Zener diode: $V_Z = 6$ V.



A) $V_L = 6$ V

B) $P_D = 6\left(\frac{3}{200} + \frac{6}{600}\right)$

$= 6(.015 + .01) = (.025) \times 6 = .150 W$

C) $I_R = \frac{3}{200} = .015$ A

D) $V_R + 6 - V_{IN} = 0$

$V_{IN} = 200(.001) + 6 = 8V$

EE Department
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

EE 262 - ELECTRONICS I

Laboratory

Experiment #____

DESIGN OF A JFET AMPLIFIER

I. Design for quiescent operating point.

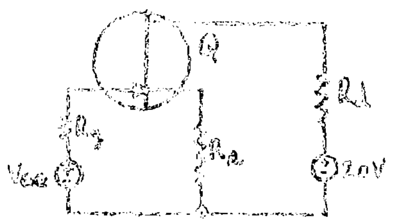


Fig. 1. D-C Circuit

Compute suitable values for your transistor so that it will have a quiescent operating point of $I_D = 2$ mA and $V_{DS} = 10$ volts. Use the known values of V_P, I_{DSS}, and N. Two cases are of interest here. They are:

(a) $V_{GG} = 0$

and

(b) $V_{GG} \neq 0$, $R_d = R_s$.

Show the results of these calculations to the lab instructor before building the amplifier.

II. The a-c amplifier.

(a) Using the results of part I, compute suitable values for R_1 and R_2 so that $R = 1$ MΩ. Build the amplifier using resistance substitution boxes for R_1, R_2, R_d, and R_s.

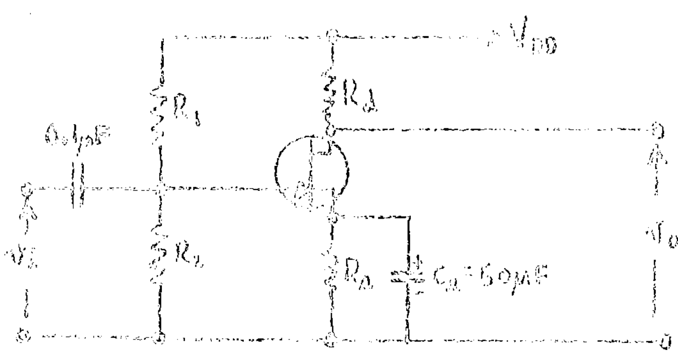


Figure 2. The JFET AMPLIFIER.

When the amplifier is completed check the quiescent conditions to see if they are $I_D = 2$ mA and $V_{DS} = 10$ v. Record these values. Explain any difference between measured values and design values.

(b) Apply an input signal from the audio generator at 1000 Hz, and measure the small signal gain of the amplifier. Observe the V_o waveform on the CRO at all times.

(c) Increase the input signal to the amplifier until distortion is plainly visible in the output voltage. Record this signal level and how it was measured. Sketch the output waveform.

(d) Under small signal conditions calculate the theoretical voltage gain of the amplifier. R_d must be accurately known for this calculation.

(e) Check the frequency response for the amplifier. Compute the low and high frequencies where the voltage gain is 707 times that at 1000 Hz.

(f) Remove the source bypass capacitor and observe how the operation of the amplifier is affected.

(g) Measure the output impedance of the amplifier at 1000 Hz with and without C_s connected. Monitor V_o at all times while performing this test. Reduce V_{in} if necessary to insure small signal operation.

(h) Measure the output conditions under the same conditions as in part (g).

References:

Angelo, E.A., "Electronics: BJT's, FET's, and Microcircuits, McGraw-Hill, N.Y. 1969.

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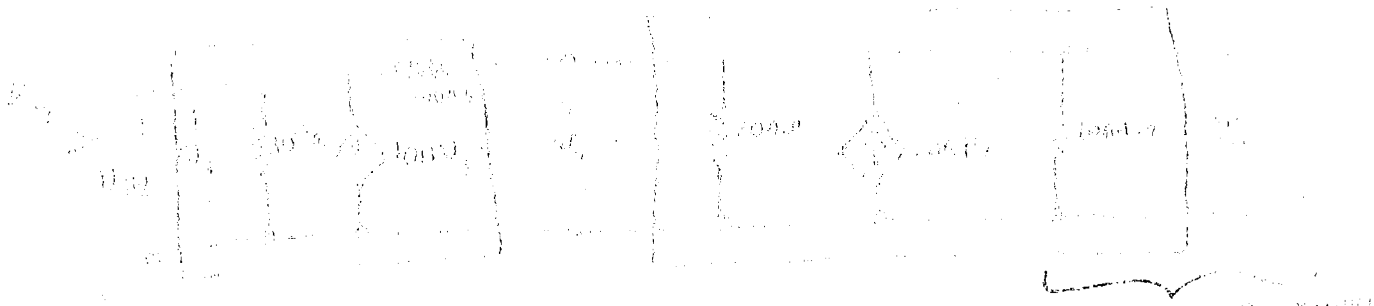
EE 2[illegible] ELECTRONICS I
Test #1
Closed Book 50 minutes

1. Two amplifiers are connected as shown. The input voltage is sinusoidal with [illegible] value of 1 mV.



$R = \frac{200 \times 1000}{1200} = 167\,\Omega$

(a) Find the gain of the amplifier, v_o/v_{in}
(b) " " " " in dB
(c) Find the power gain of the amplifier P_{load}/P_{in}
(d) What value of R_{load} would you connect to the output of the amplifier to maximize the power gain with respect to P_{in}?

Solution

$v_o = .05\, v_2 \times 167$, $v_2 = \frac{200}{5200} \times 100\, v_1$ $v_1 = v_{in}$

thus $v_o = .05 \times 167 \times \frac{200}{5200} \times 100\, v_{in}$, $\frac{v_o}{v_{in}} = \boxed{32.1}$

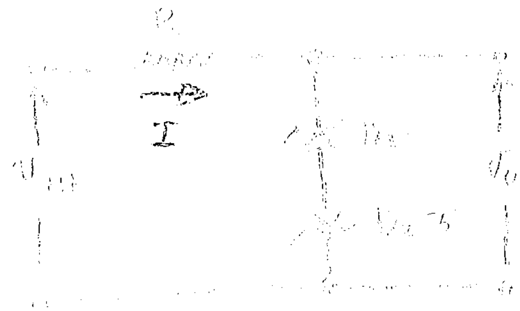
(b) $G_{dB} = 20 \log_{10} 32.1 = \boxed{30.2\ dB}$

(c) $P_o = v_2^2/200$ $P_{in} = v_{in}^2/10^4$, $\frac{P_o}{P_{in}} = \frac{v_2^2/200}{v_{in}^2/10^4}$

$= (32.1)^2 \times \frac{10^4}{200} = \boxed{51,500}$

(d) $R_{LOAD} = \boxed{1000\,\Omega}$ for maximum power out of amplifier

2. Design a clipper circuit that would limit the maximum value of v_o to +10V and the minimum value of v_o to −5 V. Use zener diodes to do this as shown below. Assume that the largest input signal to the clipper is a sinusoid of 100 V amplitude.



(a) What should the zener voltages of D_1 and D_2 be?

(b) What value should R have to limit the reverse current in the diodes to 50 mA?

(c) What should the power ratings of D_1 and D_2 be?

(d) What should be the power rating of R in the worst case, i.e., what is the maximum instantaneous power R dissipates?

SOLUTION

(a) V_Z of D_1 = **10 V** V_Z of D_2 = **5 V**

(b) max current when $v_{IN} = -100\,V$

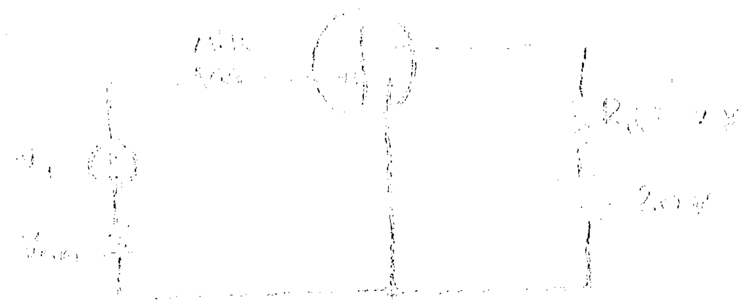
$I = \frac{-95}{R} = -.05$, $R = \frac{95}{.05}$ = ~~[illegible]~~ **1900 Ω**

(c) D_1, reverse max current = $\frac{90}{1900}$ = .0473 A $P = 10 \times .0473$ = **.473 W**

D_2, reverse max current = .05 A, $P = 5 \times .05$ = **.25 W**

(d) $P_R = (.05)^2 \times 1900$ = **4.75 W**

An N channel JFET is used in the amplifier shown. I_{DSS} = 8 mA and V_p = −3 V for this transistor. The input signal to the amplifier is [illegible]. What should be the value of V_{GG} so that the quiescent value of i_D is 5.0 mA? What is the quiescent value of v_{DS} under these conditions? Compute the power dissipated by R_d and by the transistor in quiescent [illegible]



Note: assume the exponent in the i_D equation is 1.5 instead of 2.

SOLUTION:

$$i_D = I_{DSS}\left(1 - \frac{v_{GS}}{V_p}\right)^{1.5}$$

$V_p = -3$

$v_{GS} = -V_{GG}$

$$5 = 8\left(1 - \frac{V_{GG}}{3}\right)^{1.5}$$

$$\left(\frac{5}{8}\right)^{2/3} = 1 - \frac{V_{GG}}{3} = .731$$

$$\frac{V_{GG}}{3} = .269 \qquad V_{GG} = \boxed{.807\ V}$$

quiescent $v_{DS} = V_{DS}$

$$V_{DS} = 20 - 2 \times 5 = \boxed{10\ V}$$

$$P_{Rd} = 10 \times .005 = \boxed{50\ mW}$$

$$P_T = 10 \times .005 = \boxed{50\ mW}$$

CHECK

Power from Source = 20 × .005 = 100 mW — Check!

(a) A donor material donates ELECTRONS to the lattice of silicon or germanium.

(b) Minority charge carriers come about in a semiconductor by

THERMAL AGITATION

(c) Increasing the input voltage to a class A FET amplifier (increases, **decreases**) the power dissipated by the transistor. Assume linear operation.

(d) An enhancement FET amplifier is biased by placing a negative d-c voltage in series with the input, i.e., $v_{GS} = v_i + V_{GG}$ where $V_{GG} < 0$. FALSE or **TRUE**

(e) One easy way to reduce the distortion present at the output of an amplifier is to reduce the magnitude of the input voltage to the amplifier. FALSE or **TRUE**

Electrical Engineering Depart.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana
May 20, 1971

EE365 – Electronic Ckts. I
Assignment
Due when school resumes in the Fall.

Do either or both of the following:

(A) Write a Fortran subroutine subprogram to design a common emitter transistor amplifier of the "Standard Configuration". Input to the subroutine should be V_{CC}, $beta_1$, $beta_2$, V_o, I_{C1}, I_{C2}, $V_{CE(min)}$, I_{CEO}; the subroutine should return R_1, R_2, R_c, and R_e. It should compute S_{e1} and S_{e2} and n as well.

(B) Write a Fortran subroutine subprogram to analyze the standard configuration common emitter transistor amplifier. The input to the subroutine should be V_{CC}, beta, R_1, R_2, R_e, R_c, I_{CEO}, and V_o. The subroutine should compute and return the quiescent operating point information and Se.

BOB MARKS

Electrical Engineering Department
Rose-Hulman Institute of Technology
Terre Haute, Indiana
April 27, 1971

EE 262 - Electronics I
Laboratory Quiz #1

Open Books -- 10 minutes

100

1. Which of the currents shown below is most apt to be fatal when passing through the body

   (a) 1 mA (c) 150 mA

   (b) 10 mA (d) 5 pA

2. The laboratory notebook should not contain any calculations, sketches of waveforms or similar entries.

   False or true.

3. Usually it is advised to keep most of your lab notes on random sheets of scratch paper rather than in your lab book.

   False or true.

4. Data to be presented in graphical form must be plotted in the laboratory.

   False or true.

5. It is alright to label axes on a graph with just the correct units, i.e., volts or Amperes.

   False or true.

6. Wiring diagrams aren't necessary as you can usually remember what the actual circuit employed was.

   False or true.

7. In general a 2-watt resistor is larger than a 1-watt resistor.

   False or true.

8. A resistor has color code red, red, green, silver. What does this mean

   A B C D

   $R = AB \times 10^{C} \pm D$

   $2\,2 \times 10^{5}\,\Omega \pm 10\%$

8

9. In choosing leads for connections it is better to use long ones so that the circuit may be laid out larger on the bench.

False or true.

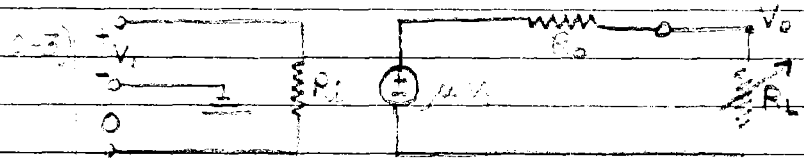
10. Generally speaking, a ground point should be provided near the input terminals of a low-level circuit, and all grounding should be made at this one point only.

False or true.

Bob Marks

(6/6)

3-17-71



$\mu = 1000$ $R_i = 5\times10^4\,\Omega$

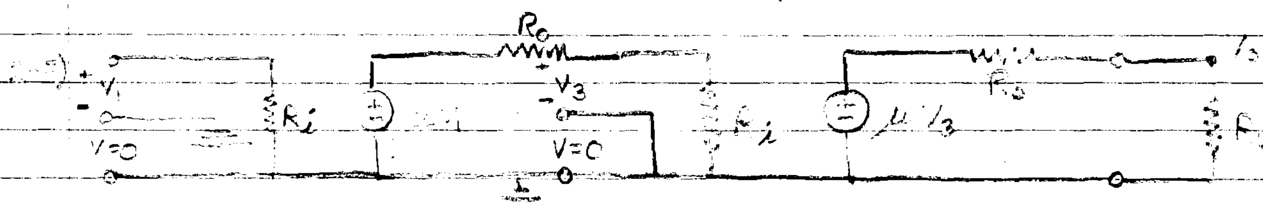
$R_o = 10^2\,\Omega$ $V_1 = 10^{-3}$

a) FOR MAX PWR. $R_L = R_o$

$V_o = \frac{R_L}{R_L+R_o}\mu V_1 \Rightarrow P_L = \frac{V_o^2}{R_L} = (\frac{1}{2}10^3 10^{-3})^2 10^{-2} = .25\times10^{-2} = 2.5$ [illegible]

b) [illegible] $= \frac{P_L}{P_i} = \frac{V_o^2}{V_1^2}\frac{R_i}{R_L} =$ [illegible] $\frac{5\times10^4}{[illegible]} = (.25\times10^6)(5\times10^2) = 1.25\times10^3$

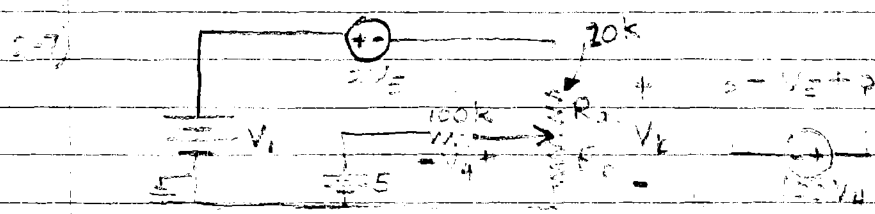
c) NO. G IS INDEPENDENT OF V_1, AND IS MAX WHEN $R_L = R_o$



[illegible] ; $R_i = $ [illegible] ; $R_o = 10^3$; $R_L = 5\times10^2$

$A_v = \frac{V_o}{V_1} = \frac{R_L}{R_L+R_o}\mu V_3\frac{1}{V_1} = \frac{R_L}{R_L+R_o}\mu\left(\frac{R_i}{R_o+R_i}\mu V_1\right)\frac{1}{V_1} = \frac{R_L R_i}{(R_L+R_o)(R_o+R_i)}\mu^2 = \frac{15}{6\cdot4}(900)$

$= \frac{5}{8}(900) = 562.5$



a) $V_2 = V_1 - 2V_5$

$V_3 = \frac{R_b}{R_a+R_b}V_2 = \frac{1}{5}V_2$; $V_4 = V_3 - 5$; $V_5 = 100\,V_4$

$V_2 = V_1 - 200\left[\frac{1}{5}V_2 - 5\right] = V_1 - 40V_2 + 1000 \Rightarrow V_2 = \frac{1}{41}V_1 + 24.5$

b) $V_1 = \frac{1}{41}(35) + 24.5 = 25.2\ V$

c) $V_1 = \frac{1}{41}(40) + 24.5 = 25.4\ V$

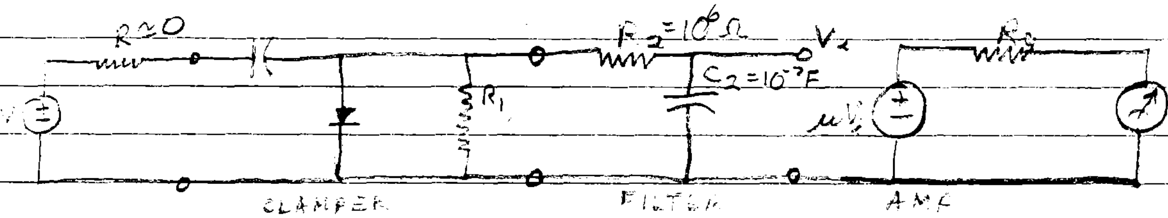
d) $dV_2/dV_1 = \frac{1}{41} = \Delta V_2/\Delta V_1$

BOE MARKS

7/8

3-10

3-7)



a) ... BEING TRANSMITTED TO AMP ≈ 10 VOLTS ✓

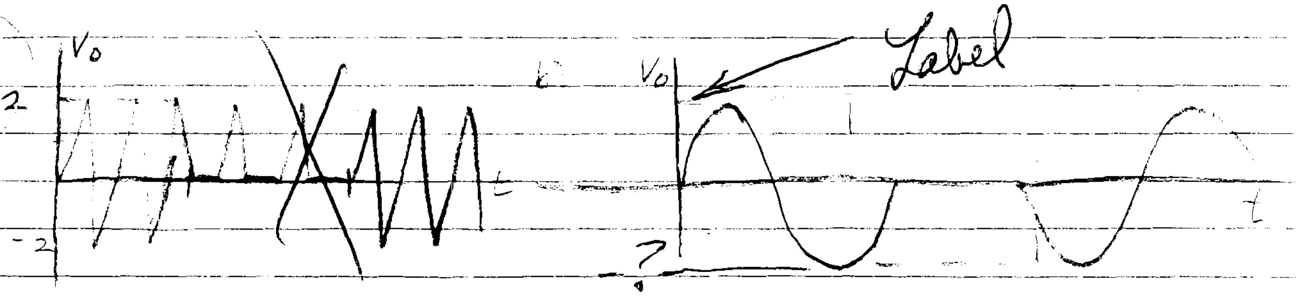
b) $\omega = 16\times10^3$ HZ ✓

BY VOLTAGE DIVIDER:

$V_c = 10\left(\frac{Z_c}{Z_c+R_2}\right) = \frac{\frac{-j10}{1.6\times10^4\times10^{-7}}}{10^6-\frac{j}{1.6\times10^{-3}}} = -j10\,\frac{.625\times10^3}{(10^6-j.625\times10^3)} \approx 1mV$

c) $V_c = 10\,\frac{\frac{1}{j16\times10^{-4}}}{10^6-\frac{j}{16\times10^{-7}}} = \frac{-10j.625\times10^5}{10^6-j.625\times10^6} \cong 1V$ ✓

3-13)



(-1)

3-14) a) $V_5 = 100V_4$; $V_2 = V_1 - 2V_5$; $5 + V_4 = V_2/5$

$\therefore 100V_4 = -500 + 20V_2$

$V_2 = -2(20V_2 - 500) + V_1$

$41V_2 = V_1 + 1000$

$V_2 = \frac{1}{41}V_1 + 10^3/41$ ✓

b) $dV_2/dV_1 = 1/41 = \Delta V_2/\Delta V_1$

c) $\Delta V_2 = \frac{1}{41}(5) = .122V$ ✓

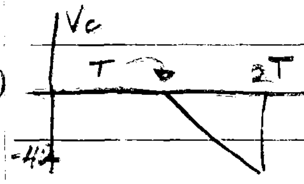
d) $\frac{V_4}{V_5} = A$

$V_2 = V_1 - 2AV_2 = V_1 - 2A\left(\frac{1}{5}V_2 - 5\right) = \frac{5}{2}V_1 + 25$

$dV_2/dV_1 = \frac{5}{2}A \Rightarrow A = \frac{25}{.01} = 2500$, YUP! (10) ✓

BOB MARKS

3-8)



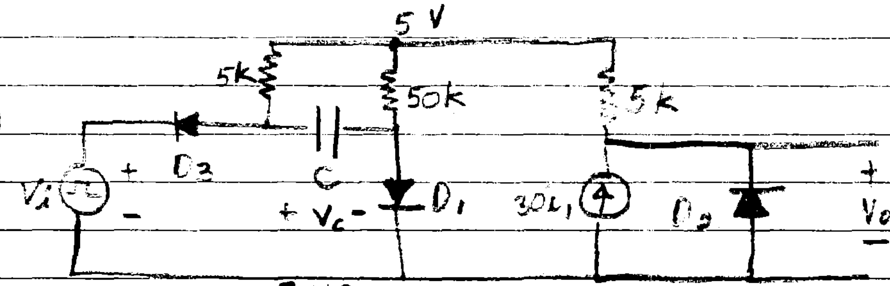
$\frac{1}{2T}\int_0^{2T} V_c\,dt = \frac{1}{2T}\;\frac{T}{2}\,40 = -10$

$\Rightarrow V_{READ\ BY\ METER} = \frac{10}{\sqrt{2}} = 7.07V$

B-3 MARKS

(2)

3-15)



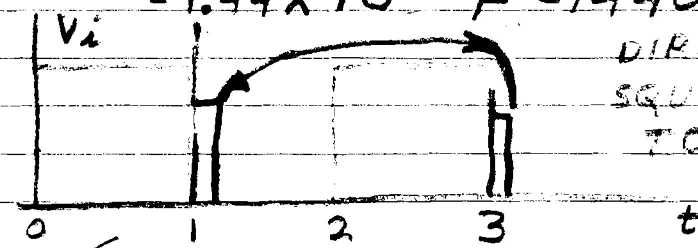
a) $V_c = 5 - 10e^{-T/\tau}$ $\tau = RC$

$5 = 10e^{-T/\tau}$

$\ln .5 = \frac{-50 \times 10^{-6}}{50 \times 10^{3} C} \Rightarrow C = 10^{-9}/\ln 2$

$= 1.44 \times 10^{-9} F = 1440 pF$

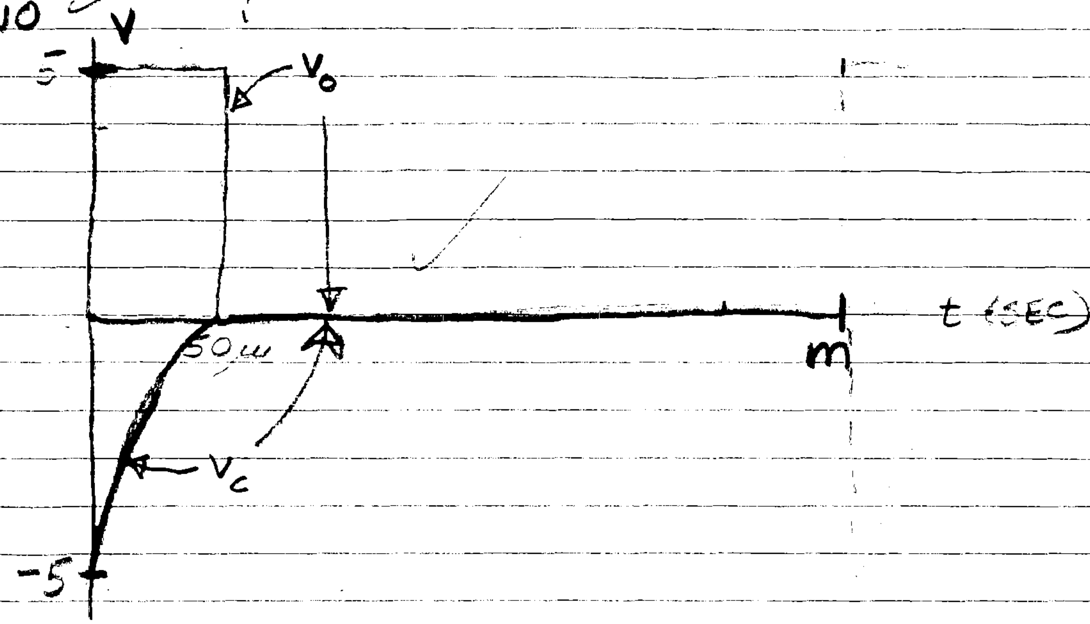
b)



DIRECTLY AFTER SQUARE WAVE GOES TO 0

c) NO

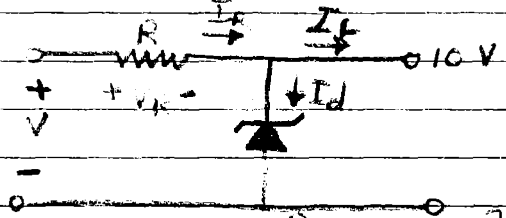
d)



BOB MARKS

(4/4)

5-1)



$20 < V < 25$

$I_d > 1\,mA$

$P_d < .250\,W$

a) $P = VI \Rightarrow I_d = P_D / V_D = \frac{.250}{10} = 25\,mA$ ✓

b) $V = 25,\ I_L = 0$

$V_R = 15\,V;\ R = V/I = 15/.025 = 600\,\Omega$ ✓

c) $I_R = I_L + I_d\ ;\ I_d = 1\,mA$

$V_R = 10_V \Rightarrow I_R = \frac{10}{600} = .0167\,A = 16.7\,mA$ ✓

$\Rightarrow I_L = 15.7\,mA$

5-2) $20 < V < 25$; $I_d > 1\,mA$; $I_L = 30$

a) $I_R = 31\,mA$; $V_R = 10\,V$

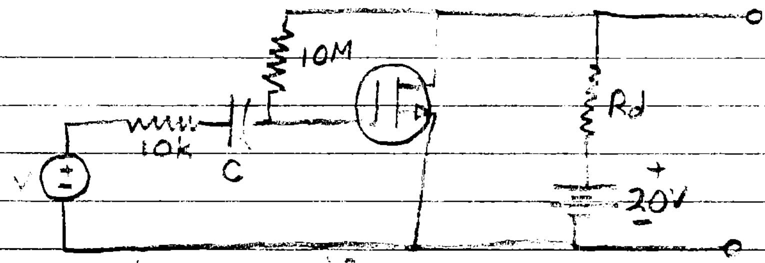
$R = 10/.031 = 322\,\Omega$ ✓

b) $I_L = 0 \Rightarrow I_R = 15/322 = .0465 \Rightarrow P = IR = .0465(10) = 465\,mW$ ✓

MARKS

6.5/8

7-3)



$K = .1\ mA/V^2$
$I_D = 2\ mA$
$V_T = 3\ V$

$I_D = K(V_{GS} - V_T)^2$

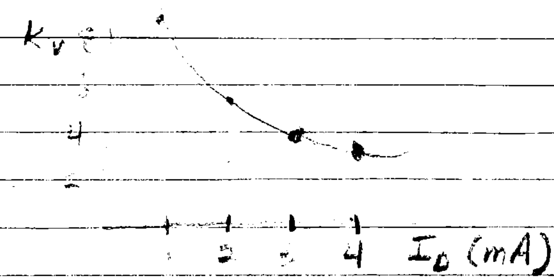
1; $1 = .1(V_{GS} - 3)^2 \Rightarrow V_{GS} = V_{DS} = 6.16$
$\Rightarrow R_d = \frac{V_{DD} - V_{GS}}{I_D} = 13.84\,K$

2; $V_{GS} - 3 = \sqrt{20} = 4.46 \Rightarrow V_{DS} = V_{GS} = 7.46$
$\Rightarrow R_d = 6.27k$

3; $V_{DS} = 8.46$; $R_d = 3.85k$
4; $V_{GS} = 9.32$; $R_d = 2.67$

$I_D = 1 \Rightarrow k_v = 2R_d(V_{GS} - V_T)$
$= (2)(13.84)(3.16)$
$= 8.75$ ✓

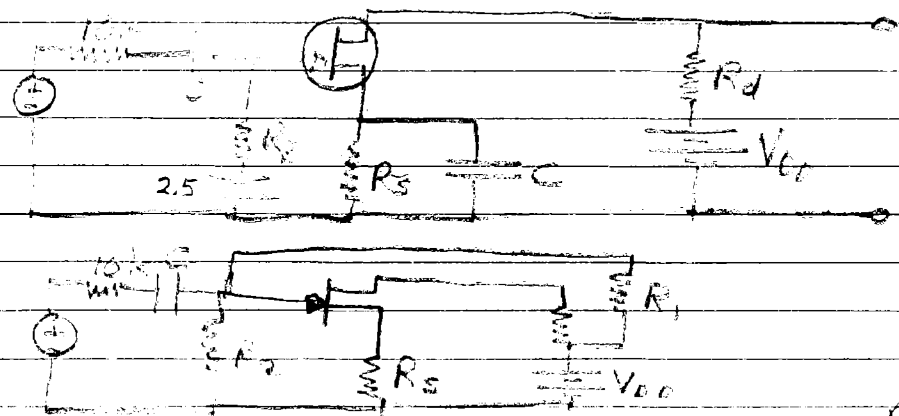
$I_D = 2 \Rightarrow k_v = (.2)(6.25)(4.46) = 5.6$ ✓
$I_D = 3 \Rightarrow k_v = 4.21$ ✓
$I_D = 4 \Rightarrow k_v = 3.37$ ✓



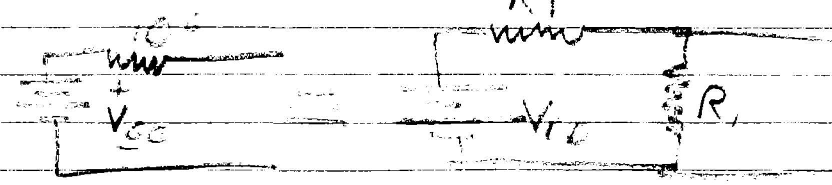
b) THE HIGHER Rd THE HIGHER THE DISTORTION AND THE HIGHER THE GAIN. MUST THUS REACH COMPROMISE IN DESIGN

MARKS

7-5)



$V_{GG} = 2.5V$
$R_G = 10^6 \Omega$
$V_{DD} = 20$



$\frac{R_1 R_2}{R_1 + R_2} = 10^6$ AND $\frac{20 R_2}{R_1 + R_2} = 2.5$

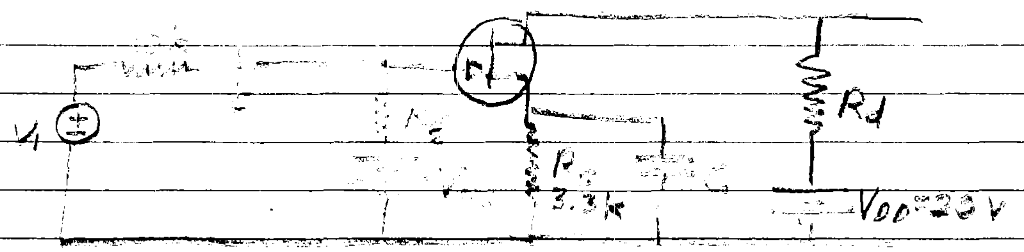
$\Rightarrow 7R_2 = R_1$

$\frac{7R_2^2}{8R_2} = 10^6 \Rightarrow R_2 = 1.14\ M$ ✓

$R_1 = 8\ M$ ✓

MARKS

7-6)



$I_{DSS}=6mA$; $V_P=-4$ $\quad I_D=1.5 \Rightarrow V_{DS}=6$

a) $I_D=I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2 \Rightarrow 1.5=6\left(1+\frac{V_{GS}}{4}\right)^2 \Rightarrow V_{GS}=-2V$

$V_{GS}=-V_S+V_{GG}$; $V_S=I_D R_S=4.95V$

$-2=-4.95+V_{GG} \Rightarrow V_{GG}=2.95V$

$V_{DS}=V_{DD}-(R_d+R_S)I_D \Rightarrow 6=20-(R_d+3.3)1.5$

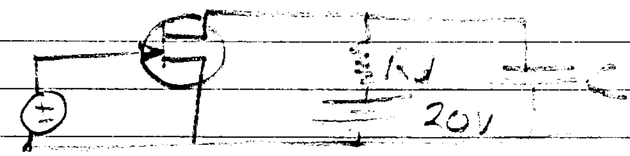
$\Rightarrow R_d=6k$

b) $k_v=\frac{-2R_d I_{DSS}}{V_P}\left(1-\frac{V_{GS}}{V_P}\right) \Rightarrow V_{GS}=-V_S+V_{GG}=-2V$

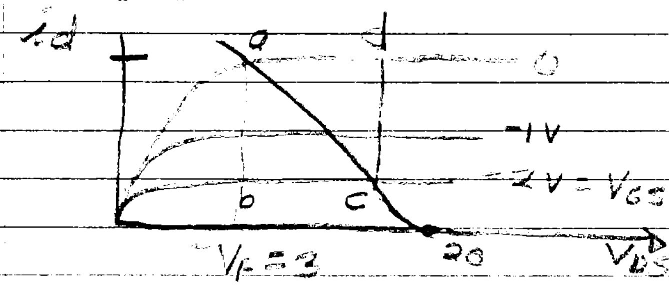
$=\frac{(2\times 6)}{}\left(1-\frac{1}{2}\right)=9$

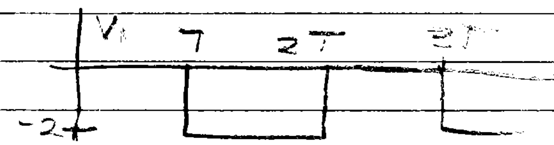
MARKS

7-7)



$I_{DSS} = 5\,mA$
$V_P = -3\,V$
$R_d = 3\,k$





a) a ; (5, X) mA, V $i_d = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$
b ; (X, X) $= 5/3$
c ; (X, X) $V_{DS} = V_{DD} - R_d\, i_d = 15\,V$
d ; (X, X)

b) $P = V_{DS}\, i_d = (15)(1.67) = 25\,mW$

(b) .55 mA 5 V.

(c) .55 mA 18.3 V

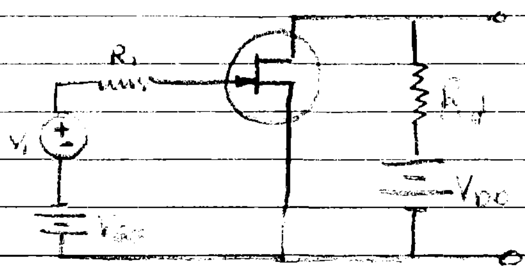
(d) 5 mA 18.3 V

-1½

PT (D) 5(18.3) = 91.5 mw

Bob Marks

9.5/18

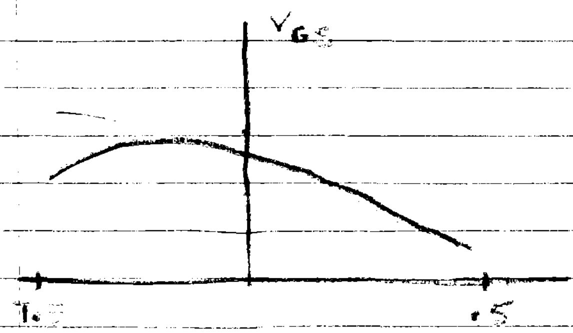
6-8) 

$I_{DSS} = 10$ mA
$V_p = -4$
$R_1 = 100k$
$R_d = 6.8k$
$V_{GG} = 2.25$ V
$V_{DD} = 25$ V

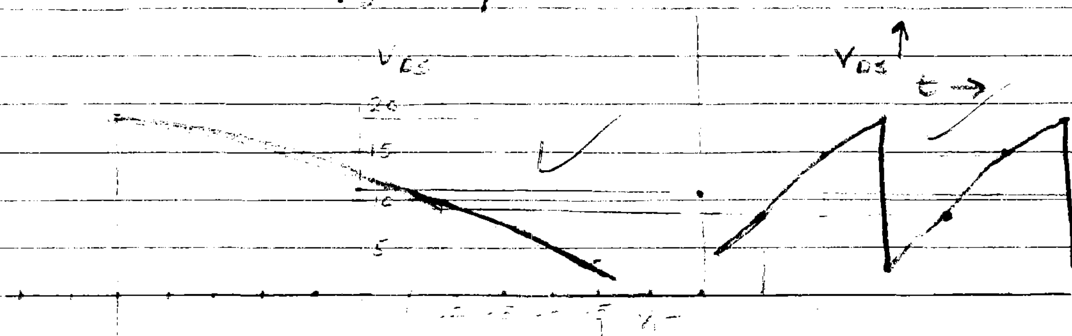
$V_{DS} = V_{DD} - R_d I_{DSS}\left(1 - \frac{V_{GG} - V_1}{V_p}\right)^2$
$= 25 - (6.8\times10)\left(1 - \frac{2.25}{4} + \frac{V_1}{4}\right)^2$
$= 25 - 68\left(.438 - \frac{V_1}{4}\right)^2 = 25 - 17(.976 - V_1)^2$

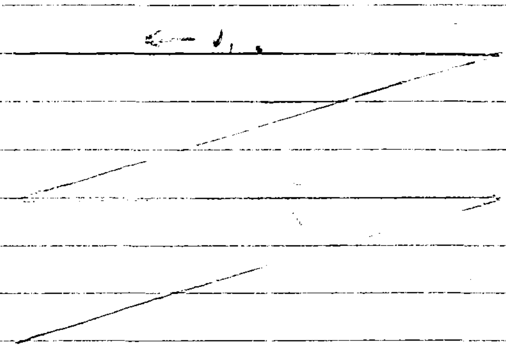
V_1	V_{GS}
0	12
-.5	18.5
.5	3.7
-1.5	24.7
-2	24.7

-2.5 22.8



b)

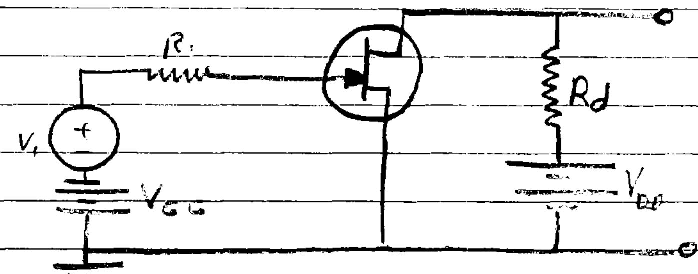




7-X PROB BY JHD ? (-2)

BOB MARKS

6.13)



$I_{DSS} = 10mA$
$V_P = -4V$
$V_{GG} = 2.25V$
$V_{DD} = 25V$
$R_1 = 1k$
$R_d = 6.8k$

$v_1 = V_1 \cos \omega t$

a) % D = 100 % $\frac{V_{i1}}{V_i}$

$V_1 = \frac{V_{GS} - V_T}{25} = \frac{2.25 + 4}{25} \times 2 = .14V$ ✓

b) $A_v = \frac{-2 \cdot 6.8 \cdot 10}{4} \left[1 - \frac{2.25}{4}\right] = 14.8$ ✓

c)

(−1)

d)

[6-13] USING 1.5 POWER ? (−2)

Bob Marks

6-14) $i = a_0 + a_1 V + a_2 V^2 + a_3 V^3$

$= a_0 + a_1 V \cos 6.28 \times 10^3 t + a_2 V^2 \cos^2 6.28 \times 10^3 t + a_3 V^3 \cos^3 6.28 \times 10^3 t$

$\cos^2\theta = \frac{1 + \cos 2\theta}{2}$

$\Rightarrow V^2 \cos^2 6.28 \times t^3 t = V^2 \left(\frac{1 + \cos 4\pi t \times 10^3 t}{2}\right)$

$\cos^3\theta = \frac{3}{4}\cos\theta + \frac{1}{4}\cos 3\theta$

$\Rightarrow i = a_0 + \frac{a_2}{2} + (a_1 + \frac{3a_3}{4})\cos\omega t + \frac{a_2}{2}\cos 2\omega t + \frac{a_3}{4}\cos 3\omega t$

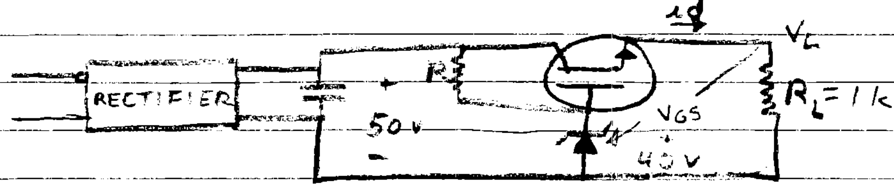
$\therefore$ FREQUENCIES OF INPUTS

$\omega = 1$ kHz

$2\omega = 2$ kHz

$3\omega = 3$ kHz

6-16)



$K = .7 mA/V^2$ $\quad V_T = 3^V$

a) $V_{GS} = 40 - V_L$

$i_d = V_L / R_L$

$i_d = K(V_{GS} - V_T)^2 \Rightarrow V_L = .7(40 - V_L - 3)^2$

$V_L^2 - 75.43 V_L + 1369 = 0$

$\Rightarrow V_L = \frac{75.43 \pm \sqrt{184}}{2}$

$V_L = 30.5$ V OR $V_L = 44.5^V$

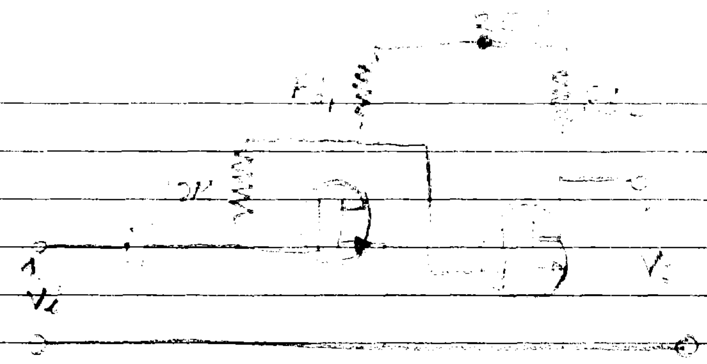
$V_{GS} < V_T \Rightarrow V_L = 30.5$V

b)

c) (-1)

Bob Mar[illegible]

7-2)



$V_{DS} = V_{DD} - R_{d1} i_d = 25 - [illegible] R_{d1}$

$V_{GS} = V_{DS}$

[illegible]

3 V

[illegible] R_{d1} [illegible]

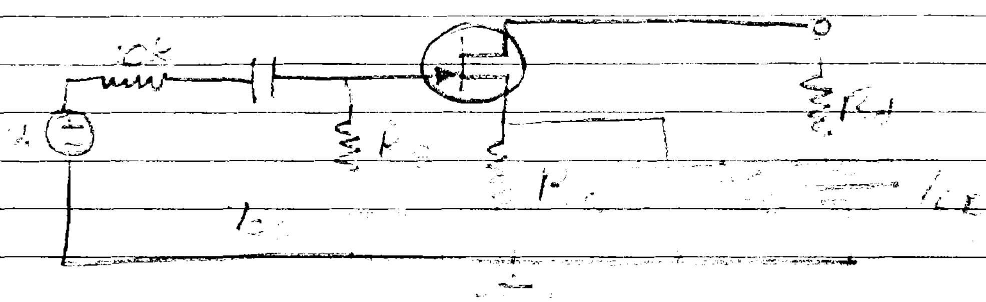
[illegible] 2.5 mA

$K_1 = K_{v2}$

[illegible] $= 46.2$

BOB MARKS

7-4)



$I_{DSS} = 8\,mA$
$V_{GS} = 0$
$V_P = -4$
$V_{DS} = 6$
$R_G = 1M$

a.

$\Rightarrow V_{GS}^2 + 8V_{GS} + 12 = 0$
$(V_{GS} + 6)(V_{GS} + 2) = 0$
$V_{GS} = -6, -2$

$R_s = \ldots K$ ✓
$R_d = \ldots = 6K$ ✓

b.)

(−1½)

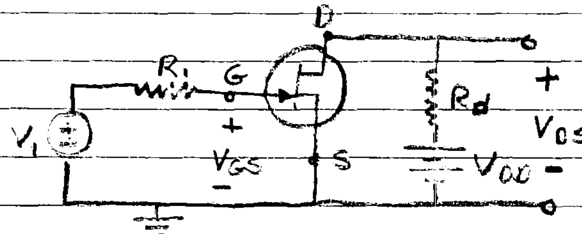
c.)

[7-11] (−2)

BOB MARKS

(7.5/8)

6-3)



$I_{DSS} = 5mA$; $V_p = -4V$
$V_{DD} = 25V$
$V_1 = V_{GS} = 0 \Rightarrow V_{DS} = 8$

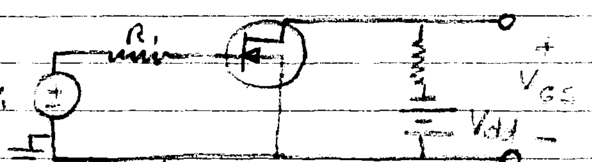
a) $R_d = \frac{V_{DD} - V_{DS}}{i_d} = \frac{17}{.005}\,\Omega = 34k$

b) $K = \frac{i_d}{(V_{GS} - V_P)^2} = \frac{.005}{(16)} = 3.14 \times 10^{-4}$

$\frac{d\,i_d}{d\,V_{GS}} \cong 2K(V_0) = (6.28 \times 10^{-4})(4) = 2.51 \times 10^{-3}\ \mho$

$A_v = R_d \frac{d\,i_d}{dV} = (3.4 \times 10^3)(2.51 \times 10^{-3}) = 8.53$ ✓

6-4)



$I_{DDS} = -4mA$; $V_P = 4V$
$V_{DD} = 25V$
$V_1 = V_{GS} = 0 \Rightarrow V_{DS} = -7V$

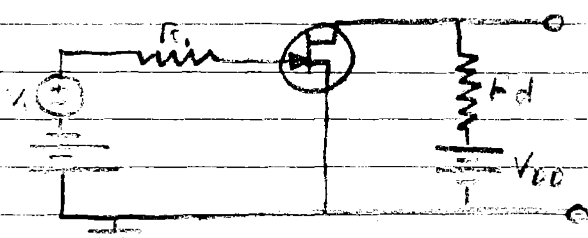
a, $R_D = \frac{V_{DD} - V_{DS}}{i_d} = \frac{18}{.004} = 4.5k$ ✓

b) $K = \frac{i_d}{(V_{GS} - V_P)^2} = \frac{-4 \times 10^{-3}}{16} = 2.5 \times 10^{-4}$

$\frac{d\,i_d}{d\,V_{GS}} = 2K\,V_P = -5.0 \times 10^{-4} \cdot 4 = {}^{+}2.0 \times 10^{-3}$

$A_v = R_d \frac{d\,i_d}{dV} = 9.0$ ✓

6-6)



$I_{DDS} = 12\,mA$; $V_P = -5V$
$R_D = 3.3k$
$V_{GG} = 1.75V$ $V_{DD} = 25V$

a) $i_d = I_{DDS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 12 \times 10^{-3}\left(1 - \frac{1.75}{5}\right) = 5.1\ mA$

$V_{DS} = V_{DD} - R_d\,i_d = 25 - (3.3)(5.1) = 8.3V$ ✓

b) $K = I_{DDS}/V_P^2 = 12 \times 10^{-3}/25 = .48 \times 10^{-3}$

$A = R_d\,2K(V_{GS} - V_P)$

$= 3.30 \times 10^3 (2)(12 \times 10^{-3})(3.25)\frac{1}{25} = 10.3$ ✓

6-7) $I_{DSS} = 10^{-2}A$; $V_P = -4V$; $V_{DD} = 25V$

a) $R_D = \frac{25-7}{10^{-2}} = 1.8k$ ✓

b) $A_v = 2R_d\,I_{DSS}/V_P = \frac{-3.6 \times 10^3 \times 10 \times 10^{-3}}{-4} = 9$ ✓

c) $R_{D2} = \frac{18}{2.5 \times 10^{-3}} = 4.5k$; $V_{GG} - V_P = \sqrt{\frac{6.4}{10}} = -2.53$

$\Rightarrow V_{GG} = 4 - 2.53 = 1.5V$ ✓

d) $A = \frac{90}{2.5}\frac{1}{4} = 14$ ✗

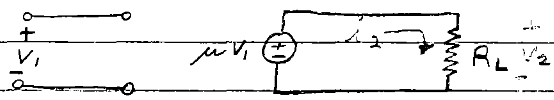
e) FIRST ✗

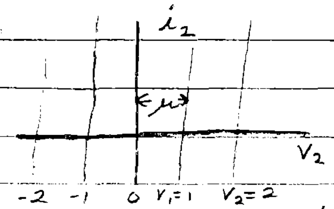
(−1/2)

I) IDEAL AMPLIFIERS

A) IDEAL VOLTAGE AMPLIFIERS

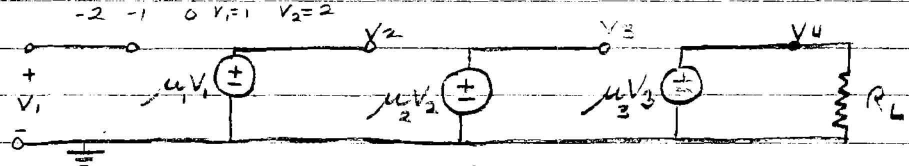
1)





$$P = \frac{(\mu V_1)^2}{R_L}$$

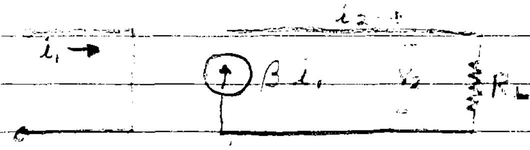
2)

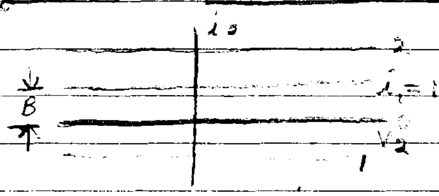


$$V_4 = \mu_1 \mu_2 \mu_3 V_1$$
$$P = (\mu_1 \mu_2 \mu_3 V_1)^2 / R_L$$

B) IDEAL CURRENT AMPLIFIER

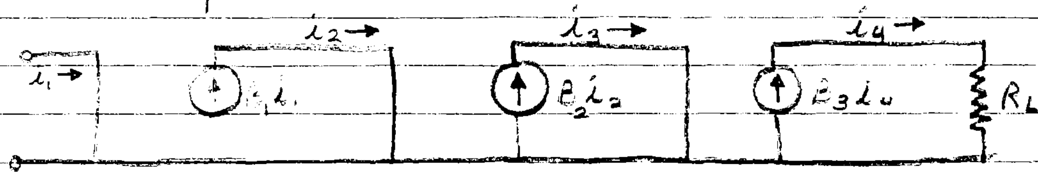
1)





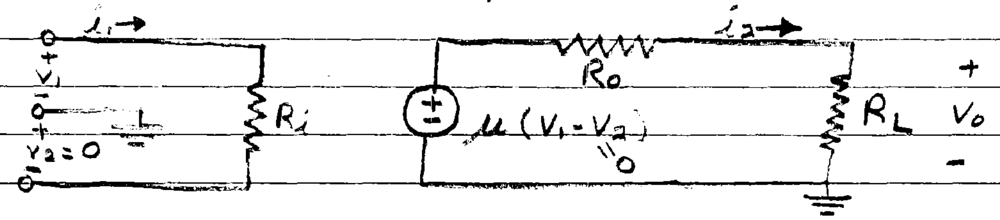
$$P = (\beta i_1)^2 R_L$$

2)



$$i_4 = B_1 B_2 B_3 i_1$$
$$P = (B_1 B_2 B_3 i_1)^2 R_L$$

C) PRACTICAL TRANSISTOR MICROAMPLIFIER



$A_v = \frac{R_L}{R_o + R_L}\mu$

$A_c = \frac{V_o}{R_L} / \frac{R_i}{V_1} = \frac{R_i}{R_L} A_v$

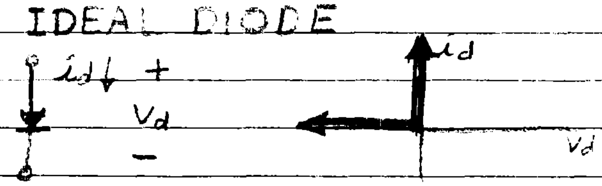
$A_p = \frac{V_o^2 R_i}{V_1^2 R_L} = A_v A_c$

D) GAIN IN DECIBELS

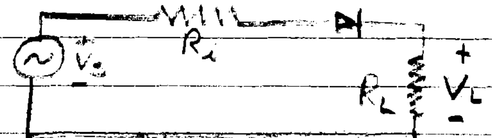
$G_p = 10 \log_{10} P_o/P_i$

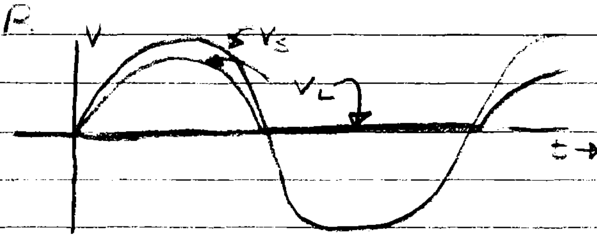
$A_v = 20 \log_{10} V_o/V_i$

II) THE IDEAL DIODE



A) THE HALF WAVE RECTIFIER

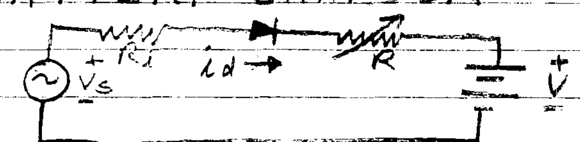


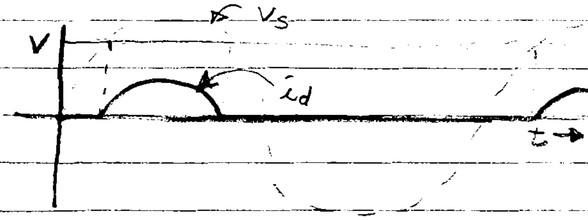


$V_L = \frac{R_L}{R_L + R_i} V_s \; ; \quad V_s > 0$

$= 0 \qquad\qquad\qquad V_s < 0$

B) BATTERY CHARGER

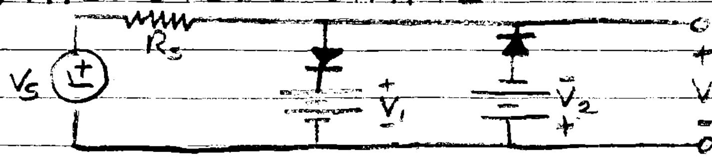


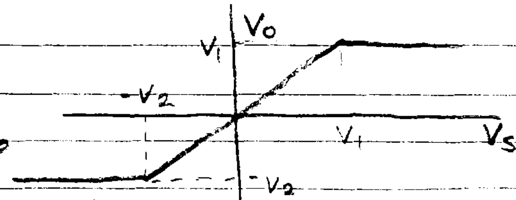


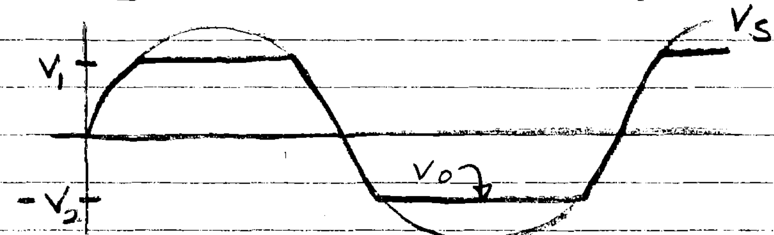
$i_d = \frac{V_s - V}{R_i + R} \; ; \quad V_s > V$

$= 0 \qquad\qquad ; \quad V_s < V$

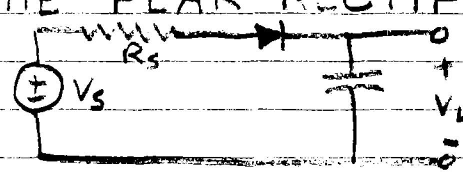
C) THE DIODE LIMITER

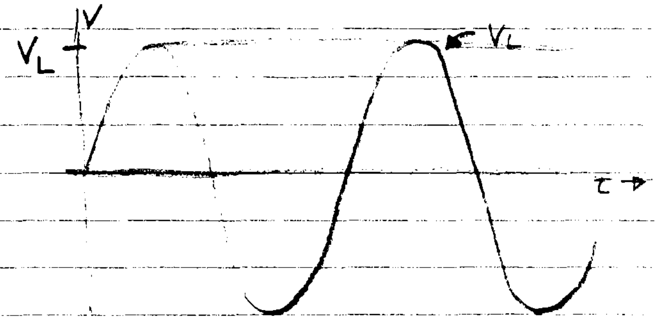




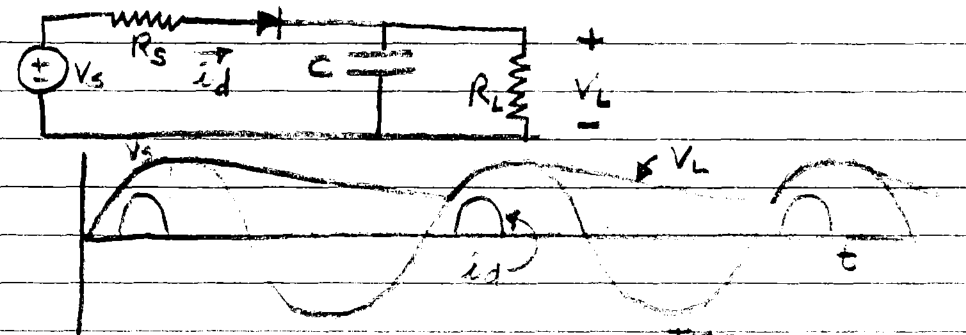


D) THE PEAK RECTIFIER

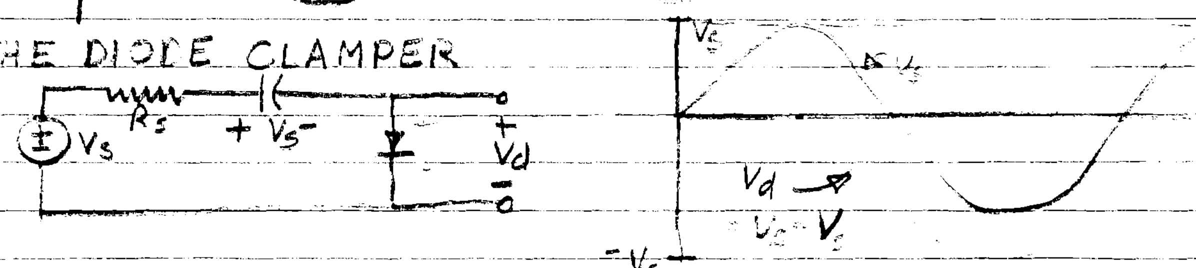




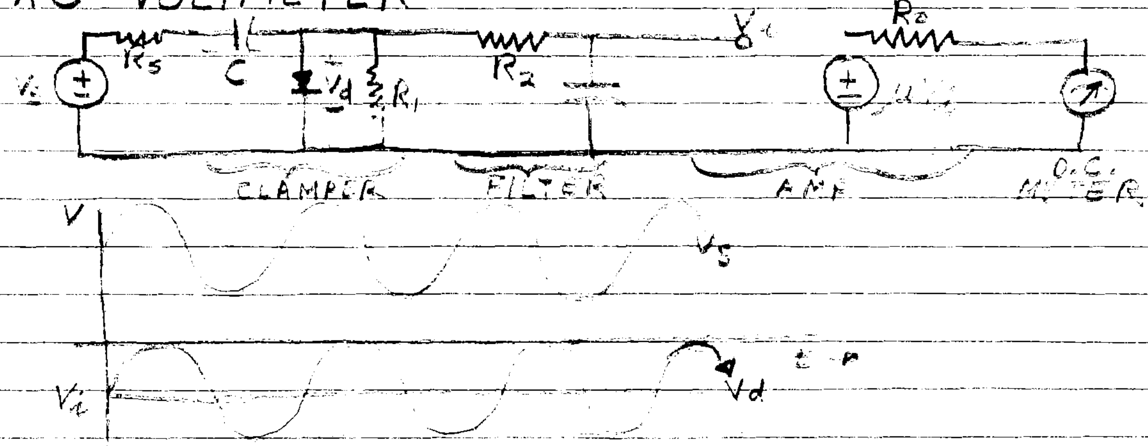
E) PEAK RECTIFIER WITH RESISTIVE LOAD



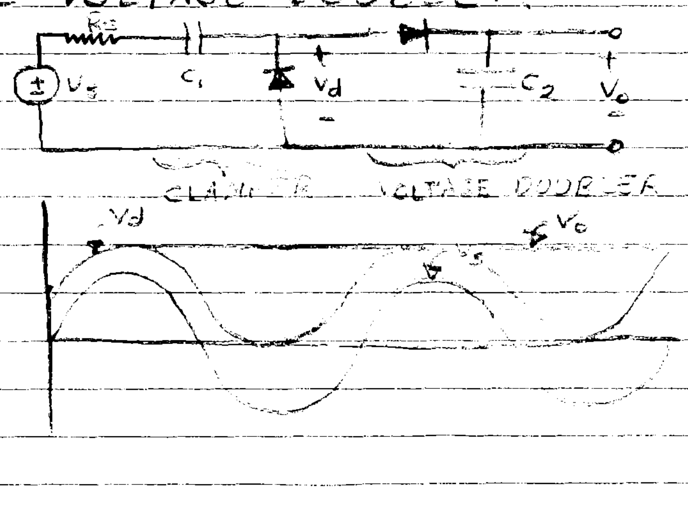
F) THE DIODE CLAMPER



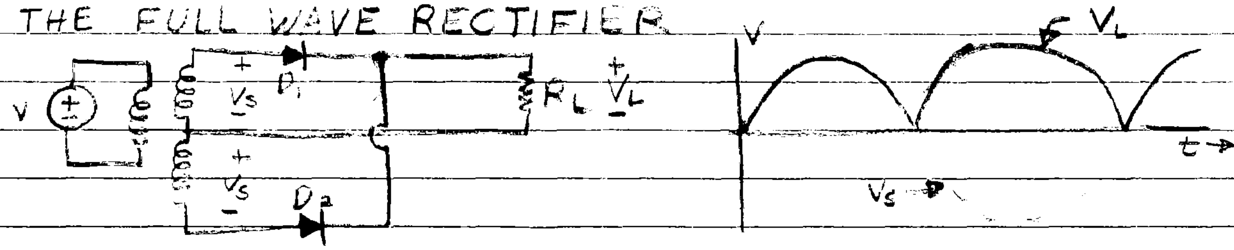
G) A-C VOLTMETER



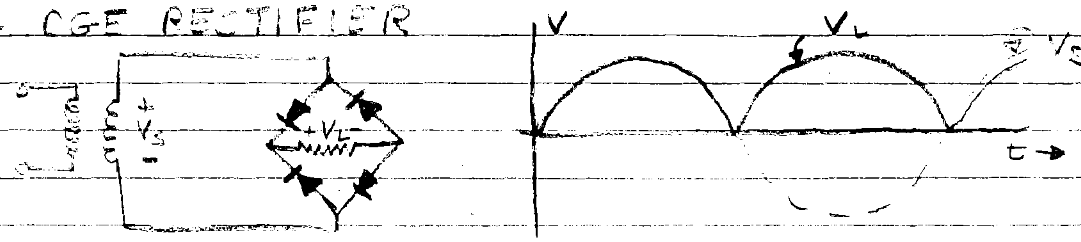
H) THE VOLTAGE DOUBLER



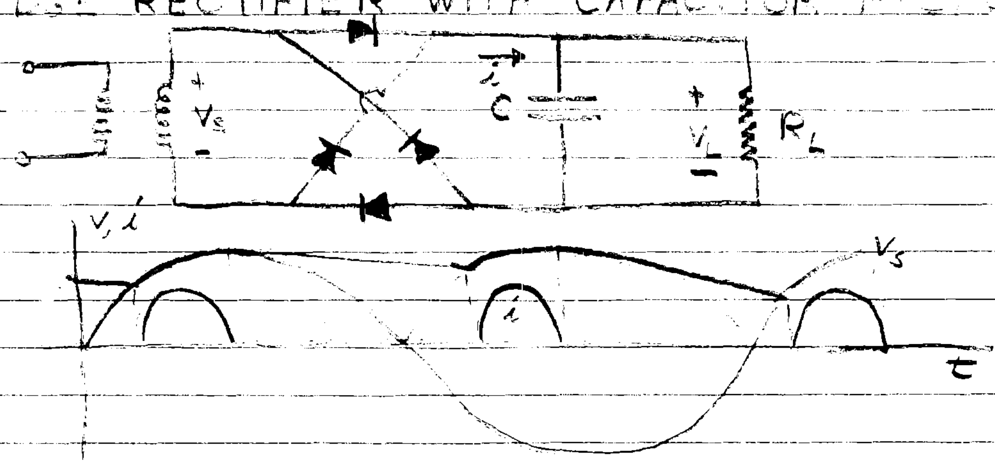
I) THE FULL WAVE RECTIFIER



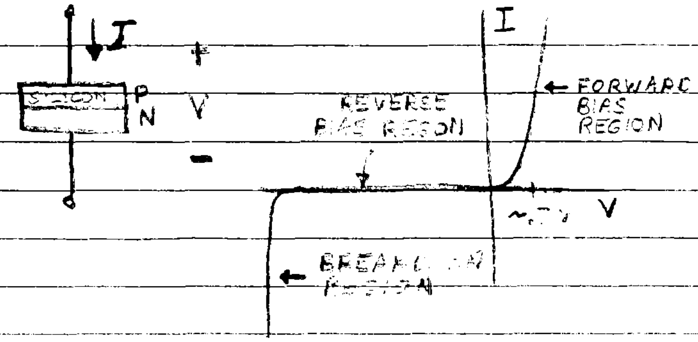
J) BRIDGE RECTIFIER



K) BRIDGE RECTIFIER WITH CAPACITOR FILTER

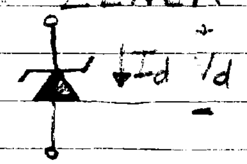


III) SEMICONDUCTOR MATERIALS AND THE P-N JUNCTION



IV) THE PN JUNCTION WITH REVERSE BIAS

A) THE ZENER DIODE (USED AS VOLTAGE LIMITER)



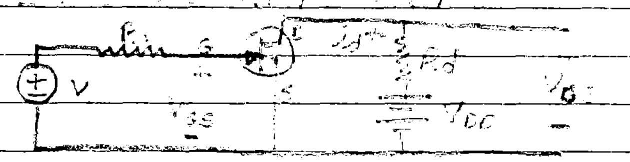
(V-i CURVE IS REV. BIAS BREAKDOWN)

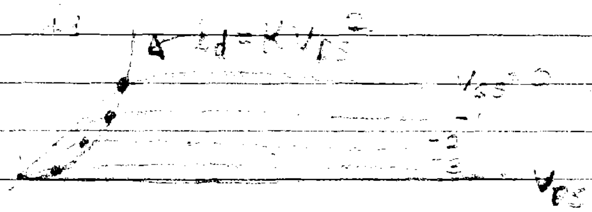
B) VOLTAGE CONTROLLED CAPACITANCE

PLUG: $C_j = \frac{K}{(\psi_o + V')^n}$

ψ_o = CONTACT POTENTIAL ACROSS JUNCTION

K = CONSTANT n = CONSTANT



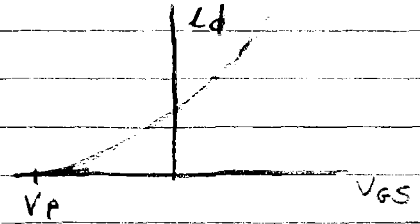


$V_P < 0$ FOR n CHANNELS

$V_P > 0$ FOR p CHANNELS

AT PINCH-OFF THRESHOLD $V_{GS} - V_{DS} = V_P < 0$

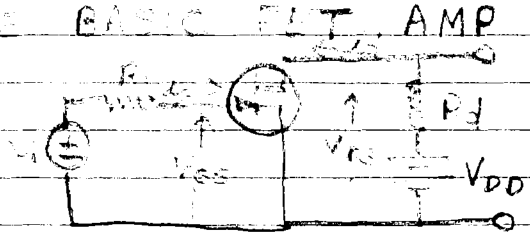
$0 < V_{GS} - V_P < V_{DS} \Rightarrow i_d = K(V_{GS} - V_P)^2$



$i_d = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

I_{DSS} IS DRAIN CURRENT AT $V_{GS} = 0$ AFTER PINCHOFF

THE BASIC FET AMP



$V_{DS} = V_{DD} - R_d i_d$

$= V_{DD} - R_d I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

[illegible]

NOTATION

CAPITOL LETTERS: $V, I \Rightarrow$ D.C. VALUES

LOWER CASE LETTERS: $v, i \Rightarrow$ TIME VARYING

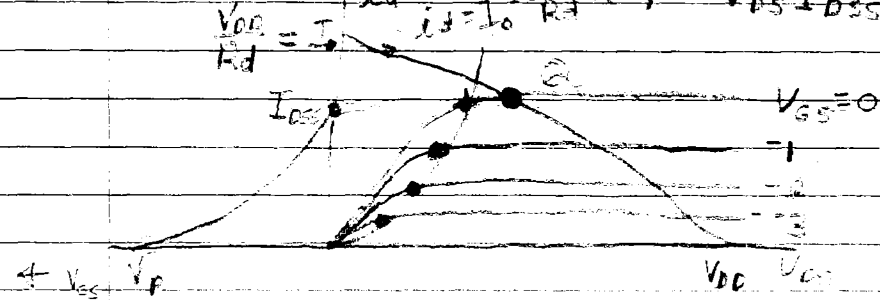
CAPITOL SUBSCRIPTS: TOTAL V OR CURRENT

LOWER CASE SUBSCRIPTS: SIGNAL COMPONENTS

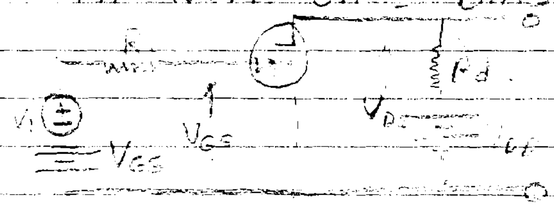
$v_i = 0 \Rightarrow$ QUIESCENT OPERATING CONDITION

AT QUIESCENCE: $i_d = I_{DSS}$

$P = V_{DS} I_{DSS} \ni V_{DS} = V_{DD} - R_d I_{DSS}$



FET AMP WITH GATE BIAS VOLTAGE



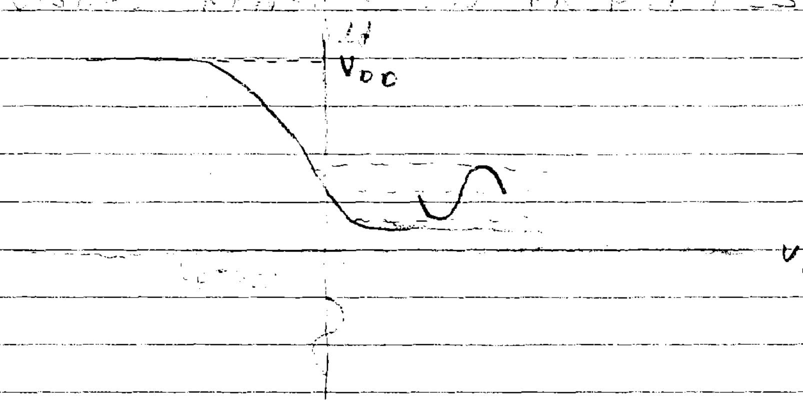
$v_{GS} = V_{GS} + v_i \Rightarrow V_{GS} = -V_{GS}$

$V_{DS} = V_{DD} - R_d I_{DSS}\left(1 - \frac{V_{GS} - v_i}{V_P}\right)^2$

$= V_{DD} - R_d I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 + 2 R_d I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)\frac{v_i}{V_P} - R_d I_{DSS}$ [illegible] V_P

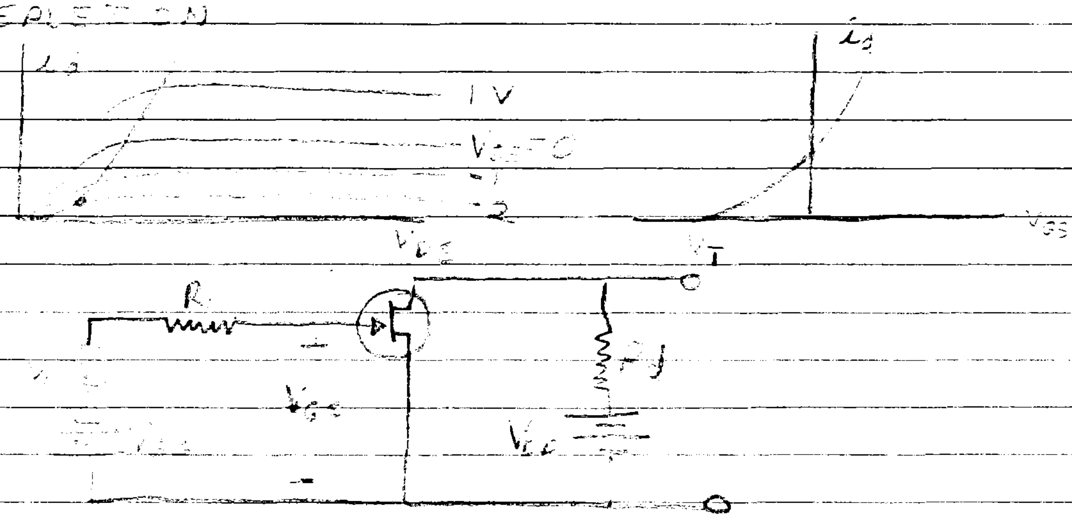
$K_v = -\frac{2 R_d I_{DSS}}{V_P}\left(1 - V_{GS}/V_P\right)$

SIGNAL TRANSFER PROPERTIES



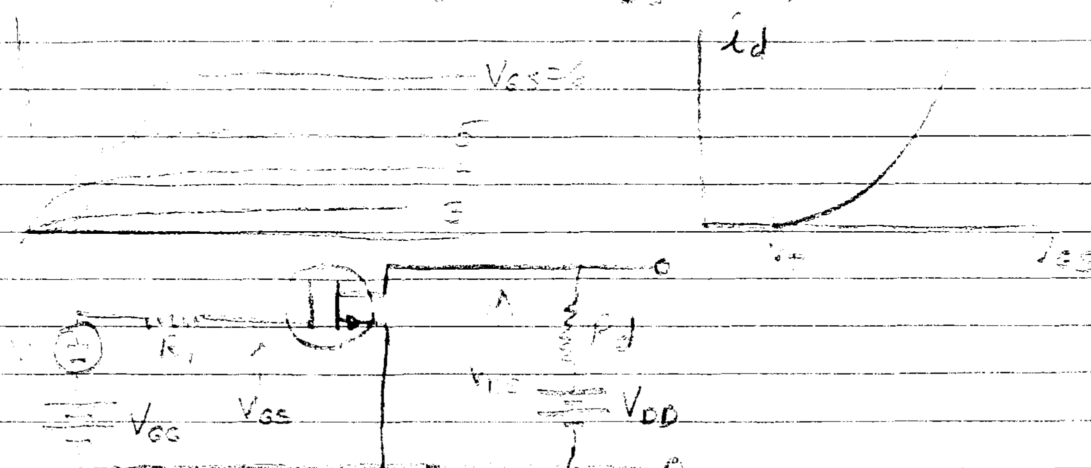
THE MOST

DEPLETION



ENHANCEMENT MOST

$0 < v_{GS} - V_T < v_{DS}$, $i_d = K(v_{GS} - V_T)^2$



$v_{DS} = V_{DD} - R_d i_D = V_{DD} - K R_d (v_{GS} - V_T)^2$

$= V_{DD} - K R_d [(V_{GS} - V_T) + v_1]^2$

$= V_{DS} - 2K R_d (V_{GS} - V_T) v_1 + K R_d v_1^2$

$\Rightarrow V_{DS} = V_{DD} - K R_d (V_{GS} - V_T)^2$

DISTORTION (PERCENTAGE)

$V_1 = 2 K R_d (V_{GS} - V_T) V_1$ (FUND. FREQ.)

$V_2 = \frac{1}{2} K R_L V_1^2$ (SECOND HARMONIC)

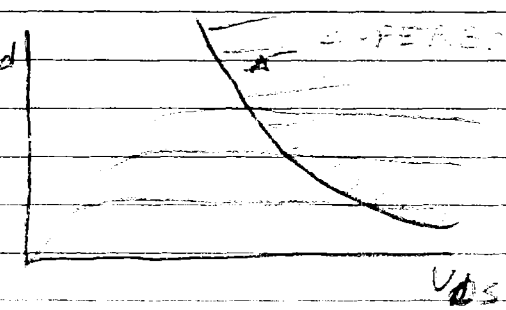
$D = 100 \frac{[illegible]}{[illegible]} = 100 \frac{[illegible]}{4(V_{GS} - V_T)}$

POWER RELATIONS IN ELECTRONIC [illegible]

$P_T = V_{CC} I_D$

[illegible]

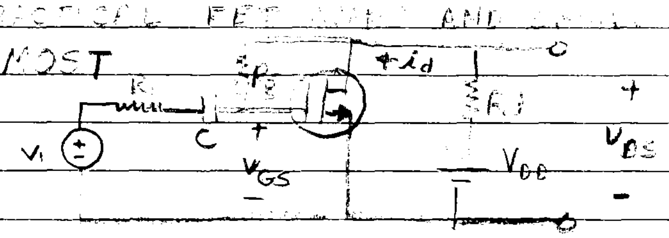
$P_{\ldots} = R_d \, i_D^2$; $P_{\ldots} = R_{\ldots} i^2 + R_d \ldots$



HYPERBOLA OF CONSTANT [illegible] (OPERATING VALUES MUST BE UNDER)

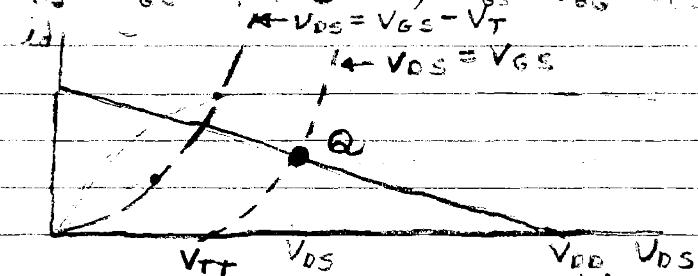
VII) PRACTICAL FET AMP AND SMALL SIGNAL MODEL

A) MOST



AT QUIESCENCE $V_i = 0$

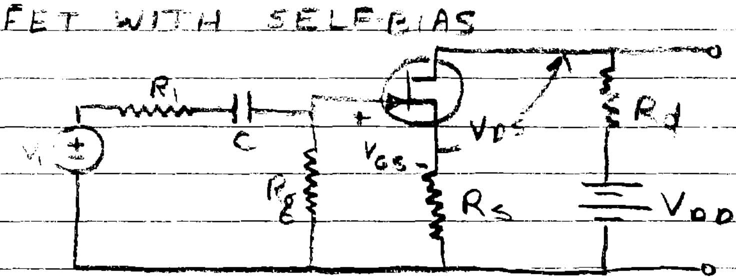
$V_{DS} > V_{GS} - V_T > 0$; $V_{GS} = V_{GG}$



$V_{DS} = V_{DD} - i_d R_d \Rightarrow i_d = \frac{V_{DS}}{R_d} - \frac{V_{DD}}{R_d}$

$i_d = K(V_{GS} - V_T)^2$

B) JFET WITH SELF BIAS

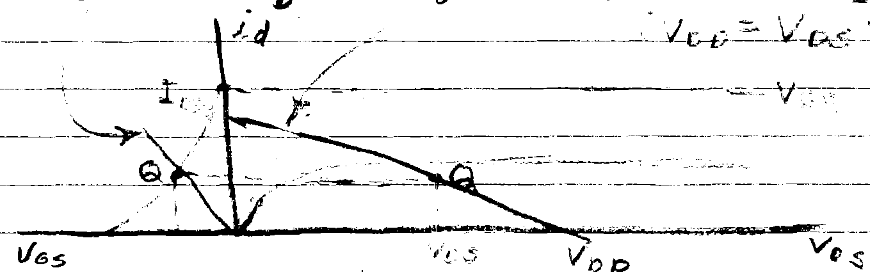


AT QUIESCENCE

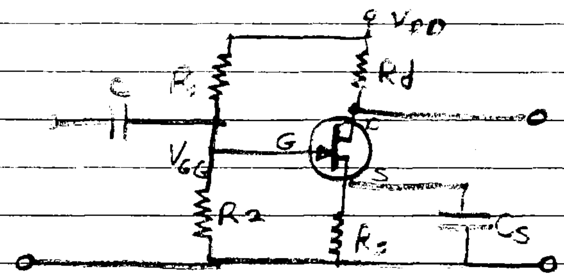
$V_{GS} = -R_S I_D$; $I_{DD} = \frac{V_{DD}}{R_d + R_s}$

$\frac{-1}{R_d + R_s} V_{DD}$

$V_{DD} = V_{DS} + (R_d + R_s) I_D$

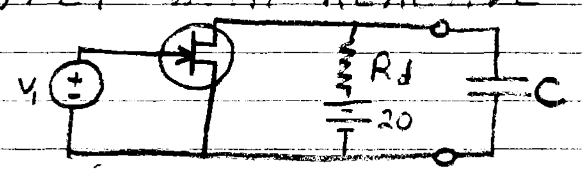


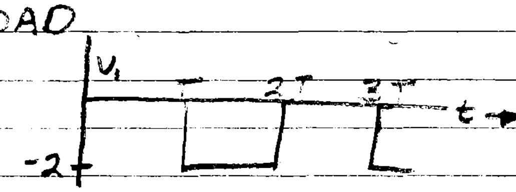
$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

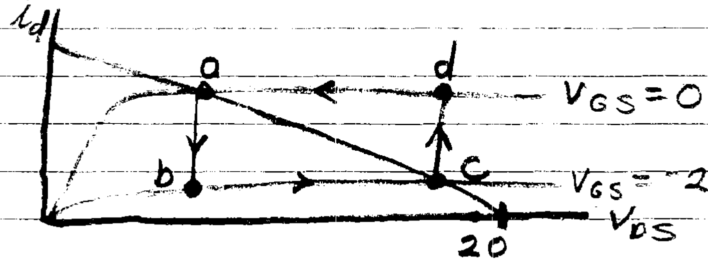


$V_{GS} = V_{GG} - R_S i_d$

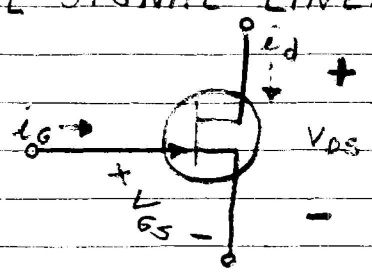
C) JFET WITH REACTIVE LOAD





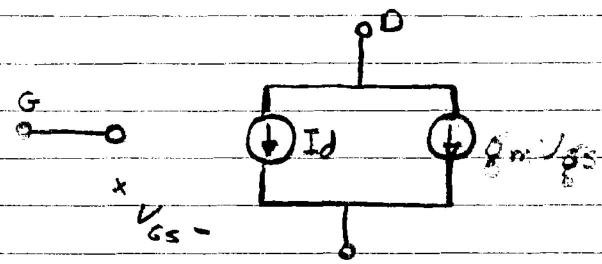


D) SMALL-SIGNAL LINEAR MODELS FOR FET'S



$g_m = \frac{-2 I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right)$

$i_d = I_d + g_m V_{GS}$



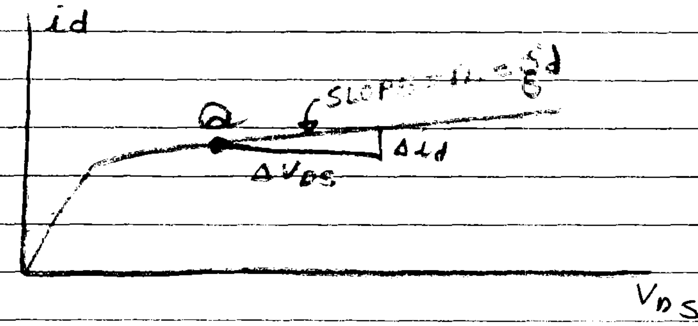
FOR SMALL SIGNAL, $I_d = 0$

$K_v \cong g_m R_d$; $\frac{d i_d}{d V_{GS}} = g_m$; $K_v = -g_m R_d \frac{R_G}{R_1 + R_G}$

if $R_G \gg R_1$

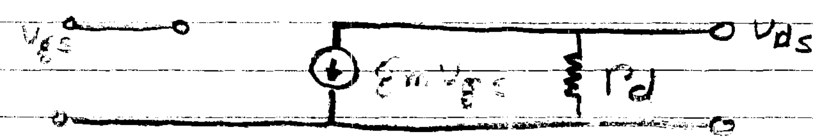
$g_m = g_{m0}(1 - V_{GS}/V_P) = \sqrt{I_D/I_{DSS}}$

E) SECOND-ORDER EFFECTS IN FETs

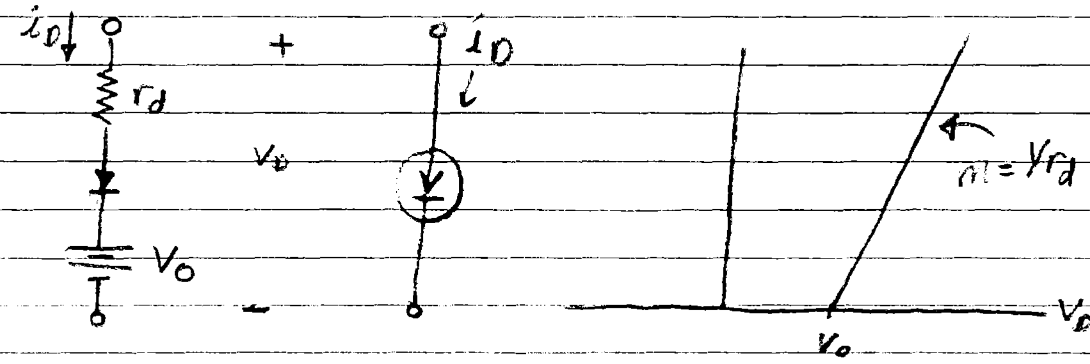


$$\frac{di_d}{dV_{DS}} = g_d = 1/r_d$$

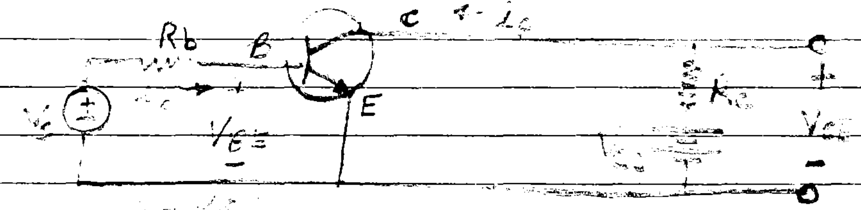
$$i_d = g_m v_{gs} + \frac{1}{r_d} v_{ds}$$

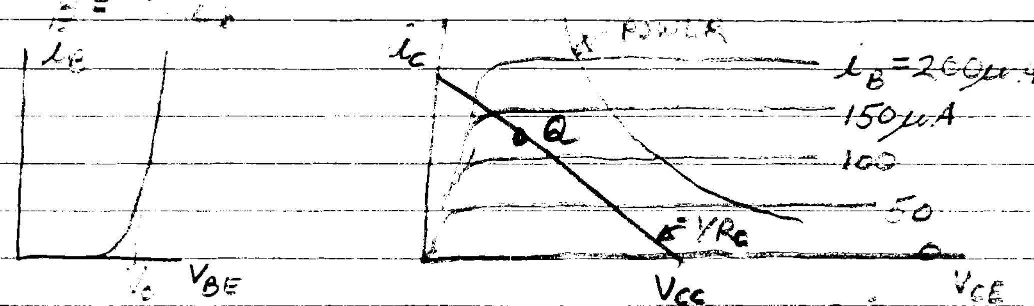


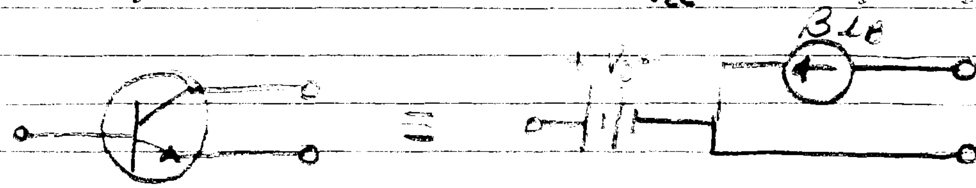
VIII) THE pn JUNCTION WITH FORWARD BIAS



IX) THE BJT AS AN AMPLIFIER

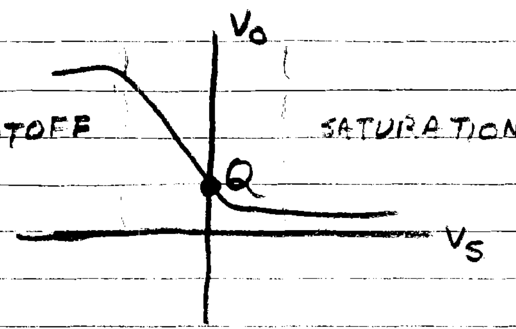




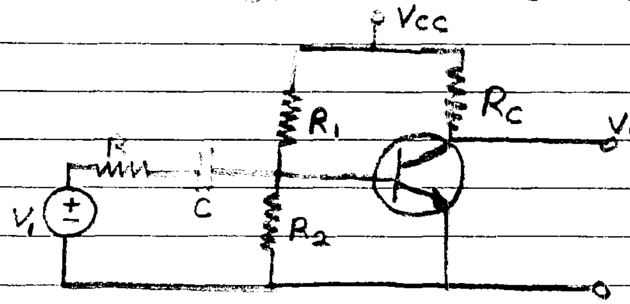


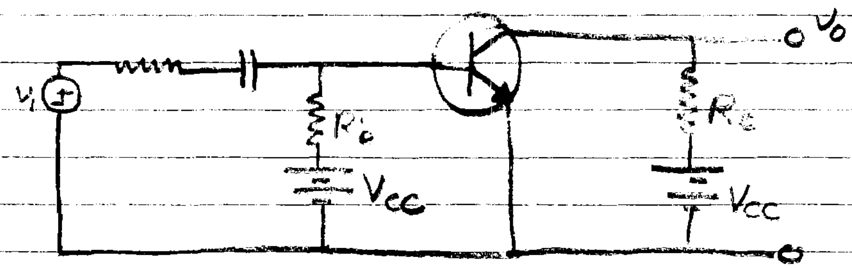
$K_v = \beta \frac{R_c}{R_i}$

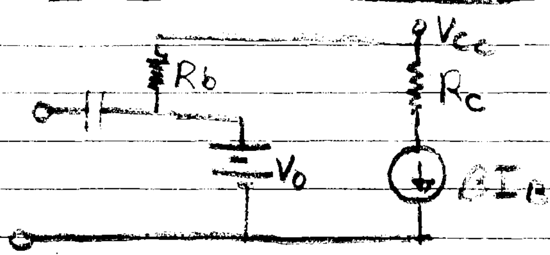
$V_{CE} = V_{CC} - R_c i_c$



X) PRACTICAL BJT AMPLIFIER AND SMALL-SIGNAL MODELS







LARGE-SIGNAL
BJT MODEL

$V_{BB} = V_{CC} / (1 + R_1/R_2)$

$R_b V_{CC} = R_1 V_{BB}$

[illegible] FINAL PLUG SHEET

$C_j = $ [illegible] $)^n$

$i_d = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

$V_{DS} = V_{DD} - R_d i_d$

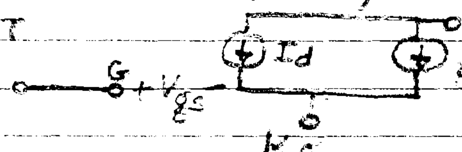
$K_v = -2R_d I_{DSS}/V_P$ [illegible]

$r = \frac{25}{[illegible]} V_T$

MOST

$V_{DS} = V_{CC} - i_d R_d$; $i_d = $ [illegible] $)^2$

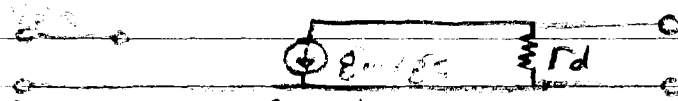
FET



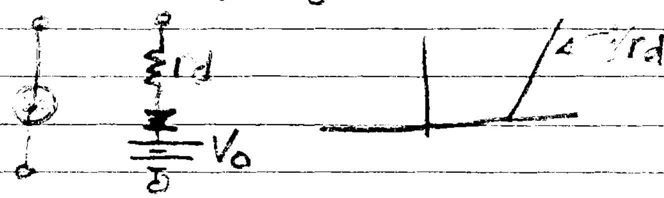
FOR SMALL SIGNAL, I_d [illegible]

$K_v = $ [illegible] ; $g_m = \sqrt{I_D/I_{DSS}}\, g_{mo}$

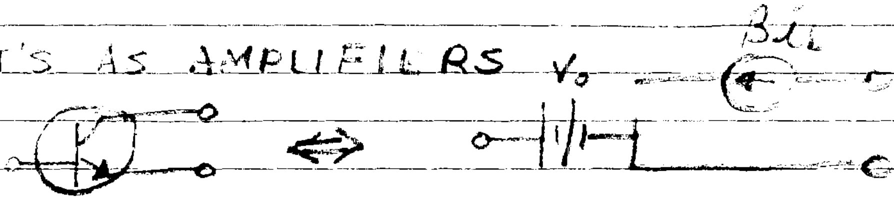
2nd ORDER EFFECTS



$i_d = g_m V_{gs} + V_{DS}/r_d$



BJT'S AS AMPLIFIERS



$K_v = $ [illegible]

$V_{CE} = V_{CC} - R_C I_C$

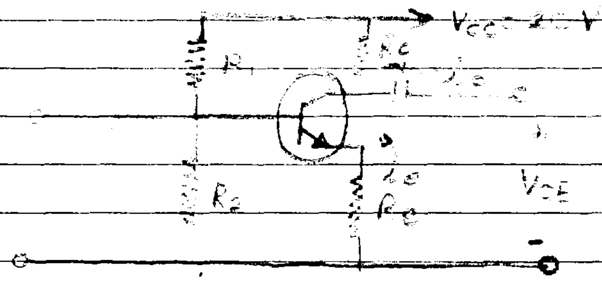
$S_{e2} = $ [illegible] ; $\frac{R_e}{R_b} = \frac{1 - S_{e2}}{S_{e2}(1+\beta_2) - 1}$

$R_b V_{CC} = R_1 V_{BB}$; $V_{BB}(1 - R_1/R_2) = V_{CC}$

MARKS

-13.5

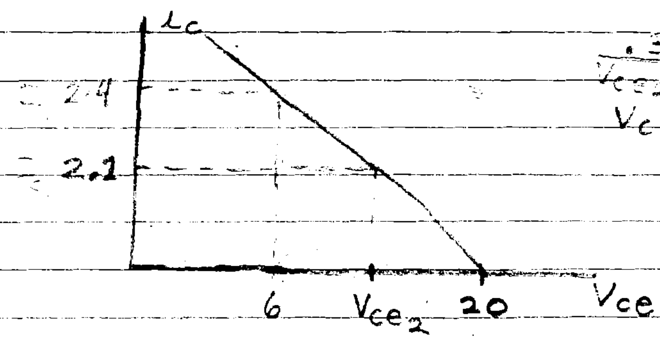
18.5 / 32



$V_{CE_1} = 6$

$V_o = .65$

$R_e = .25 R_c$



$\frac{.3}{V_{ce_2} - 6} = \frac{2.4}{14}$

$V_{ce_2} - 6 = \frac{(.3)(14)}{2.4} = 1.75$

$\Rightarrow V_{ce_2} = 7.75\,V$

$\frac{1}{R_e + R_c} = \frac{2.4}{20} \Rightarrow R_e + R_c = 8.33k$

$\Rightarrow R_c = 8.33/1.25 = 6.67\,k$

$R_e = 1.66\,k$

$S_{e_2} = \frac{\Delta I_c}{I_{c1}} \frac{B_1}{\Delta B} = \frac{.3}{2.1} \frac{40}{200} = \frac{1}{35} = .0286$ ✓

$\frac{R_e}{R_b} = \frac{1 - S_{e_2}}{S_{e_2}(1+B_2) - 1} = \frac{.9714}{(.0286)(241) - 1} = \frac{.97}{1.86} = .522$

$\Rightarrow R_b = 1.66/.522 = 3.18$

$V_{BB} = V_o + I_{c_1}\left[R_b + (1+B_1)R_e\right]\frac{1}{B_1}$

$= .65 + 2.1\left[3.18 + (41)(1.66)\right]\frac{1}{40}$

$= .65 + 2.1\left[1.78\right] = .65 + 3.74 = 4.39\,V$

$R_1 = R_b V_{cc}/V_{BB}$

$= (3.18)(20)/(4.39) = 14.5\,k$

$\frac{1}{R_2} = \frac{1}{R_b} - \frac{1}{R_1} = .315 - .069 = .246 \Rightarrow R_2 = 4.8\,k$

$\eta = V_{BB}/V_o = 4.39/.65 = 6.76$

$.59 < V_o < .72 \qquad 18.5 < V_{cc} < 21$

$(I_{cMAX}, V_{ceMAX}, B_{MAX}, V_{oMIN}) \qquad I_c = \frac{B(V_{BB} - V_o)}{R_b + (1+B)R_e}$

$V_{BB_2} = V_{cc}/1 + R_1/R_2 = 21/4.47 = 4.7$

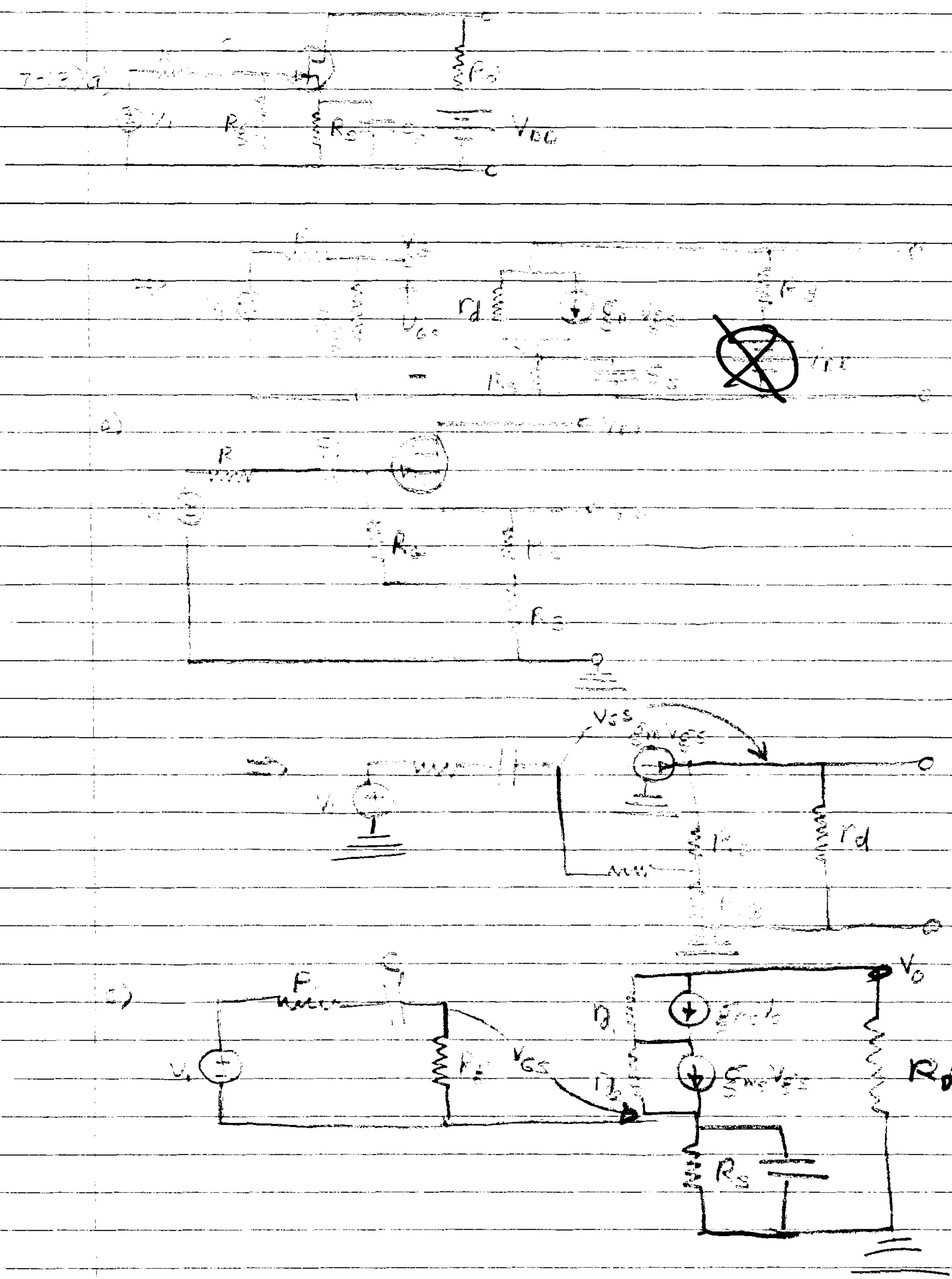
$I_{cMAX_2} = \frac{240(4)}{3.18 + 241(1.66)} = 2.33\,mA$

$V_{BB_1} = 18.5/4.47 = 4.15\,V$

$I_{c_1} = \frac{40(3.67)}{3.18 + 41(1.66)} = \frac{147}{3.18 + 68.1} = \frac{147}{71.3} = 2.06\,mA$

(-1)

mark



Marlow

a) $V_1 = 10^{-5}$ ...

$V_0 = \ldots$

$= .12 \ldots V$

b) $V_1 = 10^{-2}$ ... 10 ...

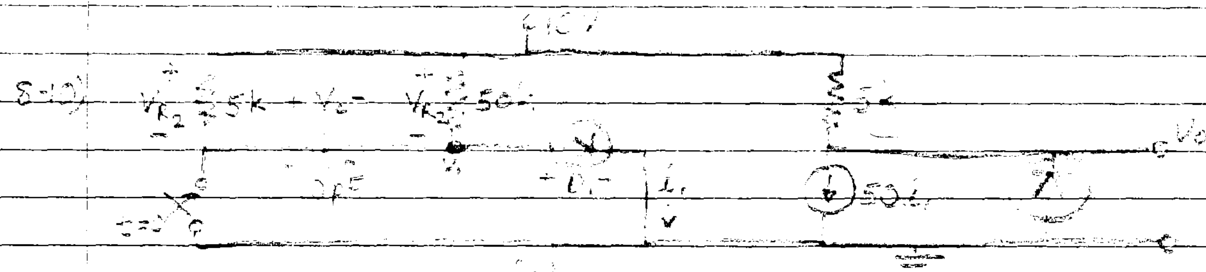
c) ... 12.9

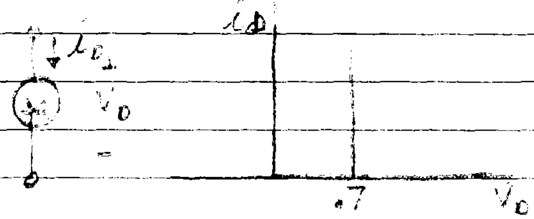
$/10^{-2}$ ... 2.79

$-\frac{1}{2}$

MARK

8-10)





At $t<0$

$V_C = V_{R_2} = 9.3\,V$; $V_D = .7\,V$

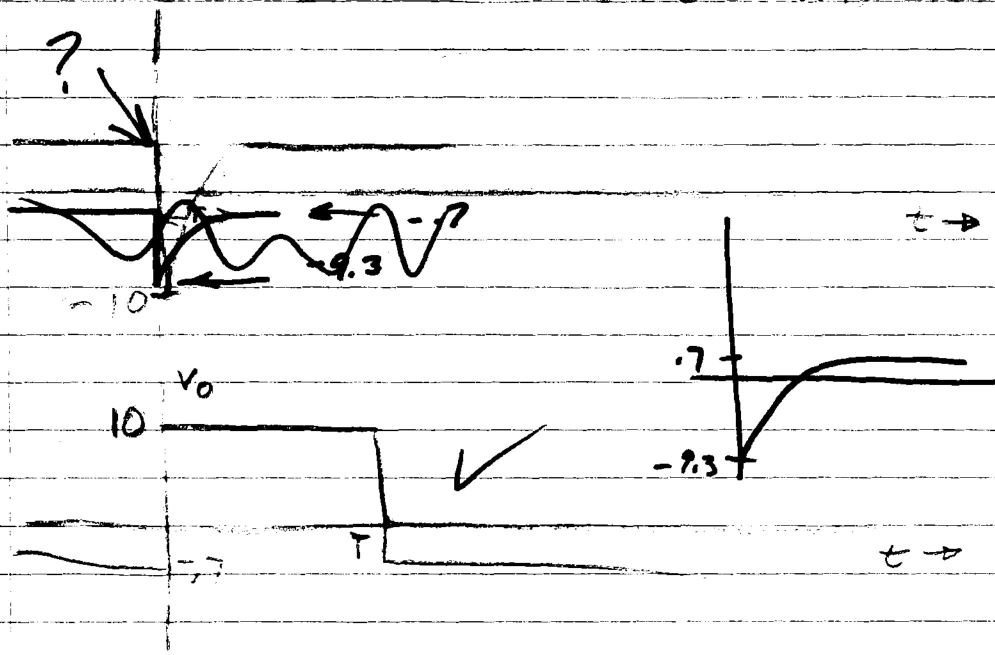
At $t \geq 0$

$V_C(0) = 9.3\,V$; $V_C(\infty) = 0$ (DISCHARGING C_1)

$\Rightarrow V_C(t) = 9.3\, e^{-t/\tau}$

$\tau = RC = (10^{-11})(5\times10^{4}) = 5\times10^{-7}$

$.7 = e^{-t/5\times10^{-7}} \Rightarrow t = 5\times10^{-7} \ln(.7) = .81\times10^{-7} = T$



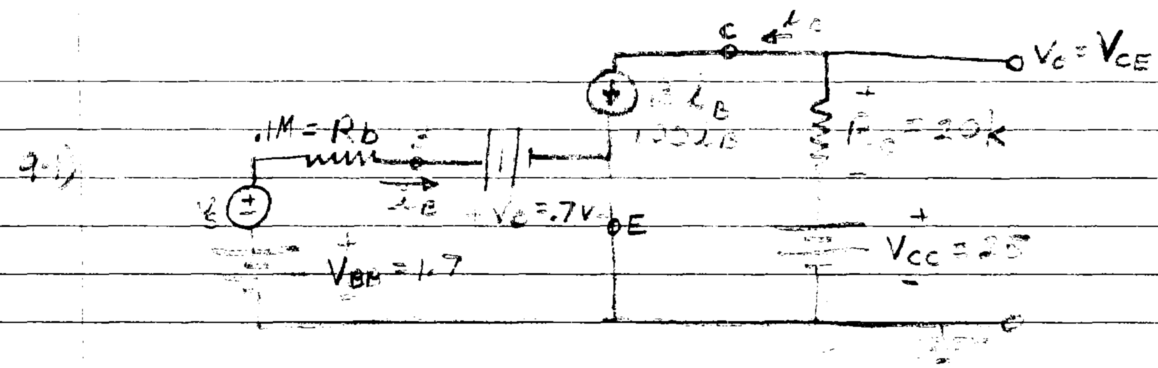
(-1)

8.2 (-2)

8.6 (-2)

M A R...

9-1)



a) AT QUIESCENCE

$I_B = \frac{V_B - V_{BB}}{R_B} = \frac{-1}{10^5} = -10^{-5}$ A ✓

$I_c = \beta I_B = -10^{-3}$ A ✓

$V_{CE} = V_{CC} - R_c I_c$

$= 25 + (20)$ ... V ✗

b) $V_{CE} = V_{CC} - R_c I_c$

$= V_{CC} - R_c \beta I_B \left(\frac{V_B - V_{BB} - V_s}{R_B}\right)$

$= V_{CC} - R_c \beta$

$= V_{CC} - R_c \beta \left(\frac{V_B - V_{BE}}{R_B}\right) + R_c \beta \frac{V_s}{R_B}$

$\frac{dV_{CE}}{dV_s} = R_c \beta$ ... b

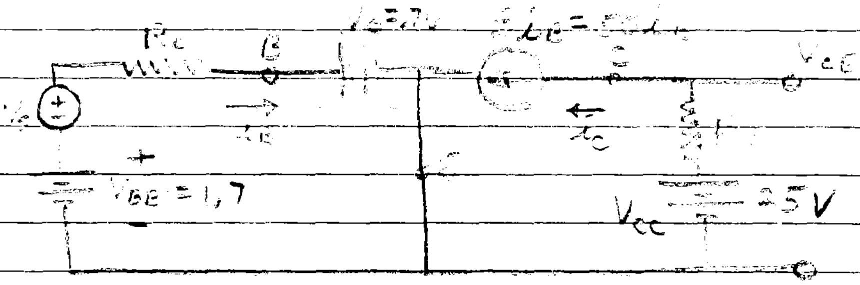
$\frac{dV_{CE}}{dV_s} \approx \frac{\Delta V_{CE}}{\Delta V_s} = \frac{R_c \beta}{R_B} = \frac{20(100)}{100} = 20$ ✓

c) V_B = 5...

(-1/2)

MARKS

3)



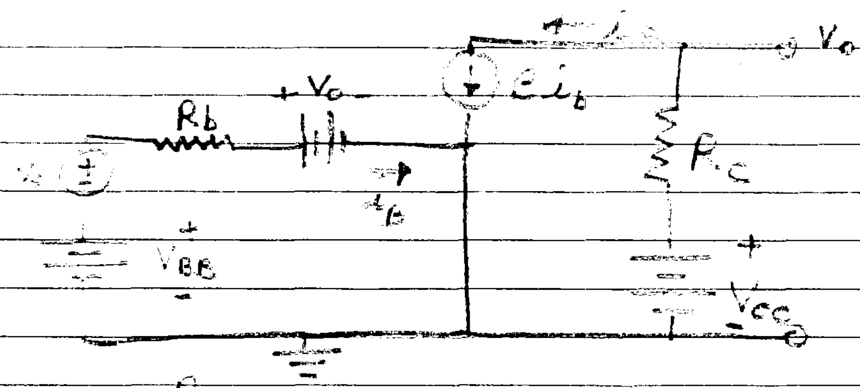
$I_c = 2\,mA$ $V_{CE} = 5\,V$

a) $I_B = \frac{V}{R_b} \Rightarrow I_c = \beta I_B = \frac{50}{R_b} = 2\,mA \Rightarrow R_b = 25\,k$

$V_{CE} = 5 = 25 - R_c I_c \Rightarrow R_c I_c = 20 = 2\,mA\,R_c \Rightarrow R_c = 10\,k$

b) $K_v = \beta \frac{R_c}{R_B} = 50 \frac{10}{25} = 20$

MARKS



$K_v = \beta \frac{R_c}{R_b}$

$V_{CE} = V_{CC} - \beta i_b R_c$

$V_{CC} - V_{CE} = \beta i_b R_c$

$i_b = (V_o - V_{BE})/R_b$

$\Rightarrow V_o - V_{BE} = i_b R_b$

$K_v = \beta \frac{R_c}{R_b} = \frac{\beta i_b R_c}{i_b R_b} = \frac{V_{CC} - V_{CE}}{V_o - V_{BB}}$ ✓

b) $V_o = .7$; $K_v = 15$; $V_{CC} = 20$

$i_c = 1\,mA$; $V_{CE} = 2V$

$V_{CE} = V_{CC} - i_c R_c$

$2 = 20 - R_c \Rightarrow R_c = 18k$ ✓

~~$K_v = \frac{V_{CC} - V_{CE}}{V_o - V_{BE}} = \frac{20 - 2}{.7 - V_{BE}} = 15V$~~

$18 = 10.5 - 15 V_{BE} \Rightarrow V_{BB} = -16.9/15$

$K_v = \frac{V_{CC} - V_{CE}}{V_o - V_{BB}} = \frac{18}{.7 - V_{BB}} = 15 \Rightarrow 18 = 10.5 - 15 V_{BB}$

$\Rightarrow V_{BB} = \frac{-16.95}{15} = 7.13$

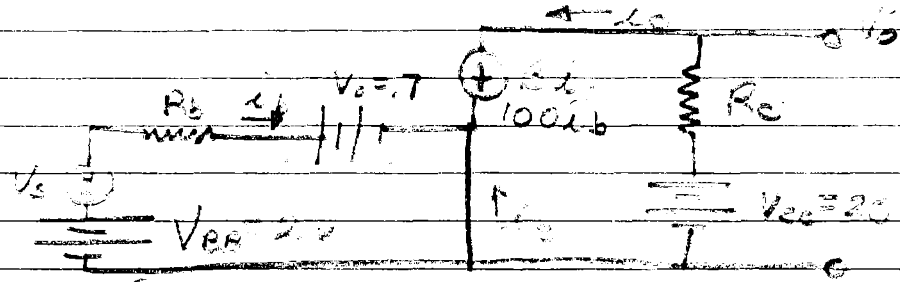
$K_v = \beta \frac{R_c}{R_b}$

$15 = \beta \frac{18k}{R_b} \Rightarrow R_b = \frac{18 \times 10^3}{15} \beta = 1.2 \times 10^3 \beta$ ✓

$V_{BB} = ?$ (-1/2)

MARKS

9-6)



$(i_c V_{CE})_{max} = 360\ mW$

a) $V_{CE} = 5\ V \quad I_c = 1\ mA$

$V_{CE} = V_{cc} - R_c I_c \Rightarrow R_c = \frac{V_{cc} - V_{CE}}{I_c} = \frac{15}{1} = 15\ k$ ✓

$I_c = 1\ mA \Rightarrow I_b = .01\ mA$

$+13 = R_b(.01) \Rightarrow R_b = 130\ k$ ✓

b) $P = I_c V_{CE}$

$= (1)(5) = 5\ mW$ ✓

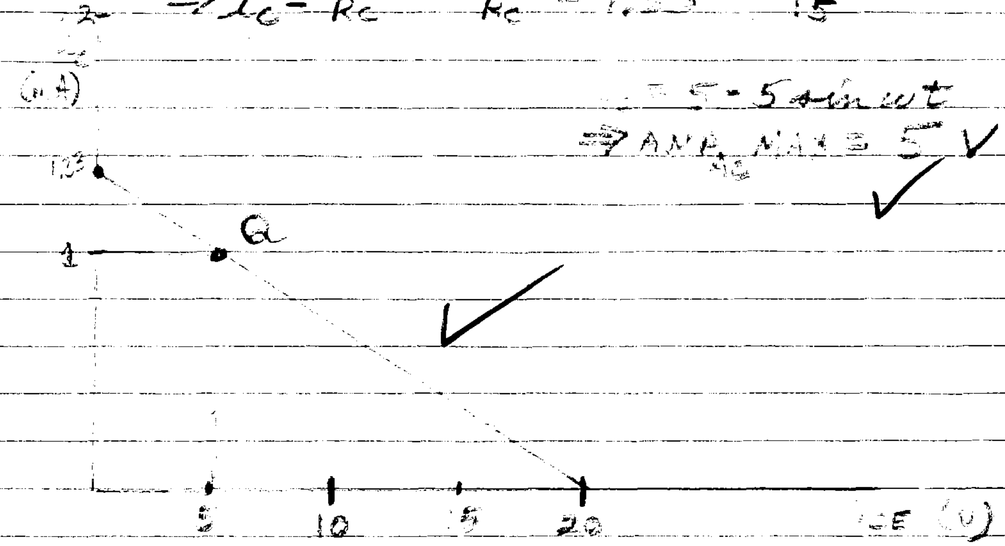
c) $K_v = \beta\ R_c/R_b = (100)\frac{15}{130} = 11.5$ ✓

d) $V_{CE} = \ldots i_c R_c$

$\Rightarrow i_c = \frac{V_{cc}}{R_c} - \frac{V_{CE}}{R_c} = 1.33 - \frac{V_{CE}}{15}$

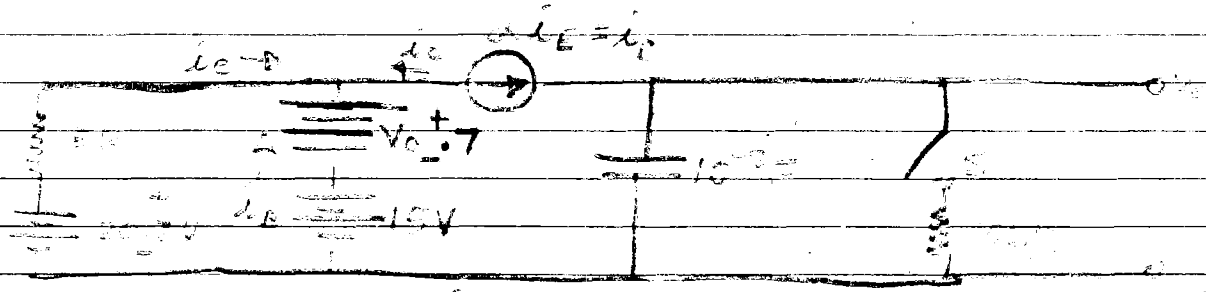
$= 5 - 5 \sin \omega t$

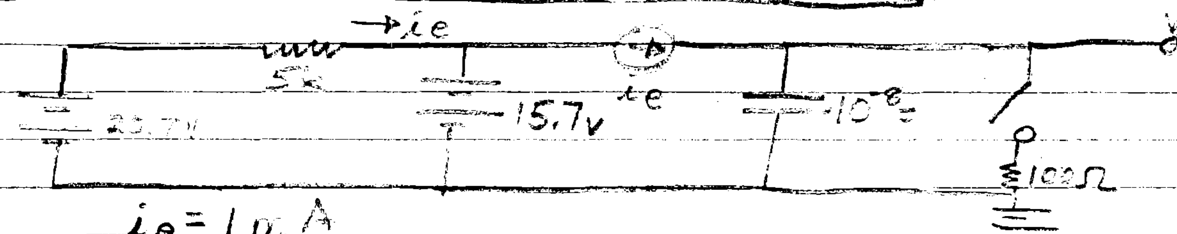
$\Rightarrow$ AMP v_{ce} MAX = 5 V ✓



✓

MARKS

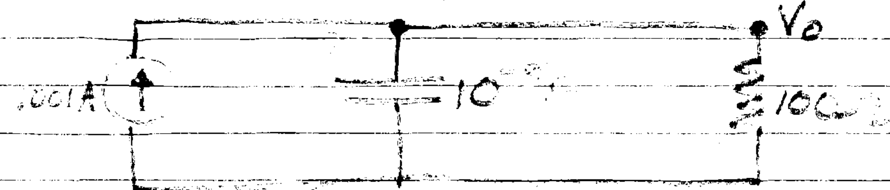




$i_e = 1\,mA$

$l_c = \int_0^t i_e\,dt = 10^5 t \qquad 0 < t < 10^{-4}$

AFTER SWITCH IS CLOSED



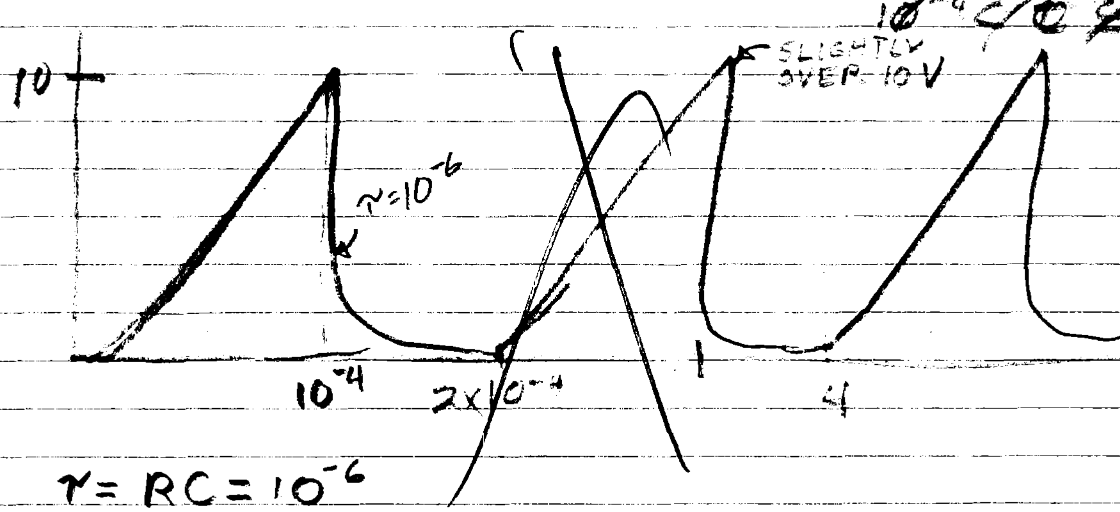
$.001 + C\frac{dV_o}{dt} + \frac{V_o}{100} = 0$

$.001 + CS\,V - C10 + \frac{1}{100}V = 0$

$V(10^{-8}S - 10^{-2}) = 10^{-7} - 10^{-3}$

$V = \frac{-10^{-3}}{10^{-8}S - 10^{-2}} = \frac{-10^{-4}}{S - 10^{-10}} \Rightarrow V_o = -10^{-4} e^{10^{-10}t}$

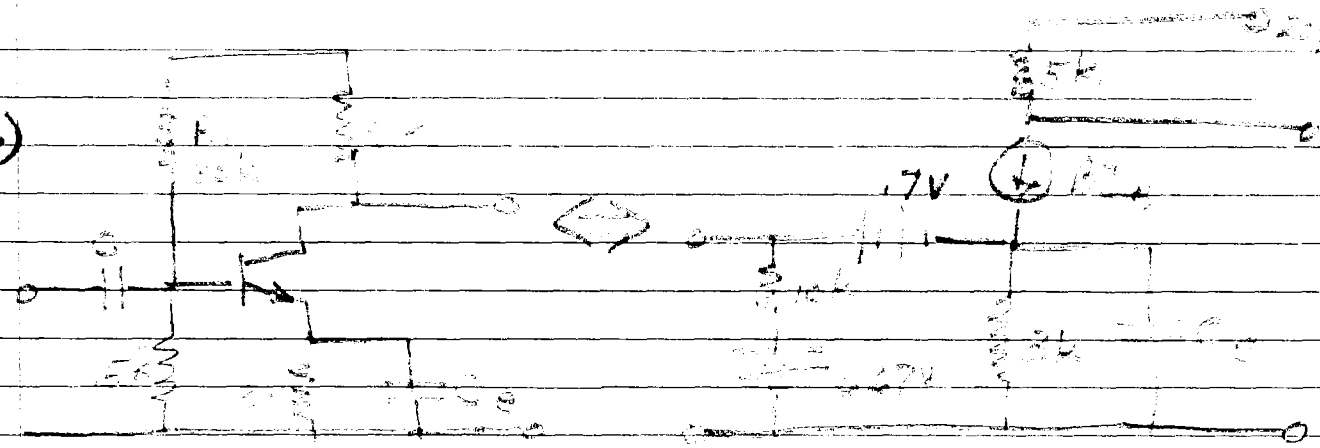
10^{-4} ...



$\tau = RC = 10^{-6}$

(-2)

6)



V_{BB} = [illegible] 7

R [illegible] 10k

[illegible]

[illegible] $\frac{5.96}{[illegible]}$ [illegible]

[illegible]

[illegible] mA

[illegible]

= 20 − [illegible] = 4.2 V

[illegible]

I_C = 60 I_B [illegible] mA

V_{CE} = 20 − 8(1.55) = 5.2 V

I_B = [illegible] = 6.5 [illegible]

I_C = [illegible] = 1.96 mA

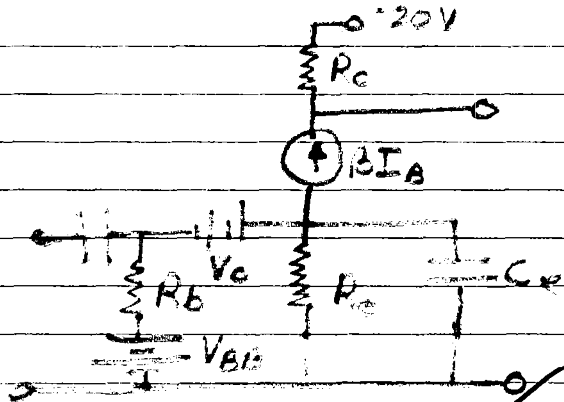
V_{CE} = 20 − 8(1.96) = 4.[illegible] V

β → ∞ I_C = $\lim_{\beta \to \infty}$ [illegible] = [illegible] mA

10.1 (−2)

10.5 (−2)

2)



$\beta = 100$

$V_o = .7$

$I_c = 1\,mA$

$V_{ce} = 4\,V$

$V_e = 4\,V$

1) $R_e = \frac{4V}{1mA} = 4k$ ✓

2) $I_c = (V_{cc} - V_{ce})/(R_c + R_e) = \ldots = 1\,mA$

$\Rightarrow R_c + R_e = 16 \ldots = 16k \Rightarrow R_c = 12k$ ✓

3) $I_B = \frac{1}{\beta} I_c = 10\,\mu A$

[illegible]

$\times 10^{-2}\,V$

$I_c = \frac{\beta(V_{BB} - V_o)}{R_b + (1+\beta)R_e} = 1\,mA$

$S_o = \ldots = 100(V_{BB} + .7)/421.1$

$V_{BB} = \ldots = 4.8\,V$

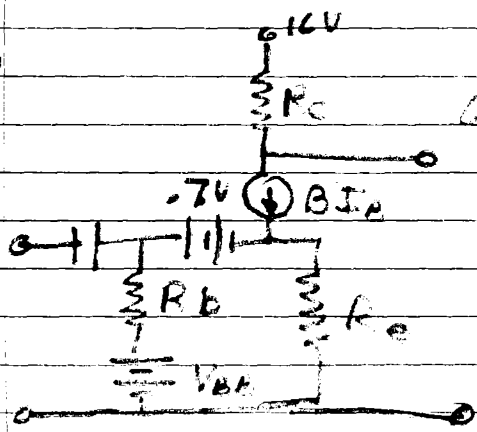
$R_1 = R_b \ldots = 17.1 \ldots$ ✓

4) $V_{BB} = \frac{R_2}{R_1 + R_2} V_{cc} \Rightarrow R_2 = \ldots$

$\Rightarrow R_2 = \ldots 69/.758 = \ldots$ ✓

HARKS

10.9)



$2 < V_{ce} = 6$

$I_c = 2mA$ when $V_{ce} = 4V$

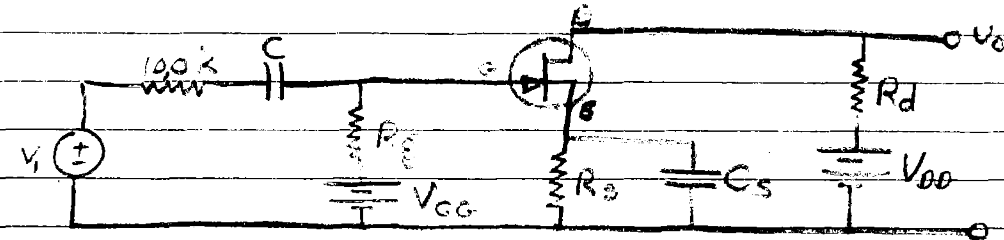
$I_c = \frac{V_{cc} - V_{ce}}{R_c + R_e} \Rightarrow 2 = \frac{12}{R_c + R_e}$

$\Rightarrow R_c + R_e = 6K$

$I_c = \frac{10}{6K} = 1.67mA$

$S_{ec} = .0494$ ✓

7-4)



$I_{DSS} = 8mA$ $\quad V_{GG} = 0 \Leftrightarrow V_{DD} = 20$

$V_p = -4$

$V_{DS} = 6V$ $\quad R_g = 1M$

$I_D = 2mA$

a) $V_{DS} = V_{DD} - (R_d + R_s) I_D$

$6 = 20 - (R_d + R_s) 2 \Rightarrow R_d + R_s = 7K$

$V_{GS} = V_{GG} - R_s I_D$

$I_D = I_{DSS} (1 - V_{GS}/V_p)^2$

$(\sqrt{I_D/I_{DSS}} - 1) V_p = V_{GS}$

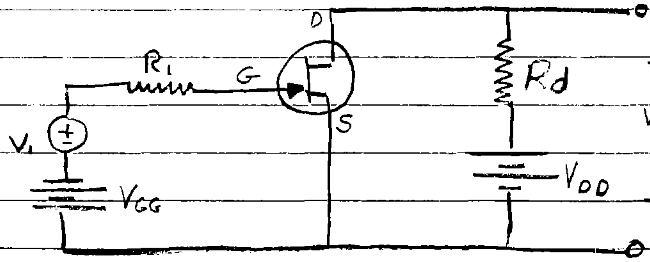
$\Rightarrow V_{GG} - R_s I_D = (\sqrt{I_D/I_{DSS}} - 1) V_p$

$R_s = -1/I_D (\sqrt{I_D/I_{DSS}} - 1) V_p$

$= .5 (1 - 1/2) 4 = 1k$

$\therefore R_d = 6K$

6-7)



$I_{DSS} = 10\,mA$
$V_P = -4$
$V_{DD} = 25\,V$

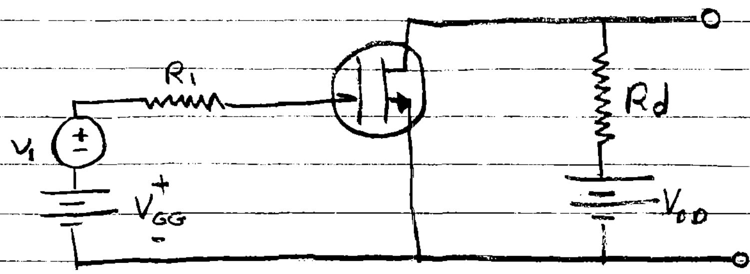
a) $V_{DS} = V_{DD} - R_d\, i_d$
$7 = 25 - R_d\, 10 \Rightarrow R_d = 1.8\,k$

b) $K_v = \frac{-2 R_d I_{DSS}}{V_P} = \frac{(3.6)(10)}{4} = 9$

c) $I_D = 2.5\,mA$
$I_D = I_{DSS}\left(1 + \frac{V_{GG}}{V_P}\right)^2 \Rightarrow \sqrt{I_D/I_{DSS}} = 1 + \frac{V_{GG}}{V_P}$
$\Rightarrow V_{GG} = V_P\left(1 - \sqrt{I_D/I_{DSS}}\right)$
$= -4\left(1 - \sqrt{1/4}\right) = -2\,V$

d) $K_v = \frac{-2 R_d I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right)$
$= 9\left(1 + \frac{2}{4}\right) = \frac{3}{2} \cdot 9 = 13.5$

6-10)

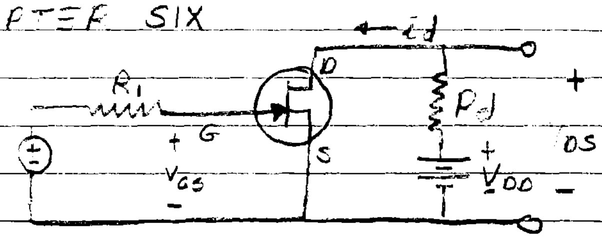


$v_{DS} = V_{DS} - 2K R_d (V_{GS} - V_T)\, v_1 - K R_d v_1^2$
$= V_{DD} - K R_d \left[(V_{GS} - V_T) + v_1\right]^2$

a) $\frac{v_{DS}}{v_i} = \frac{V_{DS}}{v_i} - 2K R_d (V_{GS} - V_T) + K R_d v_1$
$\Rightarrow K_v = 2K R_d (V_{GS} - V_T)$

CHAPTER SIX

6-3)



$I_{DSS} = 5mA$
$V_p = -4$
$V_{DS} = 8 \quad V_{DD} = 25$

a) $i_d = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$

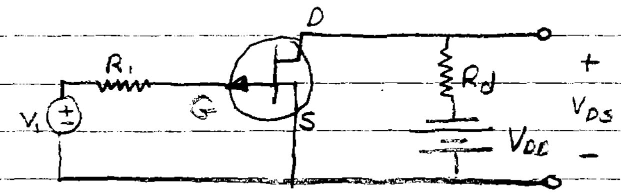
$V_{DS} = V_{DD} - i_d R_d$

$8 = 25 - 5R_d \Rightarrow R_d = \frac{17}{5} = 3.4\,k$

b) $K_v = -2R_d I_{DSS}/V_p$

$= \frac{6.8(5)}{+4} = 8.5$

6-4)



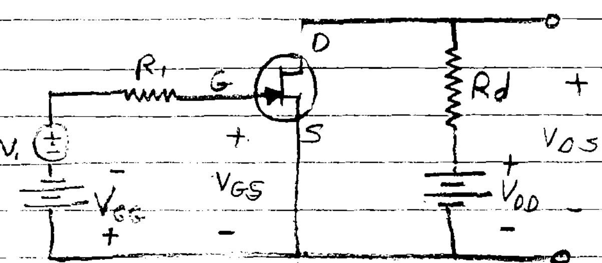
$V_p = 6\,V$
$V_{DD} = 25\,V \quad I_{DSS} = -4\,mA$
$V_{DS} = -7\,V$

a) $V_{DS} = -V_{DD} - R_d I_{DSS}$

$-7 = -25 + R_d 4 \Rightarrow R_d = \frac{18}{4} = 4.5\,k$

b) $K_v = \frac{-2R_d I_{DSS}}{V_p} = \frac{(9.0)(4)}{4} = 9.0$

6-6)



$I_{DSS} = 12\,mA$
$V_p = -5$
$R_d = 3.3\,k$
$R_1 = 50\,k$
$V_{GG} = 1.75\,V$
$V_{DD} = 25\,V$

a) $i_d = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$

$= 12\left(1 - \frac{-1.75}{-5}\right)^2 = 12(.65) = 7.8\,mA$

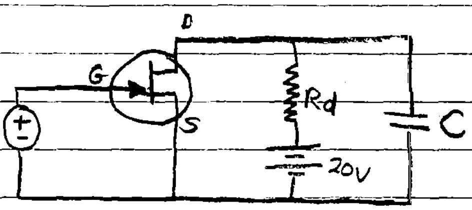
$V_{DS} = V_{DD} - i_d R_d$

$= 25 - 7.8(3.3) = 25 - 25.4 = -.4\,V$

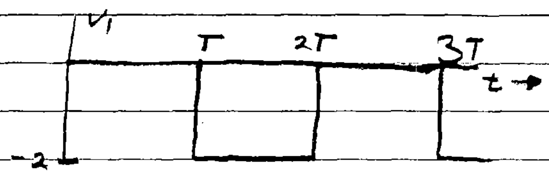
b) $K_v = -\frac{2R_d I_{DSS}}{V_p}\left(1 - V_{GS}/V_p\right)$

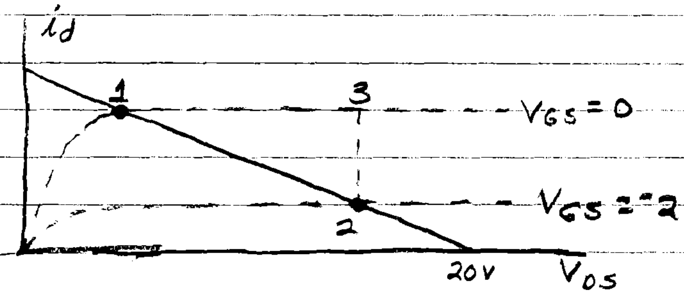
$= \frac{(6.6)(12)}{5}\left(1 - \frac{-1.75}{-5}\right) = 8.7$

7-7)



$I_{DSS} = 5mA$
$V_p = -3$
$R_d = 3k$





$V_{DS} = 20 - i_d(3)$
$i_d = \frac{1}{3}(20 - V_{DS})$

a) $i_d = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$

$i_{d1} = I_{DSS} = 5mA \Rightarrow V_{D1} = 20 - 15 = 5V$

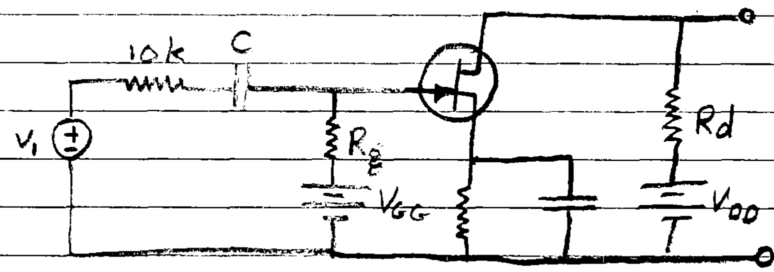
$i_{d2} = 5\left(1 - \frac{-2}{-3}\right)^2 = 5/9 = .555\ mA$

$V_{d2} = 20 - \frac{5}{9}(3) = 18.3V$

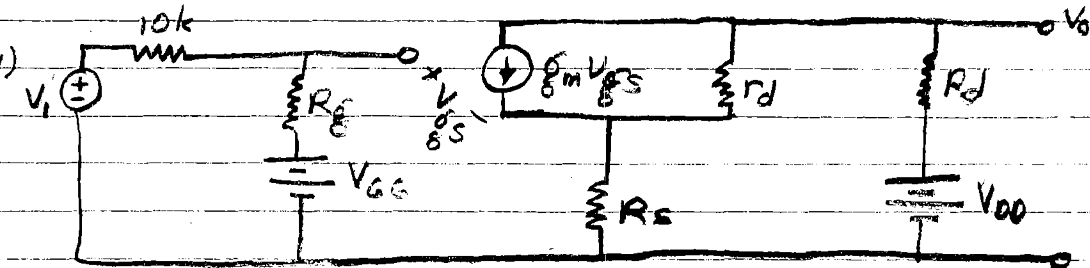
b) $i_{d\,MAX} = 5mA$; $V_{DS\,MAX} = 18.3$

$\Rightarrow P_{MAX} = (5)(18.3) = 91.5\,mW$

7-11)



a)



$I_{DSS} = 8mA$ $\quad R_d = 6.8k$

$g_{mo} = 4m\mho$ $\quad R_g = 1M$

$r_d = 30k$ $\quad I_D = 2mA$

b) $g_m = g_{mo}\sqrt{I_D/I_{DSS}} = 4\sqrt{2/8} = 2m\mho$

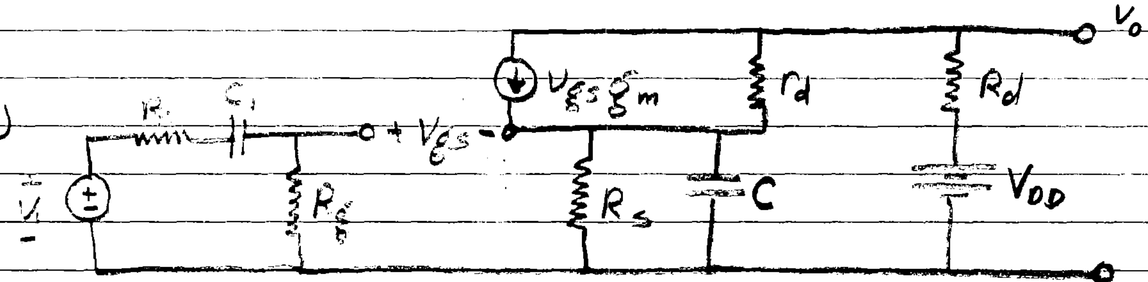
c) ~~$K_v = g_m R_d = (.02)(6.8) = 5$~~

$R = R_d \parallel r_d = \frac{194.0}{36.8} = 5.54$

$V_{gs}/V_0 = R g_m = (5.54)(2) = 11.08$

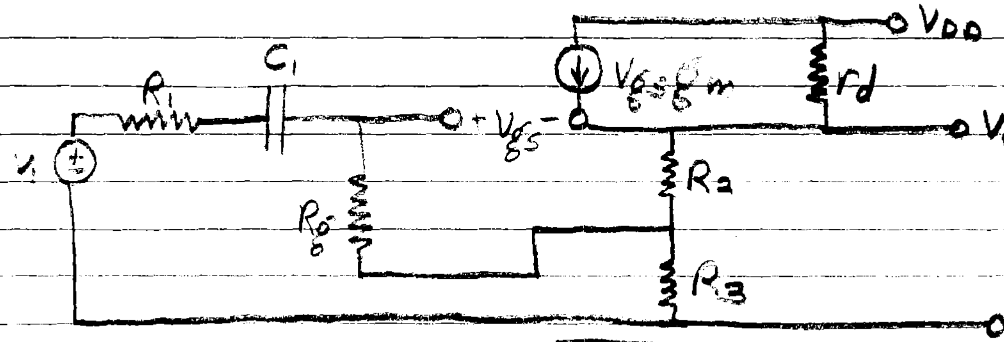
$V_i \cong \frac{10^9}{10^9} = 1 \Rightarrow K_v = 11.08$

7-13) a)



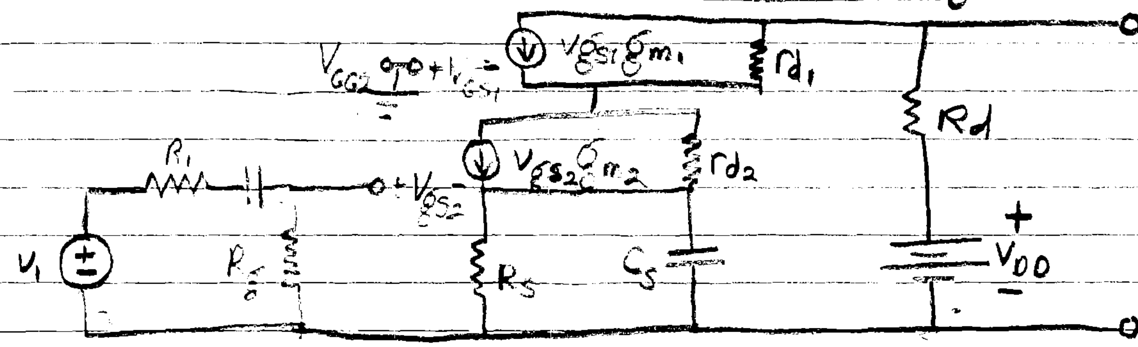
R_1
C_1
v_i
R_G
$+ V_{gs} -$
$V_{gs} g_m$
r_d
R_d
R_s
C
V_{DD}
v_o

b)



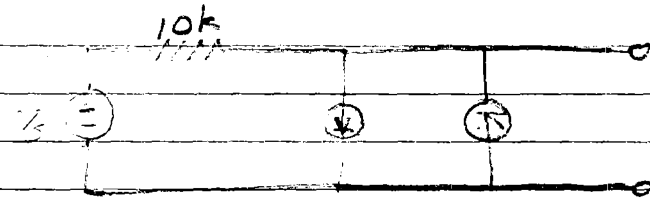
R_1
C_1
v_i
R_G
$+ V_{gs} -$
$V_{gs} g_m$
r_d
V_{DD}
V_o
R_2
R_3

c)

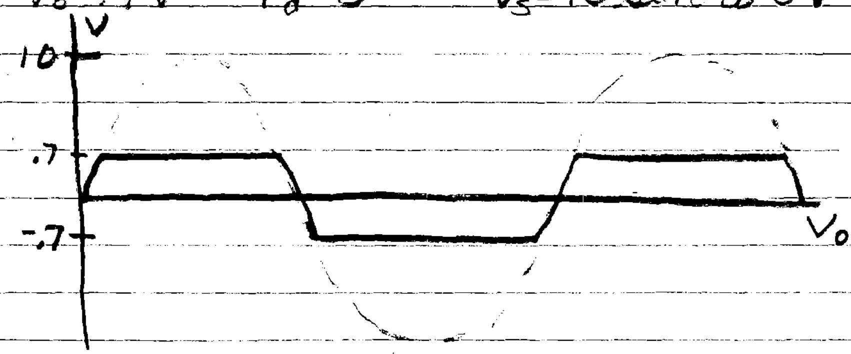


V_{GG2}
$+ V_{GS1} -$
$V_{gs1} g_{m1}$
r_{d1}
R_d
$V_{gs2} g_{m2}$
r_{d2}
R_1
v_1
R_G
$+ V_{gs2} -$
R_S
C_S
V_{DD}

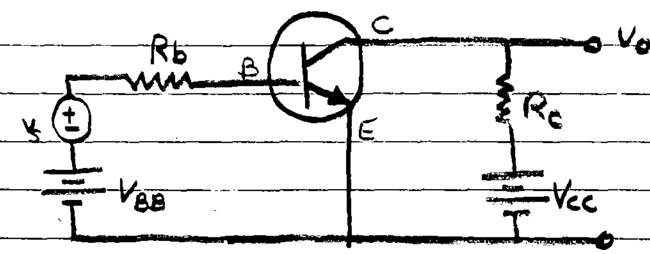
8-6)



$V_o = .7\,V \quad r_d = 0 \quad v_s = 10 \sin \omega t\ V$

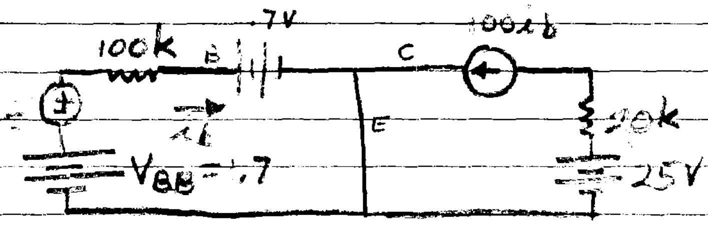


9-1)



$\beta = 100$
$V_o = .7$
$R_b = 100k$
$R_c = 20k$
$V_{BB} = 1.7V$
$V_{cc} = 25V$

a)



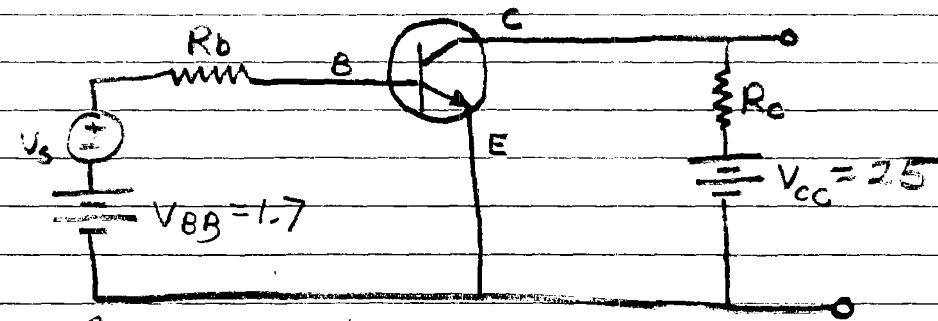
~~$V_{CE} = 25 + 20 \times 100 I_b$~~
~~$I_b = .7/100 = .007$ mA~~
~~$\Rightarrow V_{CE} = 25 + 20 \times .7 = 140 / ... = 16.5 V$~~

$I_b = .01$ mA $\Rightarrow I_c = 1$ mA
$V_{CE} = 25 - 20 = 5V$

b) $K_v = \beta \frac{R_c}{R_b} = 100 \frac{1}{5} = 20$

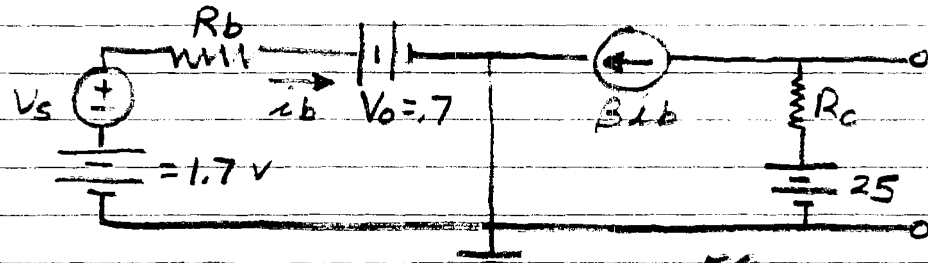
c) $v_s = .01 \sin \omega t$
$V_{CE} = 20 V_s = .2 \sin \omega t$ V

9-3)



$\beta = 50$ $\quad V_o = .7V$

a) $I_c = 2mA$ $\quad V_{CE} = 5V$



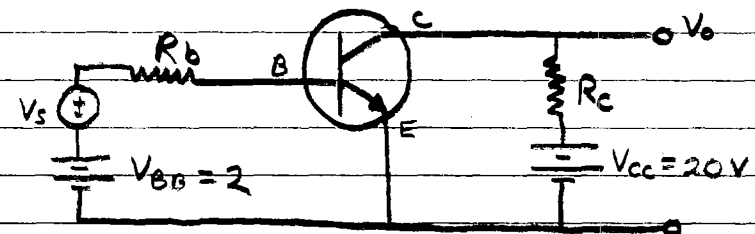
$I_b = 1/R_b \Rightarrow I_c = 50 I_b = \frac{50}{R_b} = 2 \Rightarrow R_b = 25k$

$V_{CE} = 25 - R_c(50)\frac{1}{25} = 5$

$\Rightarrow R_c = 10k$

b) $K_v = \frac{R_c}{R_b}\beta = \frac{10}{25} 50 = 20$

9-6)



$\beta = 100$; $V_o = .7\,V$ $P_{MAX} = 360\,mW$

a) $V_{CE} = 5\,V$; $I_c = 1\,mA$

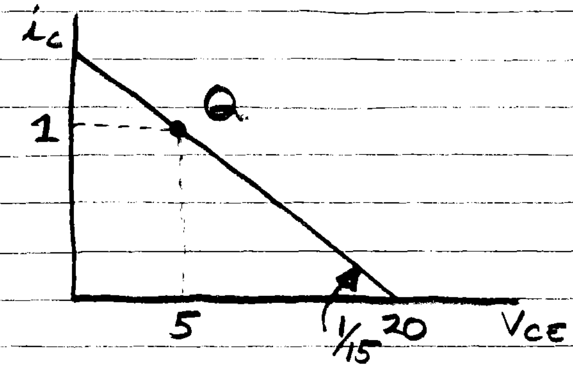
$I_B = 1.3/R_b \Rightarrow I_c = 1 = (100)(1.3)/R_b \Rightarrow R_b = 130\,k\Omega$

$V_{CE} = 5 = 20 - R_c \Rightarrow R_c = 15\,k$

b) $P = i_c V_{CE} = 5\,mW$

c) $K_v = \frac{R_c}{R_b}\beta = \frac{15}{13.0}(10) = 11.6$

d)



$V_{CE} = 20 - 15 i_c$

$\Rightarrow V_{ce} = 0$

$\Rightarrow i_c = 20/15 = 1.33$

$\Rightarrow i_{cMAX} = 1.33$

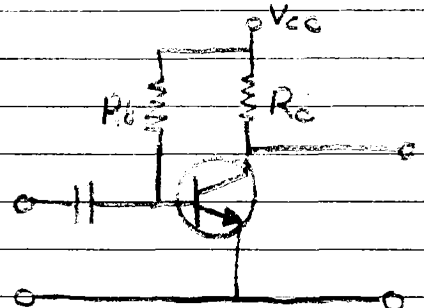
OR

$i_{bMAX} = .0133\,mA$

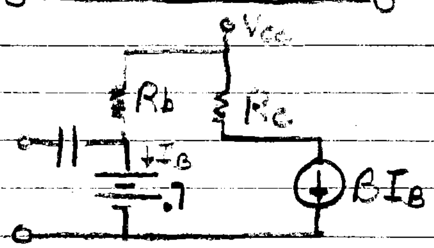
NOW, $V_{S_{MAX}} = 1.3 + (130)(.013)$

$= 1.3 + 1.69 = 1.99\,V$

10.1)



$I_c = 2$
$V_{CE} = 4$
$V_{CC} = 20$
$V_o = .7$
$\beta = 50$



$V_o = V_{CC} - R_c I_B$

a) $I_B = \frac{19.3}{R_b} \Rightarrow I_c = \beta I_B = 2 = \frac{(50)(19.3)}{R_b} \Rightarrow R_b = 483\,;\ I_B = .04\,mA$

$4 = 20 - R_c(.2) \Rightarrow R_c = 16/2 = 8k$

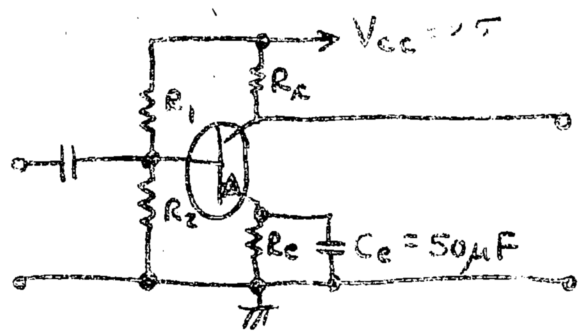
b) $V_{CE} = 20 - (\quad)2 = 4$

Electrical Engineering [illegible]
Rose-Hulman Institute of Technology
Terre Haute, Indiana
May 17, 1971

EE 262 -- Electronics I
Experiment No. ____
COMMON EMITTER AMPLIFIER

1. Measure V_o for your 2N718 transistor either on the curve tracer or otherwise.

2. Design a common emitter transistor using the circuit diagram below. The instructor will give you the quiescent point requirements for the circuit. The beta spread for this transistor is 40-120. Make your design based on these values.



3. Build the amplifier using substitution boxes and measure the quiescent operating conditions. Comment on their agreement with desired values. Experiment with the value of R_1 to see if you can make the quiescent operating conditions better.

4. Measure the voltage gain of the amplifier. Be sure to keep a CRO on the output voltage at all times.

5. Measure the frequency response by noting the upper and lower .707 frequencies.

6. Increase the input voltage until distortion is noted. Record the value of v_{in}.

7. Display the voltage transfer characteristic.

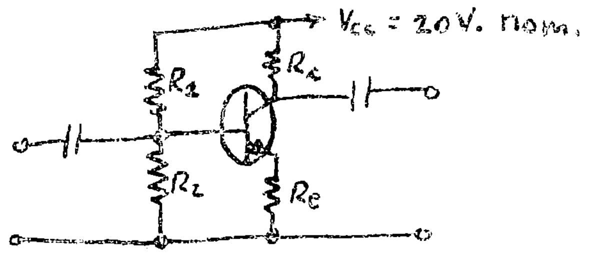
$$V_{BB} = V_0 + I_{C1}\left[R_b + (1+\beta_1)R_e\right]\frac{1}{\beta_1}$$

$$n = \frac{V_{BB}}{V_C}$$

Electrical Engineering Dept.
Rose-Hulman Inst. of Tech.
Terre Haute, Indiana
May 17, 1971

EE262 - Electronics 1
Homework problem

Design a transistor amplifier using the circuit shown below assuming that the beta spread of the transistor is 40-240. The maximum I_C is to be 2.4 mA and the minimum I_C is to be 2.1 mA. Assume a value of .65 V. for V_σ. You may neglect the effect of I_{CEO}. The minimum value of V_{CE} is to be 6 V. Partition $R_c + R_e$ such that $R_e = .25\ R_c$.



After the amplifier is designed, compute the worst case quiescent conditions assuming the two values of beta and also assuming that V_σ varies between .59 and .72 V. Let us also assume for the purposes of this problem that V_{CC} may be expected to vary between 18.5 and 21.0 V. Assume that the actual values of resistors calculated in the design portion are available and that their values are exact and do not change.

SUBROUTINE LINEQ4

SYSTEMS LIBRARY - CDC 6500 ONLY

PURPOSE

Solves the complex matrix equation AX=B with NR right-hand sides.

Usage

CALL LINEQ4(A,B,X,ND,N,NR,S)

Description of parameters

A	-	(N x N) complex coefficient matrix.
B	-	(N x NR) complex right-hand side array.
X	-	(N x NR) complex array for return of solution vectors.
ND	-	the number of rows for the arrays A, B, and X in the dimension statement in the user program.
N	-	the number of equations to be solved.
NR	-	the number of right-hand sides to be solved.
S	-	integer variable returned non-zero only if matrix A is singular to machine accuracy.

Remarks

Arrays A and B are not destroyed.

At execution time, the field length of your program will be increased for temporary storage needed by this subroutine.

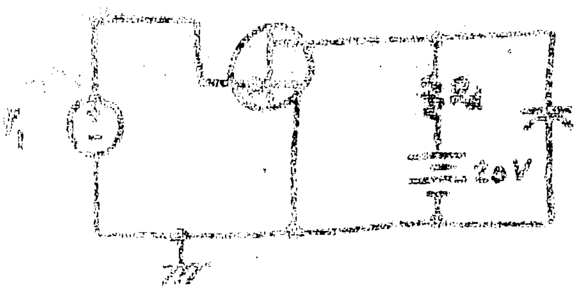
Method

The matrix A is factored into lower and upper triangular matrices L and U and then the equations LZ=B and UX=Z are solved in turn. Double precision accumulation of inner products and iterative refinement are used so solutions are very accurate whenever S is returned equal to zero.

Ralston and Wilf Mathematical Methods for Digital Computers Volume 2 Wiley 1967.

Written by David S. Dodson.

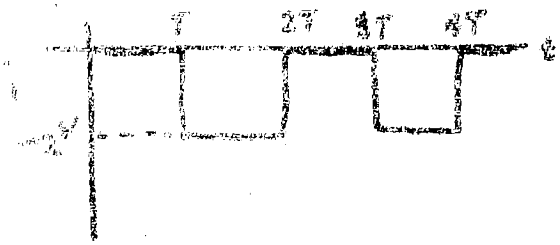
14.7.7 Angelo

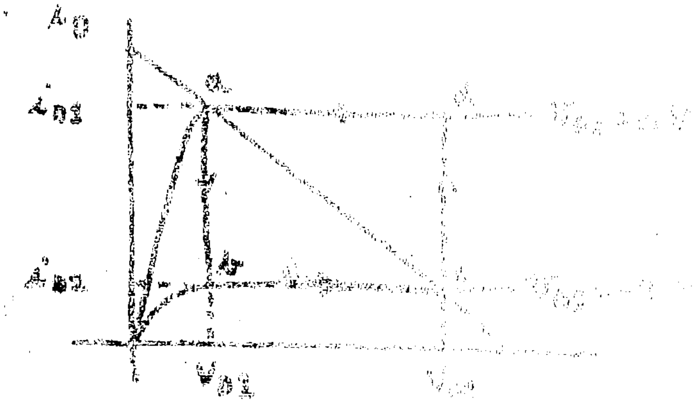


$I_{DSS} = 5\ mA$

$V_P = -3\ V$

$R_d = 3K$





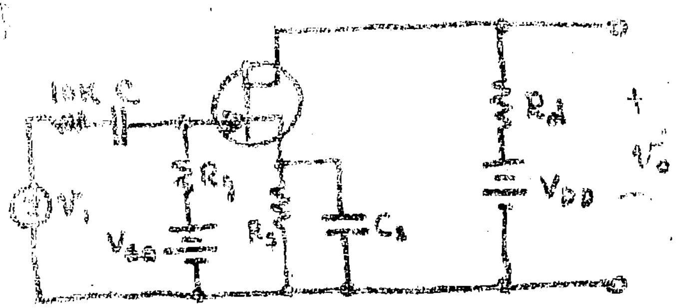
$i_{D1} = I_{DSS} = \boxed{5\ mA}$, $V_{D1} = 20 - 5 \cdot 3 = \boxed{5\ V}$

$i_{D2} = 5\left(1 - \frac{2}{3}\right)^2 = 5 \times \frac{1}{3}^2 = \frac{5}{9} = \boxed{.555\ mA}$

$V_{D2} = 20 - 3(.555) = 20 - \frac{15}{9} = \frac{165}{9} = \boxed{18.3\ V}$

$P_D(max) = V_{D2}\, i_{D2} = 18.3 \times 5 = \boxed{91.5\ mW}$

Problem 186.7.11 Angelo



$I_{DSS} = 8$ mA

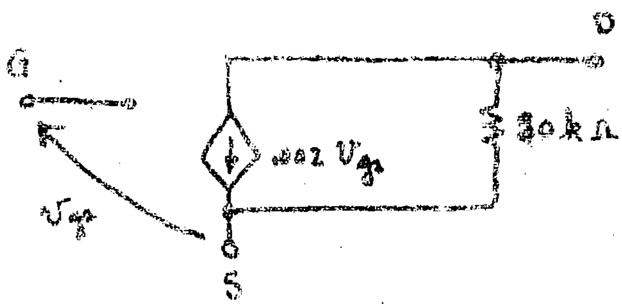
$g_{mo} = 4 \times 10^{-3}$ S

$r_d = 30$ kΩ

$R_d = 6.8$ kΩ $R_g = 1$ MΩ

$I_D = 2.0$ mA

(a) $g_m = g_{mo}\sqrt{\frac{I_D}{I_{DSS}}} = 4\sqrt{\frac{2}{8}} = 4 \cdot \frac{1}{2} = \boxed{2\text{ mS}}$ (b)



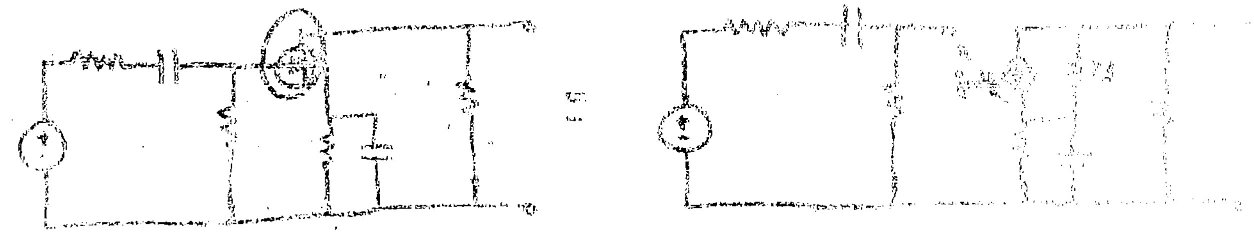
(c) $R_d \parallel r_d = 6.8 \parallel 30 = \frac{6.8 \times 30}{36.8} = 5.54$ kΩ

$\frac{V_o}{V_{gs}} = 0.002 \times 5540 = -11.08$ $\frac{V_{gs}}{V_{in}} = \frac{10^6}{10^4 + 10^6} \approx .99$

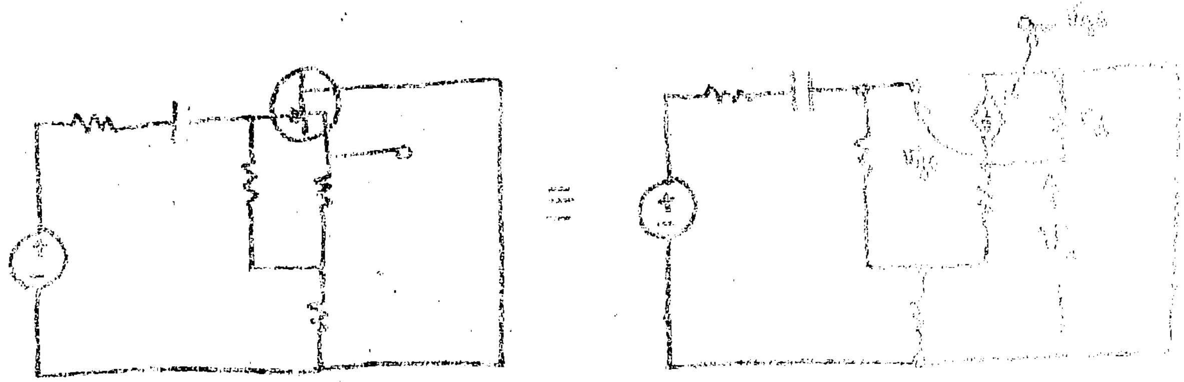
$\frac{V_o}{V_{in}} = -11.08 \times .99 = \boxed{-10.95}$

PROBLEM 180.7.13 ANGELO

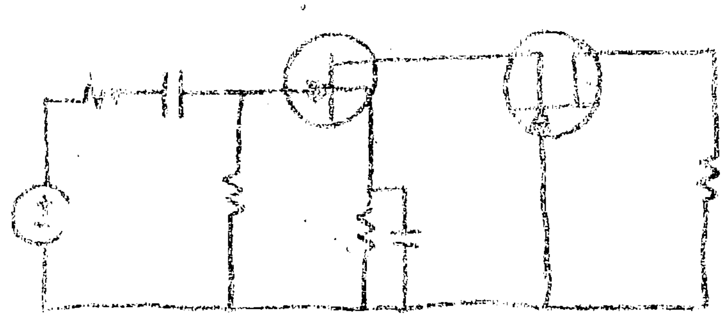
(a)



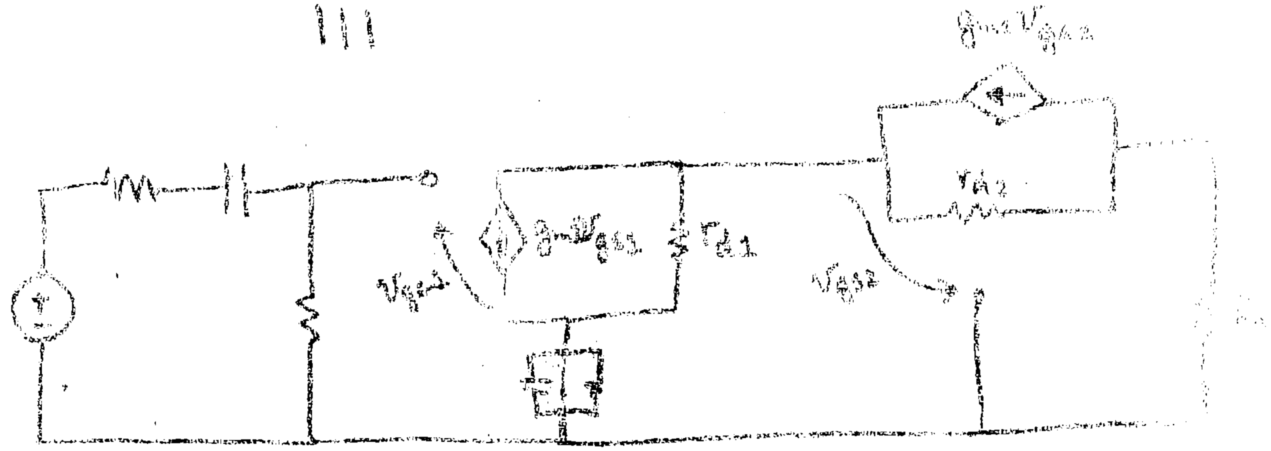
(b)



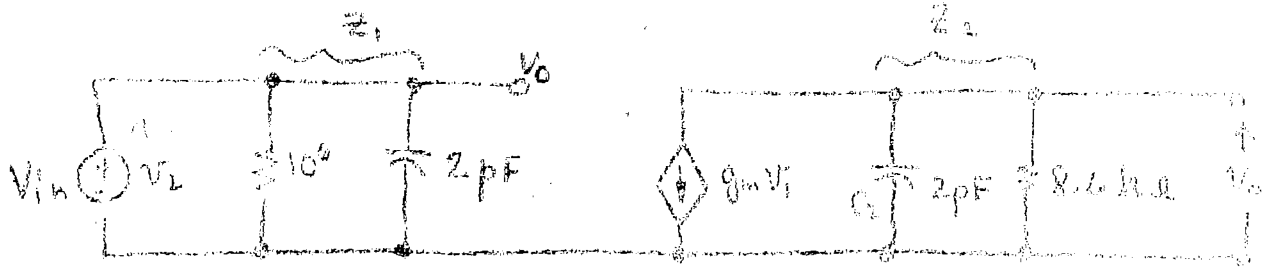
(c)



III



Problem 187.7.14 Angelo



(a) $V_1 = 10\ mV \quad f = 1000\ Hz$

$$Z_2 = \frac{R_d}{1 + j R_d C_2 \omega}, \quad Z_2(1000) = \frac{8600}{1 + j 10^3 \cdot 6.28 \times 8.6 \times 10^3 \times 2 \times 10^{-12}}$$

$$= \frac{8600}{1 + j\, 1.08 \times 10^{-4}} \doteq 8600$$

$$V_o = -1.5 \times 10^{-3} \times 8.6 \times 10^3 = \boxed{-12.9\ V_2}$$

(b) $f = 10^7\ Hz$

$$Z_2(10\ MHz) = \frac{8600}{1 + j\, 1.08} = \frac{8600}{1.47 \angle 47.2^\circ}$$

$$= 5850 \angle -47.2^\circ$$

$$V_o = -1.5 \times 10^{-3} \times 5.85 \times 10^3 \angle -47.2^\circ V_2 = -87.8 \angle -47.2^\circ\ V$$

$$= \boxed{87.8 \angle 132.8^\circ\ V_{in}}$$

PROBLEM 208.8.2 ANGELO

$$i = I_s(e^{\lambda v} - 1) \quad , \quad I_s + i = I_s e^{\lambda v}$$

$$e^{\lambda v} = 1 + \frac{i}{I_s} \rightarrow \lambda v = \log_e\left(1 + \frac{i}{I_s}\right)$$

$$\frac{dv}{di} = r = \frac{1}{\lambda} \frac{1}{1 + \frac{i}{I_s}} \cdot \frac{1}{I_s}$$

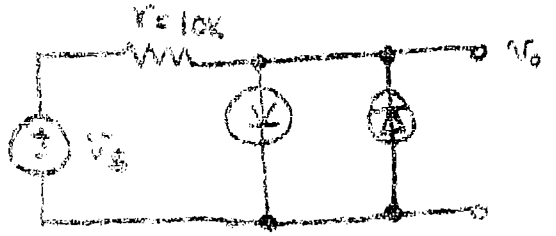
$$r = \frac{1}{\lambda(I_s + i)} \Rightarrow I_s + i = \frac{1}{\lambda r} \quad , \quad i = \frac{1}{\lambda r} - I_s$$

$r = 10$: $\quad i = \dfrac{1}{40 \times 10} - 10^{-15} = \dfrac{1}{400} = \boxed{2.5\ mA}$

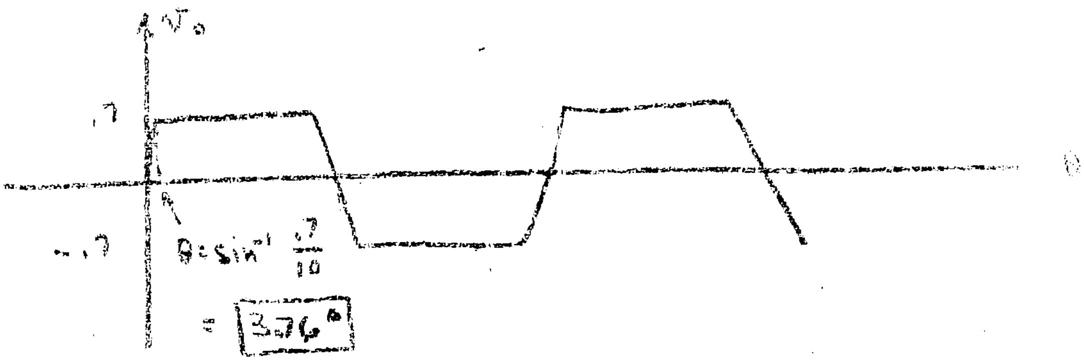
$r = 10^5$: $\quad i = \dfrac{1}{40 \times 10^5} - 10^{-15} = \boxed{.25\ \mu A}$

PROBLEM 210. 8.6. ANGELO

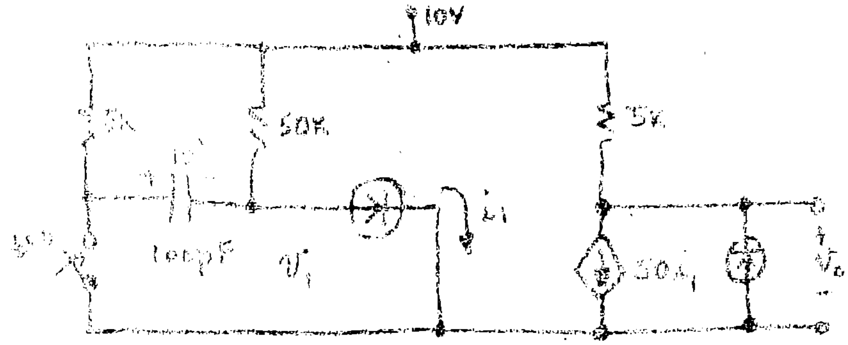
$V_D = .7V$, $V_d = 0$



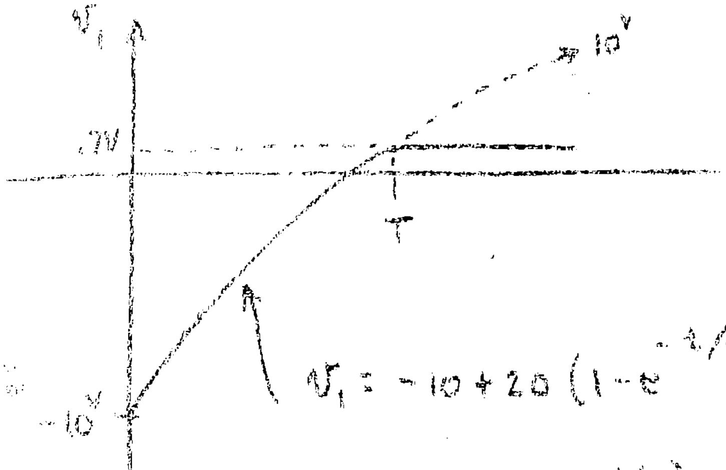
$v_s = 10 \sin \omega t$ V

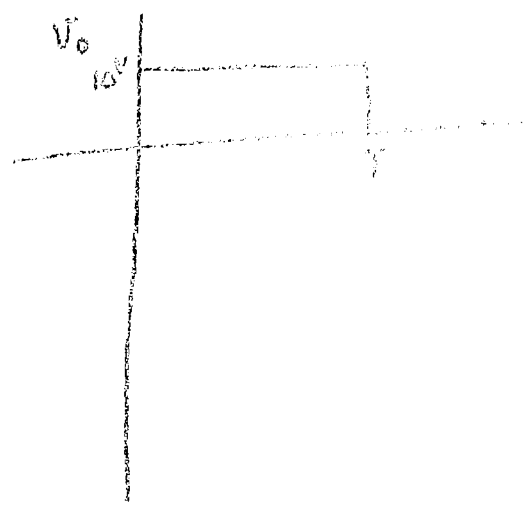


PROBLEM 212, 8.10 - Angelo



$V_o = .7$ for Si diode





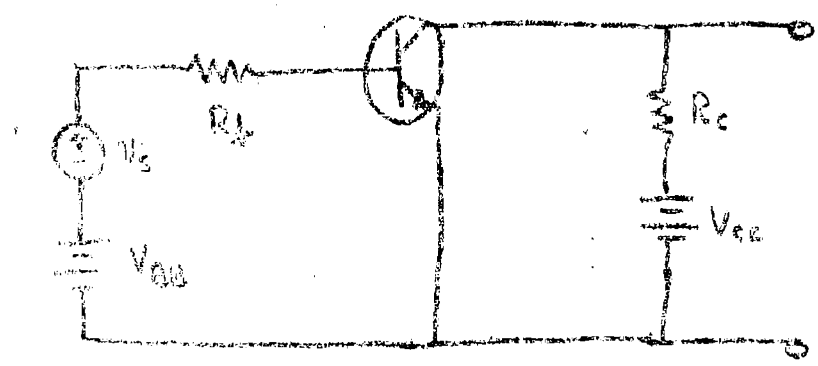
$$v_1 = -10 + 20\left(1 - e^{-t/T}\right)$$

$$.7 + 10 = 20\left(1 - e^{-t/T}\right)$$

$$\frac{10.7}{20} = 1 - e^{-t/T} \qquad e^{-t/T} = \frac{9.3}{20} = .465, \quad \frac{t}{T} = .768$$

$T = .768$

PROBLEM 250.9.1 Angelo



$\beta = 100$

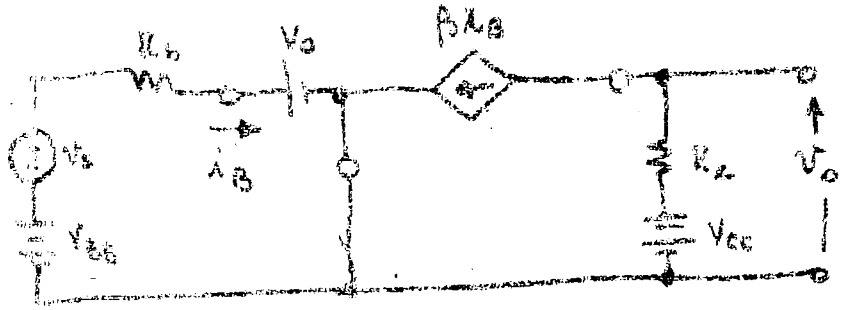
$V_0 = .7V$

$R_b = 100\,k\Omega$

$R_c = 20\,k\Omega$

$V_{BB} = 1.7V$

$V_{CC} = 25V$



(a) $I_B = \frac{1.7 - .7}{.1} = \boxed{10\,\mu A}$ $\quad I_c = 1000\,\mu A = \boxed{1.0\,mA}$

$V_{CE} = 25 - 20 = \boxed{5.0\,V}$

(b) $K_v = \beta \frac{R_c}{R_b} = 100 \cdot \frac{20}{100} = \boxed{20}$

(c) $v_s = .01 \sin \omega t\,V \implies v_o = \boxed{-0.2 \sin \omega t\,V}$

PROBLEM 251.9.3 Angelo

$\beta = 50$ $V_0 = 0.7\,V$ $V_{BB} = 1.7\,V$ $V_{CC} = 25\,V$

(a) $I_C = 2\,mA$ $V_{CE} = 5\,V.$

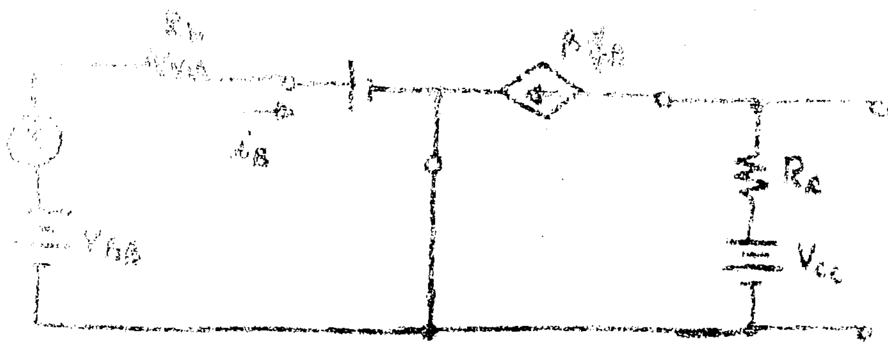
$$R_c = \frac{25-5}{2} = \boxed{10\,k\Omega}$$

$$I_B = \frac{2}{50} = 40\,\mu A \rightarrow R_b = \frac{1}{40} = .025\,M\Omega$$

$$= \boxed{25\,k\Omega}$$

(b) $K_V = 50 \times \frac{10}{25} = \boxed{20}$

PROBLEM 25.44 Angelo



(a) $$K_v = \beta \frac{R_c}{R_b} = \beta \frac{\frac{V_{CC} - V_{CE}}{I_C}}{\frac{V_{BB} - V_o}{I_B}} = \boxed{\frac{V_{CC} - V_{CE}}{V_{BB} - V_o}}$$

(b) $K_v = 15 \quad V_{CC} = 20\,V \quad I_C = 1\,mA \quad V_{CE} = 2\,V$

$$R_c = \frac{20 - 2}{1} = \boxed{18\,K} \qquad 15 = \frac{18}{V_{BB} - V_o} \rightarrow$$

$$V_{BB} - V_o = \frac{18}{15} = 1.2 \longrightarrow V_{BB} = \boxed{1.4\,V}$$

$$\frac{1.2}{R_b} = \frac{1}{\beta} \rightarrow \boxed{R_b = 1.2\,\beta}$$

PROBLEM 252.9.6 AUGELO

$V_{CC} = 20\,V \qquad V_{BB} = 2\,V \qquad \beta = 100 \qquad V_o = 0.7\,V$

$P_c(max) = 360\ mW$

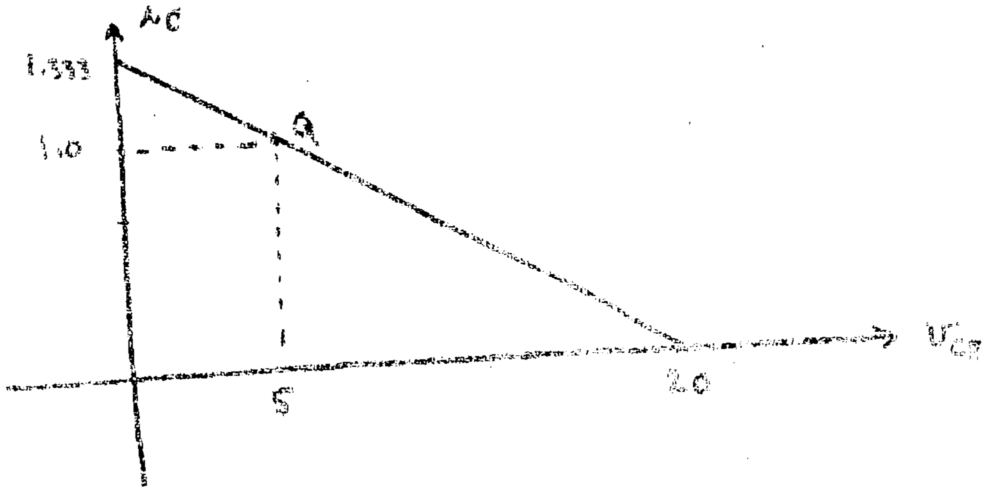
(a) $R_c = \dfrac{20-5}{1} = \boxed{15\,k} \qquad I_B = \dfrac{1}{100} = .01\ mA$

$R_b = \dfrac{2-.7}{.01} = \dfrac{1.3}{.01} = \boxed{130\,k}$

(b) $P_o = V_{CE} \times I_c = 5 \times 1 = \boxed{5.0\ mW}$

(c) $K_v = \beta \dfrac{R_c}{R_B} = 100 \times \dfrac{15}{130} = \boxed{11.6}$ [illegible]

(d)

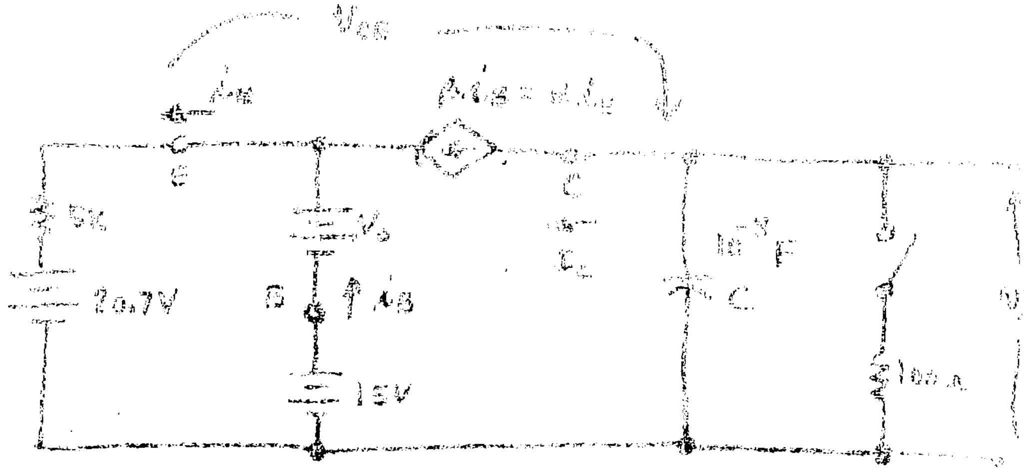


Saturation occurs at $i_c = 1.333\ mA \rightarrow i_B = .01333\ mA$

$\dfrac{V_s + V_{BB} - V_o}{R_b} = .01333\ , \quad V_s = .01333 \times 130 - 2 + .7$

$= 1.735 - 1.3 = \boxed{.435\ V}$ [illegible]

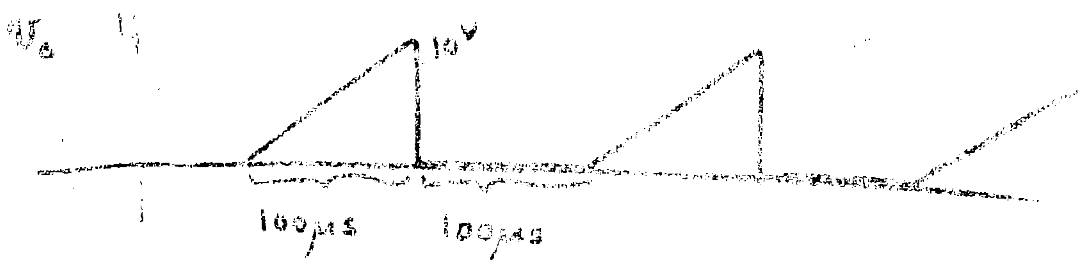
Problem 2.3.9.8 Angelo



SWITCH OPEN

$$i_E = -\frac{20.7 - .7 - 15}{5K} = -1.0\,mA = I_c \qquad V_c = \frac{-\int i_c\,dt}{C}$$

SWITCH CLOSED: C DISCHARGES THROUGH 100 Ω,



Check V_{CE} during time switch open.

$V_{CE} = 5 - 20.7 + V_0 = V_0 - 15.7^V$ which is < 0 all the time.

PROBLEM 2.9.10.1 ANSWERS

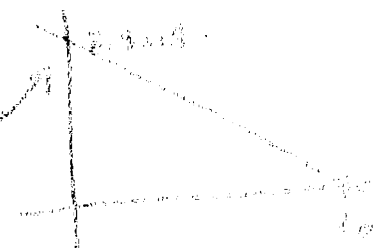
Q-POINT: $I_C = 2.0\,mA$ $\quad V_{CC} = 20V$ $\quad \beta = 50$

$V_{CE} = 4\,V$ $\quad V_B = .7V$ $\quad I_{CBO} = 0$

(a) $$R_C = \frac{V_{CC} - V_{CE}}{I_C} = \frac{20 - 4}{2} = \boxed{8K}$$ $, I_B = \frac{2}{50} = .04\,mA$

$$R_b = \frac{20 - .7}{.04} = \frac{19.3}{.04} = \boxed{483\,k\Omega}$$

(b) $I_B = .04\,mA$ $\quad I_C = 80 \times .04 = 3.2\,mA$



TRANSISTOR SATURATES.

$$\boxed{\begin{array}{l} I_C = 2.5\,mA \\ V_{CE} = 0\,V \end{array}}$$

Problem 300.10.5 Answer

$V_B = 7V$

$I_{CBO} = 0$

$\beta = 60 \rightarrow 300$ (100 typ)

$V_{CC} = 20V$

Q-POINT: $I_C = 2mA$, $V_{CE} = 4V$ for $\beta = 100$

(a) $R_C = \frac{20-4}{2} = \boxed{8\,k\Omega}$ $R_B = \frac{20 - \ldots}{.01}$ [illegible]

(b) $\beta = 60$ $I_C = 60 \times .01 = \boxed{0.6\,mA}$ ←

$V_{CE} = 20 - .6 \times 8 = 20 - 4.8 = \boxed{15.2\,V}$ ← [illegible]

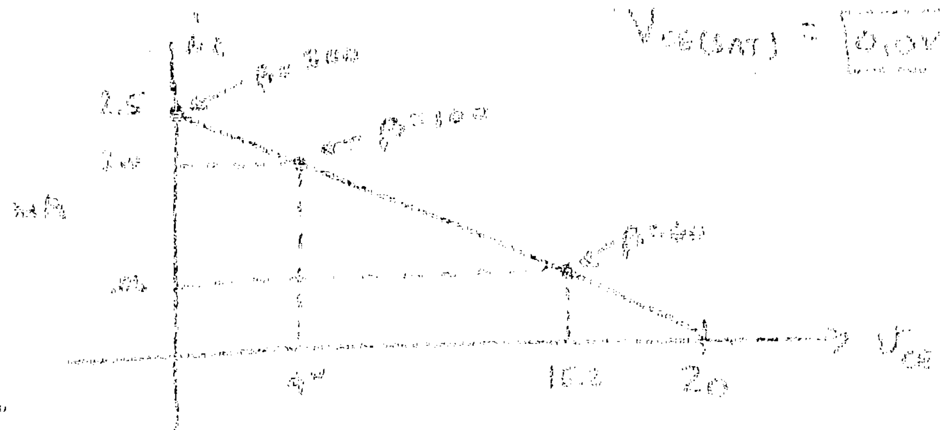
$\beta = 300$ $I_C = 300 \times .01 = 3\,mA$

$V_{CE} = 20 - 3 \times 8 = -4\,V$ ← [illegible]

$I_{C(SAT)} = \frac{20}{8} = \boxed{2.5\,mA}$

$V_{CE(SAT)} = \boxed{0.0V}$

(c)



PROBLEM 301.10.6 ANSWERS

$V_0 = 0.7V \qquad \beta = 60 - 300$

(a) $I_c = \dfrac{\beta(V_{BB} - V_0)}{R_b + (1+\beta)R_e}$

$V_{BB} = \frac{1}{3} \cdot 20 = $ [illegible]

$R_b = \dfrac{30 \times 15}{30 + 15} = $ [illegible]

$\beta = 60$

$I_c = \dfrac{60 \times 5.97}{10 + 61 \times 3} = \dfrac{60 \times 5.97}{193} = \boxed{1.855 mA}$ $V_{CE} =$ [illegible]

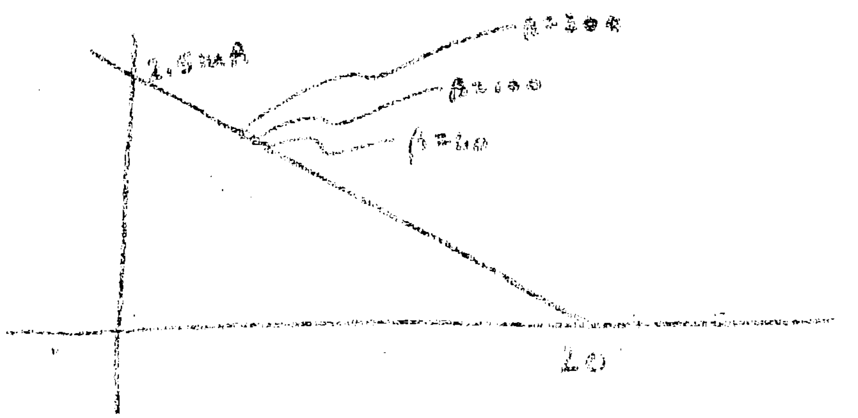
$\beta = 100 \quad I_c = \dfrac{100 \times 5.97}{10 + 101 \times 3} = \boxed{1.91 mA}$ $V_{CE} = 20 -$ [illegible]

313

$\beta = 300 \quad I_c = \dfrac{300 \times 5.97}{10 + 301 \times 3} = \boxed{1.96 mA}$ $V_{CE} = 20 -$ [illegible]

913

(b)



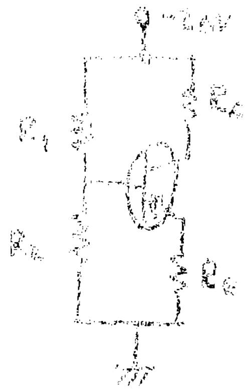
(c) $\lim_{\beta \to \infty} I_c = \dfrac{V_{BB} - V_0}{R_e} = \dfrac{5.97}{3} = \boxed{1.99 mA}$

Problem Solving Answer

$V_{CC} = -20\ V$ $\qquad \beta = 100$ $\qquad V_E = 4\ V$

$V_D = -0.7\ V$

$\left.\begin{matrix} I_C = -1\ mA \\ V_{CE} = -4\ V \end{matrix}\right\}$ Q-point $\qquad S_e = .05$



$R_E = \frac{4}{1} = \boxed{4\ k\Omega}$

$R_C = \frac{20-4-4}{1} = \boxed{12\ k\Omega}$

$$\frac{R_E}{R_b} = \frac{1-S_e}{S_e(1+\beta)-1} = \frac{.95}{.05 \times 101 - 1} = \frac{.95}{4.05}$$

$$R_b = \frac{R_E}{.235} = 17.0\ k$$

$I_B = \frac{1}{100} = .01\ mA$ $\qquad V_{BB} = -(V_{RE} + V_D + I_B R_b)$

$\qquad = -(4 + .7 + .01 \times 17)$

$\qquad = -4.87\ V$

$$\frac{R_2}{R_1+R_2} = \frac{4.87}{20} = .244$$

$.244\, R_1 = 17 \rightarrow R_1 = \boxed{69.6\ k\Omega}$

$\frac{R_2}{69.6+R_2} = .244$ $\qquad R_2 = .244(69.6 + R_2)$

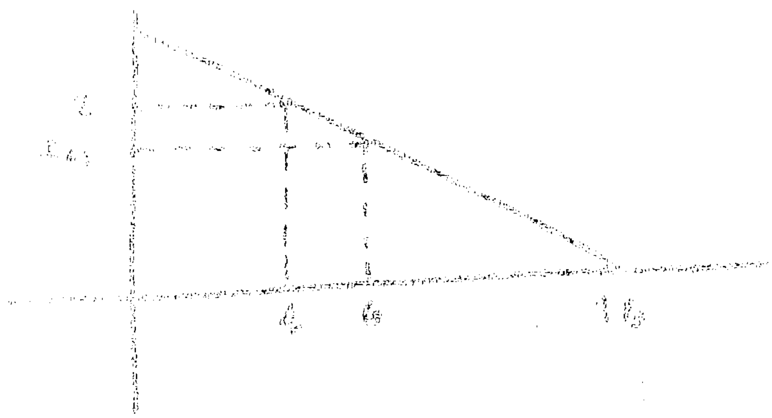
$R_2(1 - .244) = .244 \times 69.6$

$$R_2 = \frac{.244}{.756} \times 69.6 = \boxed{22.5\ k\Omega}$$

Problem 201.50.4 Angelo

$V_{CC} = 16V$ $V_B = .7V$ $\beta = 60 \to 300$

$4V < V_{CE} < 16V$ $I_{C2} = 2\,mA$ for $V_{CE} = 4V$



[illegible]

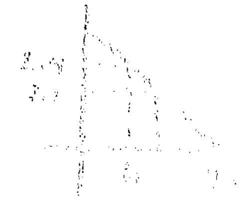
$$S_{\beta 1} = \frac{\frac{I_{C2} - I_{C1}}{I_{C1}}}{\frac{\beta_2 - \beta_1}{\beta_1}} = \frac{\frac{4/3}{1.67}}{\frac{240}{60}} = \frac{\frac{4/3}{10/6}}{4} = [illegible]$$

Sample Problem

Due 5.17.71

$I_{C1} = 2.1\ mA$ $V_o = .6\ V$

$\beta = 40 - 240$ $I_{C2} = 2.4\ mA$ V_{sat} = [illegible]



$V_{CC} = 20V$

$$R_c + R_e = \frac{20-6}{2.4} = \frac{14}{2.4} = 5830\ \Omega$$

$$1.25 R_c = 5830$$

$$R_c = \boxed{4670\ \Omega} \qquad R_e = \boxed{1165\ \Omega}$$

$$S_{e_2} = \frac{\frac{.3}{2.1}}{\frac{200}{40}} = \frac{1}{35} = .0286$$

$$\frac{R_e}{R_b} = \frac{1 - S_{e2}}{S_{e2}(1+\beta_2) - 1} = \frac{.9714}{.0286 \times 241 - 1} = \frac{.9714}{6.9 - 1} = .1645$$

$$R_b = \frac{1165}{.1645} = 7090\ \Omega$$

$$V_{BB} = \frac{2.4}{240}\left[7090 + 241 \times 1165\right] = .01\,(7.07 + 281) = 2.88V$$

$$\frac{R_2}{R_1 + R_2} = \frac{V_{BB}}{V_{CC}} = \frac{2.88}{20} = .144 \qquad .144\,R_1 = 7.09$$

$$R_1 = \boxed{49.2\ K}$$

$$R_2 = .144\,(49.2 + R_2)$$

$$R_2\,(1 - .144) = 49.2 \times .144 \qquad R_2 = \frac{49.2 \times .144}{.856} = \boxed{8.26\ K}$$

(OVER)

$I_C(max)$ occurs for β_2, $V_{CC}(max)$, $V_E(min)$

$$I_{C\,max} = \frac{240(.144 \times 21 - .59)}{7.09 + 241 \times 1.165} = \frac{240 \times 2.43}{288}$$

$$= \boxed{2.025\ mA}$$

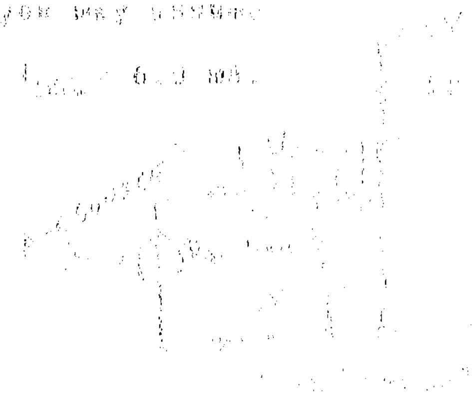
$$I_{C\,min} = \frac{40(.144 \times 18.5 - .72)}{7.09 + 41 \times 1.165} = \frac{40 \times 1.77}{54.9}$$

$$= \boxed{1.29\ mA}$$

[illegible]
[illegible]
[illegible]
May 21 1991

EE 302 - Electronics I
Test No. 2
Closed book - 50 minutes.

1. Shown is an FET amplifier. For this FET you may assume $i_D = I_{DSS}(1 - v_{GS}/V_p)^2$ where $V_p = -2.5V$ and $I_{DSS} = 6.0$ mA. Second order effects may be neglected.



(a) Find I_D and V_{DS}, the quiescent operating point values.

(b) Find v_G.

(c) What instantaneous value of v_s will cause the transistor to be on the threshold of cutoff during one instant of the a-c cycle.

(d) What is the small signal voltage gain of the amplifier, v_o/v_s?

SOLUTION

(a) $V_{GS} = -1^V$ $\quad I_D = 6\left(1 - \frac{1}{2.5}\right)^2 = 6(1-.4)^2 = 6 \times .36$

$= \boxed{2.16\ mA}$ $\quad V_{DS} = 20 - 1.8 \times 2.16$

$= 20 - 3.89$

$= \boxed{16.11\ V}$

(b) $V_G = \boxed{1\ V}$

(c) cutoff is when $i_D = 0$

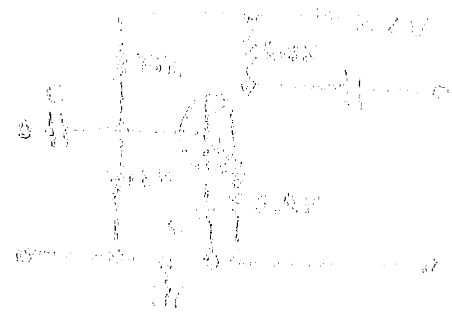
$v_{GS} = -2.5$ is cutoff

$-1 + v_s = -2.5 \quad v_s = \boxed{-1.5\ V}$

(d) $g_m = \frac{\partial i_D}{\partial v_{GS}} = \frac{2 I_{DSS}}{-V_p}\left(1 - \frac{v_{GS}}{V_p}\right) = \frac{2 \times 6}{2.5}\left(1 - \frac{1}{2.5}\right) = \frac{2 \times 6 \times .6}{2.5}$

$= 2.88 \times 10^{-3}\ S \quad K_v = -2.88 \times 1.8 = \boxed{-5.18}$

[illegible]



(a) Find I_C.

(b) Find V_{CE}.

(c) n the ratio of V_{BB}/V_0.

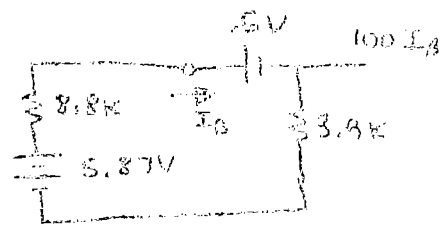
(d) S_e.

SOLUTION:

(a) $V_{BB} = \frac{12}{45} \times 22 = 5.87V$

$R_b = \frac{12 \times 33}{45} = 8.8 k\Omega$

base circuit



$5.87 - 8.8 I_B - .6 - 101 \times 3.9 I_B$

$5.87 - 0.6 = (8.8 + 101 \times 3.9) I_B$

$I_B = \frac{5.27}{403}$

$= 13.1 \mu A$

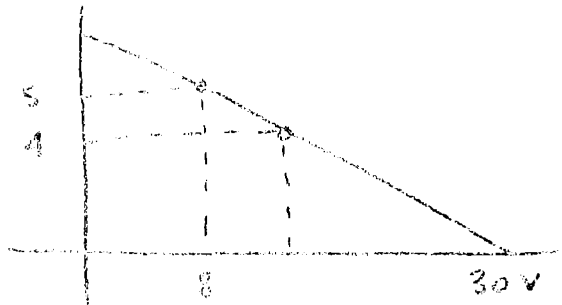
$I_c = 100 \times 13.11 = \boxed{1.31 mA}$

$V_{CE} = 22 - 10.7 \times 1.31 = 22 - 14 = \boxed{8 V}$

(c) $n = \frac{5.87}{.6} = \boxed{9.79}$

(d) $S_e = \frac{R_b + R_e}{R_b + (1+\beta)R_e} = \frac{8.8 + 3.9}{8.8 + 394} = \frac{12.7}{403} = \boxed{.0315}$

A transistor amplifier is being designed with [illegible] stabilizing the [illegible] operating point with respect to variations in β. The beta spread is known to be 70-200, and V_{BE} is 0.7V. If the dc supply voltage is 30V, select values of R_1, R_2, R_e, and R_c such that I_C is guaranteed to lie between 4 and 5 mA and V_{CE} is 8V when I_C = 5 mA.



$$R_c + R_e = \frac{22}{5} = 4.4\ k\Omega$$

$$1.25 R_c = 4.4$$

$$R_c = \boxed{3.52\ k\Omega}$$

$$R_e = \boxed{880\ \Omega}$$

$$S_{\beta 2} = \frac{\frac{1}{4}}{\frac{130}{70}} = \frac{70}{520} = \boxed{.135}$$

$$S_{\beta 2} = \frac{1 + \frac{R_e}{R_b}}{1 + (1+\beta_2)\frac{R_e}{R_b}} \qquad .135 = \frac{1 + x}{1 + 201x} \qquad .135(1 + 201x) = 1 + x$$

$$.135 - 1 = x - .135(201x)$$

$$x = \frac{.865}{26} = .0332 = \frac{R_e}{R_b} \qquad R_b = \frac{880}{.0332} = 26.5\ k\Omega$$

$$\frac{R_2}{R_1 + R_2} = \frac{V_{BB}}{V_{CC}} \qquad 5 = \frac{200(V_{BB} - .7)}{\underbrace{26.5 + 201 \times .88}_{203}} \qquad V_{BB} = \frac{5 \times 203}{200} + .7 = 5.77\ V$$

$$\frac{R_2}{R_1 + R_2} = \frac{5.77}{30} = .192 \qquad .192 R_1 = 26.5$$

$$R_1 = \boxed{138\ k\Omega}$$

$$\frac{R_2}{138 + R_2} = .192 \rightarrow R_2 = .192(138 + R_2)$$

$$R_2(1 - .192) = 26.5$$

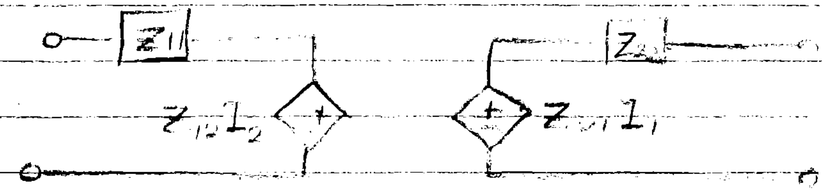
$$R_2 = \frac{26.5}{.808} = \boxed{32.8\ k\Omega}$$

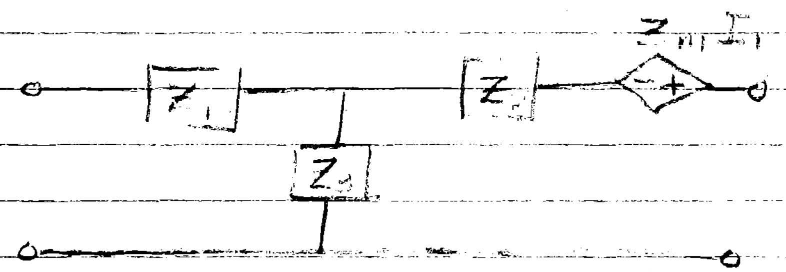
EE LAB

3-22-72 (WED)

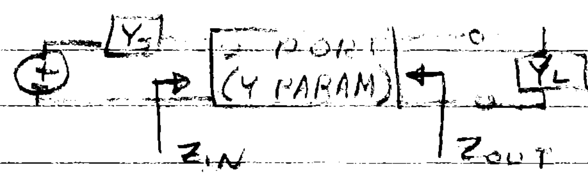
YZØRZY (Y11, Y12, Y21, Y22, Z11, Z12, Z21, Z22)

INPUT — RETURNED





AMPROP



2-29-72 (WED)

COMPLEX FUNCTION POL (Z)

POLAR2 (N, Z1, Z2, ..., ZN)

OUR FORDE IS PURDUE'S FØRKYU

#41031 STUDENT, T10, P10, CM 45000.

MAP(PART)

FUN(S)

PFILES(GET, EE215)

REWIND(EE215)

FUN(G,,,EE215)

7/8/9

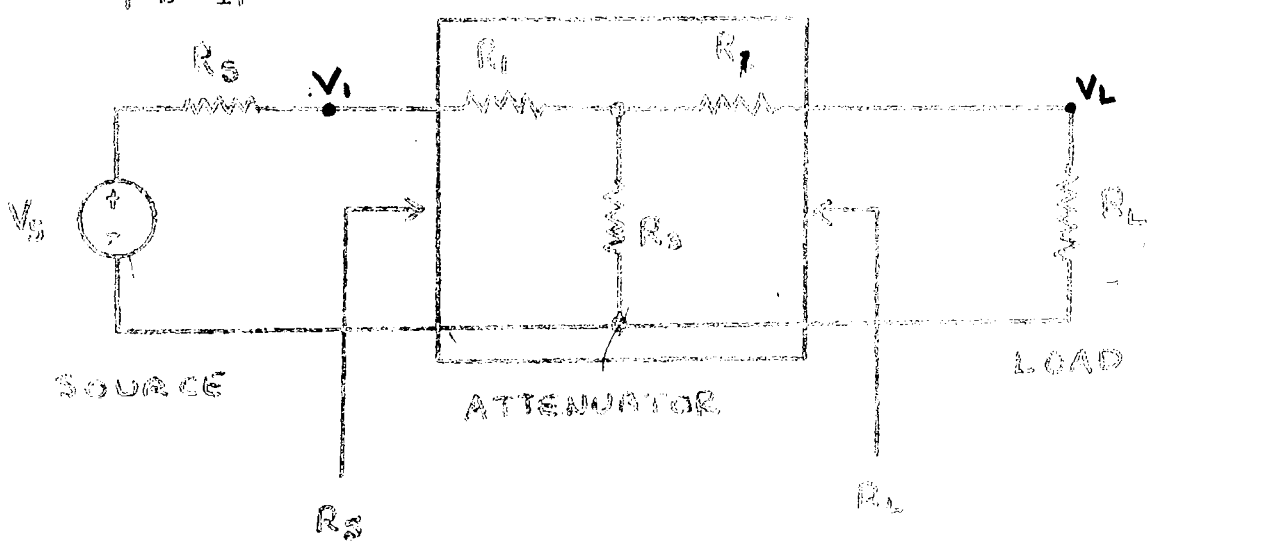
Electrical Engineering Department
Rose-Hulman Institute of Technology
Terre Haute, Indiana
March 15, 1972

EE215
First computer assignment
Due Thursday, March 23, 1972

DESIGN OF A "T" ATTENUATOR (FORTRAN)

The purpose of this computer program is to design a "T" type attenuator circuit. Given R_s and R_L and $|V_2/V_1|$, the computer will calculate values of R_1, R_2, and R_3. (For this problem we will assume That $R_L = R_s$, thus making $R_1 = R_2$.)

Write the program in FORTRAN to run on the IBM 1130. You will read in a card with R_s, R_L and $|V_2/V_1|$ on it and the computer will then print out R_1, R_2, and R_3.
$|V_2/V_1|$ is between 0 and one noninclusive.



The load should see its resistance of R_L and the source should see a resistance of R_s. Thus both are "matched" to their respective resistances.
Test your program by putting in $R_L = R_s = 50$ Ohms and V_2/V_1
.0001, .001, .1, ~~x~~ .3, .707, .95, .9999.

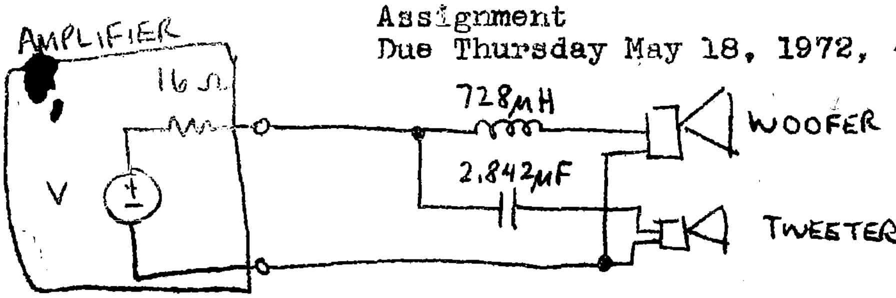
Prepare a convolution program which will convolve two functions that are stored as arrays of [illegible] values. You are to assume that the sampling increments are equal for the two arrays and the sampling is uniform. Use the stored integration subroutine INTEG, which is explained on another handout. Assume the sampling increment is 0.1 second and that both functions are time [illegible].
F1 is of 2 seconds duration and begins at t = [illegible]
F2 is of 3 seconds duration and begins at t [illegible]

Plot both functions and $f_1 * f_2$ on the same graph paper.

The arrays for f_1 and f_2 may be gotten by calling subroutine GSJD/ARRAY (A, NA, B, NB) where A and B are the arrays and NA and NB are the number of points in each, respectively.

Electrical Engineering Department
Rose-Hulman Institute of Technology
Terre Haute, Indiana
May 4, 1972

EE215
Assignment
Due Thursday May 18, 1972, 4:00 PM FIRM.

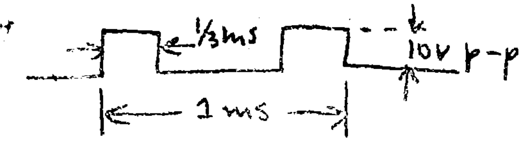


Let us analyze the hi-fi speaker system shown to see if it truly reproduces the sound put into it. Assume that the audible sound out of each speaker is Ki, where i is the current through the speaker. Assume that each speaker has an impedance of 16 + j 0 Ohms at all frequencies. (A rather radical, but simplifying assumption.) For each signal from the amplifier compute and plot the combined sound from both speakers on a sheet of graph paper on which is also plotted the original function. Assume that the ear successfully performs a non-weighted addition of the sound output of the two speakers. Our assumtion as that the waveform we're interested in are all non-sinusoidal, periodic functions of time.

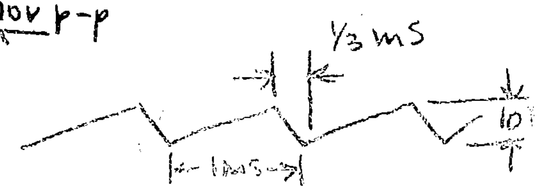
Three waveforms are to be analyzed. They are:

no d-c component

(i)



(b)



(c) A 1000 Hz waveform from any musical instrument from the following list.

piano (sustained note), clarinet, violin, oboe, flute, accordion, saxophone, human female voice (soprano)

Electrical Engineering Department
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SUBRØUTINE FØRDE computes Fourier series coefficients for a periodic function of time defined by an array of sampled values. Usage is as follows:

CALL FØRDE(F,NF,TDEL,START,PERØD,WØ,A,B,NW,DC)

where F is the array of points defining the function in the time domain; NF is the number of values in the array NF; TDEL is the sampling increment in the time domain; START is the time corresponding to the first point in F; PERØD is the period of the function described by F; WØ is returned and is 2π/PERØD; A and B are arrays of [redacted]sine and cosine coefficients respectively. NW is the number of coefficients you want computed; and DC is the zero frequency or "d-c value" of the Fourier series. A and B must be dimensioned at least NW. Presently NW $\leq$ 200. The method used is brute force.

JHD
4.12.72

Electrical Engineering Department
Rose-Hulman Institute of Technology
Terre Haute, Indiana

SUBRØUTINE INTEG finds the area under a curve defined by an array of sample values. Usage is as follows:

CALL INTEG(FUNC,N,AREA,XINC)

where FUNC is the array of points defining the curve in question, N is the number of values in array FUNC, AREA is the area found, and XINC is the sampling increment on the abscissa axis. The method used is Simpson's one-third rule.

JHD
4.12.72

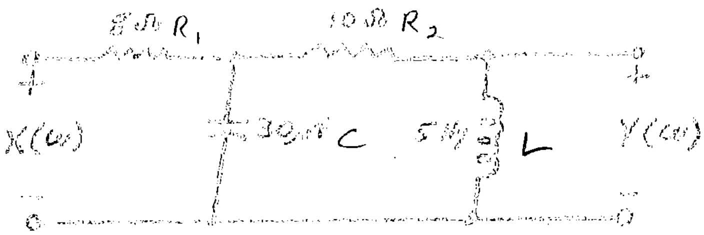
Graph input & output signals

EE 215
Assignment

SYSTEM ANALYSIS IN THE FREQUENCY DOMAIN

PURPOSE: To pass a signal through a system by performing the transform of convolution in the frequency domain. In the frequency domain, convolution is replaced by multiplication.

PROBLEM: Given the same function you used in the Fourier series assignment, let it be your time-limited signal. Obtain the Fourier transform of this signal. Then obtain the Fourier transform of the impulse response of the system. This is called the system function. Then obtain the Fourier transform of the output signal $Y(\omega)$ by multiplication. The system is shown below.



USE OF SUBROUTINE DEFØR:

A subroutine named DEFØR is available on the IBM 1130 which computes $Re\{F(\omega)\}$ and $Im\{F(\omega)\}$ in the form of arrays. Its usage is as follows.

```
CALL DEFOR (F,NF,TI,R,X,NW,BW,WDEL,TDEL)
```

where

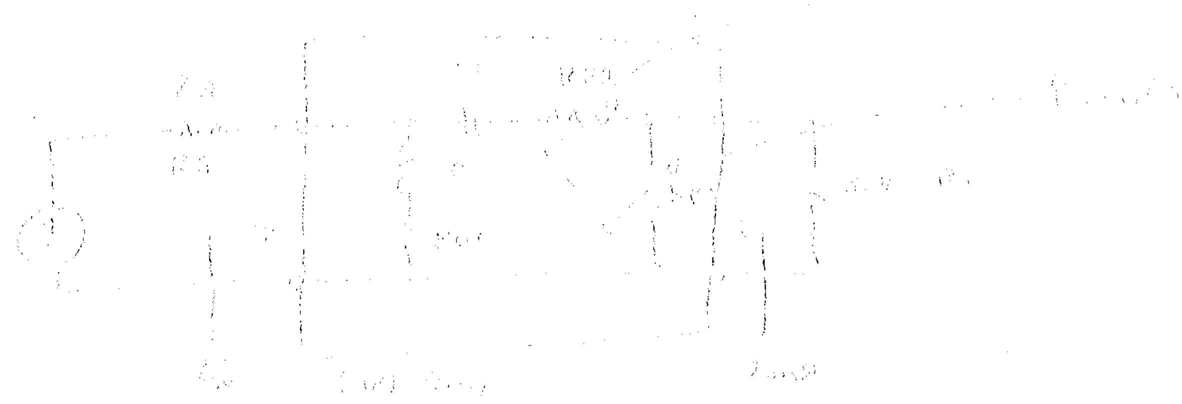
F is the array defining the function to be transformed
NF is the number of sample values in the array NF
TI is the time when the time function begins
R, X are the returned arrays of $Re\{F(\omega)\}$ and $Im\{F(\omega)\}$ respectively.
NW is the number of values computed in the R and X arrays
BW is the bandwidth in rad/sec over which you want the Fourier transform computed.
WDEL, TDEL are the sampling increment in the frequency and time domain respectively.

At the present time NF is limited to a value of 201.

$$F(\omega) = R(\omega) + j\,X(\omega)$$

Obtain $y(t)$ from $Y(\omega)$.

WRITE



[illegible]

[illegible]

What are the [illegible] input [illegible] amplification [illegible] output impedance [illegible] as a function of [illegible] frequency [illegible]

Program

```
PROGRAM MAIN(INPUT, OUTPUT)
COMPLEX [illegible]
REAL [illegible]
DATA [illegible]
[illegible]
Y1 = 1.0/[illegible]
[illegible]
[illegible]
```

HANDOUT [illegible]4507

Prepare a computation program which will Convolve two functions that are stored as arrays of N values. You are to assume that the sampling increments are equal for the two arrays and the sampling is uniform. Use the stored integration subroutine INTEG, which is explained on another handout. Assume the sampling increment is 0.1 second and that both functions are time-limited.

F1 is of 2 seconds duration and begins at t = 1.0.

F2 is of 3 seconds duration and begins at t = [illegible]

Plot both functions and $f_1 * f_2$ on the same graph paper.

CALL INTEG(FUNC, N, AREA, XINC)

→ARRAY →VALUES →AREA →INCR.

The arrays for f_1 and f_2 may be given by calling subroutine GSJD1 (A, NA, B, NB) where A and B are the arrays and [illegible] points in each respectively.

Rose-Hulman Institute of Technology
Terre Haute, Indiana

ES215 A & B
Convolution Computer Program

Given two functions stored in the subroutine library of the IBM 1130, you are to develop a computer program which will convolve these two functions.

The functions are

FUN1(T)

and FUN2(T)

where

FUN1(T) = 0.0 for T<0.0 & T>2.0

FUN2(T) = 0.0 for T<0.0 & T>3.0.

Use 25 points in a "Trapezoidal" integration scheme to obtain the desired result. Your program need only output the result of the convolution but for your own peace of mind you may wish to tabulate the functions.

Make your program general enough that different functions, limits, and numbers of   points may be easily run.

PØLAR

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE PØLAR(RECT,PØLMAG,ANGLE)

Inputs:

RECT - A complex FORTRAN variable

Computed values:

PØLMAG - the magnitude of RECT

ANGLE - the angle of RECT

This subroutine converts a complex number from rectangular to polar form.

JHD
10.4.71

AMPRØP

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subroutine

```
SUBRØUTINE AMPRØP(Y11,Y12,Y21,Y22,YL,YS,ZIN,ZØUT,
                  AV,AI,AP,APA,API,APT)
```

Inputs:

Y11,Y12,Y21,Y22, the network y-parameters	)	
	)	Complex
YL,YS - source and load admittances	)	

Computed values:

ZIN,ZØUT, the input and output impedances	)	
	)	Complex
AV,AI, voltage gain and current gain	)	

AP	Power gain	)	
APA	Available power gain	)	
		)	Real
API	Insertion power gain	)	
APT	Transducer power gain	)	

This subroutine computes important properties of an amplifier (two-port) given the y-parameters.

JHD
10.4.71

YZØRZY

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE YZØRZY(A11,A12,A21,A22,B11,B12,B21,B22)

Inputs: A11,A12,A21,A22 - Y or Z parameters (complex)

Computed values:

B11,B12,B21,B22 - Z or Y parameters (complex)

This subroutine converts from y-parameters to z-parameters or vice-versa.

JHD
10.4.71

ZTØZT

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE ZTØZT(Z11,Z12,Z21,Z22,Z1,Z2,Z3,ZM)

Inputs: Z11,Z12,Z21,Z22 (Complex)

Computed values: Z1,Z2,Z3,ZM (Complex)

This subroutine gives the elements in the T form of the z-parameter two-port network.

JHD
10.4.71

Electrical Engineering Department
Rose-Hulman Institute of Technology
Terre Haute, Indiana
March 15, 1972

EE-215

Notes on Computer Assignments.

Feel free to hand in your computer assignments ahead of time. When you've begun obtaining output you may check with the instructor to see if your results are correct. Use as many significant figures as is required for the problem.

Hand in all programs still accordion-folded as they come from the computer center. Always include banner page and day file on CDC6500 jobs. If you do not own a computer center manual, obtain one for the course. They are available in the Bookstore for $1.00. Any material you're handing in with your programs should be slipped inside of the folded computer output. <u>Be sure to put your name on the front of your output</u>.

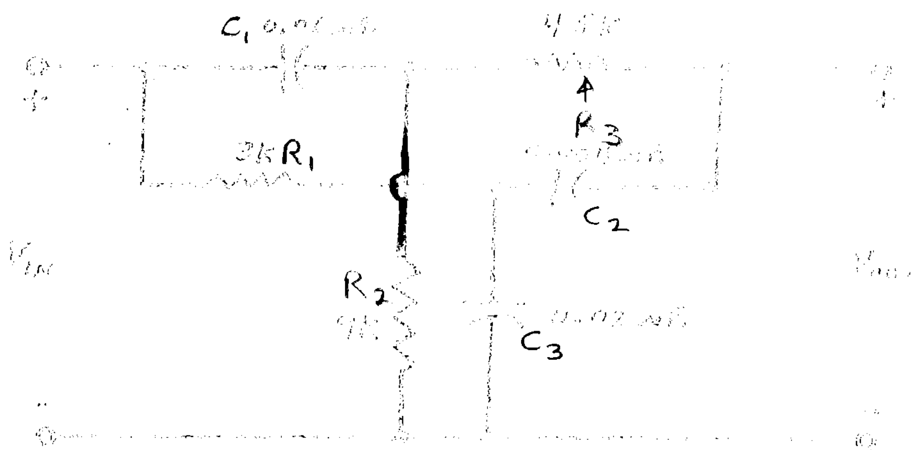
[illegible]
[illegible]

[illegible]

The objective of this assignment is the design of a FORTRAN program which will [illegible] the frequency response of the [illegible] network shown below utilizing [illegible] subroutines. These subroutines are presently available [illegible] on the [illegible] system. The subroutines to be used in the program are:

[illegible]
[illegible]
[illegible]
[illegible]
[illegible].

Program sheets describing the subroutines are available from the [illegible] section.



The desired output should consist of the voltage gain and input and output impedances (in polar form) for enough points between 500 Hz and 50 KHz to allow smooth curves to be plotted. You are to give the output on ~~[illegible]~~ logarithmic ~~paper~~: $|A_V|$, $|Z_{IN}|$ $|Z_{OUT}|$ vs f (LOG-LOG) and $\angle A_V$, $\angle Z_{IN}$, Z_{OUT} (SEMI-LOG)

The [illegible] must be of the following form

```
$JOB          Name
[illegible],STUDENT,P10,T10,[illegible].
RUN(S)
[illegible]
LGO.
7/8/9
....FORTRAN Program....
7/8/9
....Data....
6/7/8/9
```

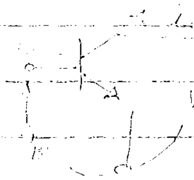
9-13-71 [illegible]

READ pp. [illegible]-228 PROB. 10-13; USE h-PARAMETER MODEL

[illegible] 11, 3 EXAMS

NOTES:

SIGNAL FLOW G[illegible] [illegible]



$v_{BE} = f_1(i_B, v_{CE})$

$i_C = f_2(i_B, v_{CE})$

$dv_{BE} = [illegible]$

$di_C = [illegible]$

INCREMENTALS: $\Delta v_{BE} = h_{ie}\,\Delta i_B + h_{re}\,\Delta v_{CE}$

$\Delta i_C = h_{fe}\,\Delta i_B + h_{oe}\,\Delta v_{CE}$

NOW [illegible]

[illegible] SMALL [illegible]

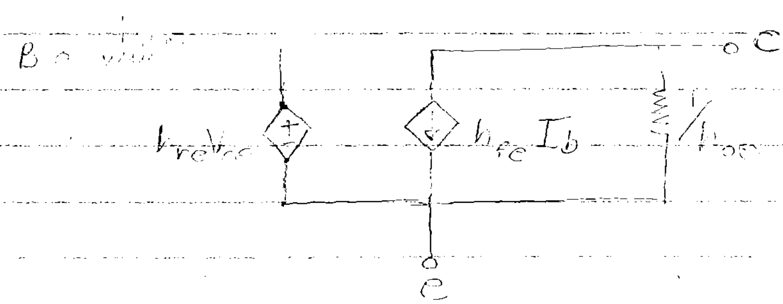
$v_{be} = h_{ie}\, i_b + h_{re}\, v_{ce}$

[illegible]

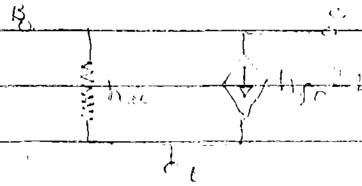
OR $V_{be} = h_{ie}\, I_b + h_{re}\, V_{ce}$ [illegible]

$I_c = h_{fe}\, I_b + h_{oe}\, V_{ce}$

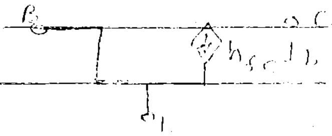
h PARAMETER MODEL ([illegible] SMALL SIGNAL)



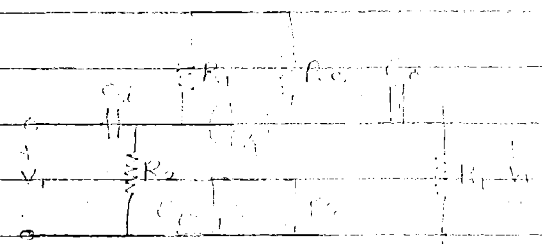
9-14-71

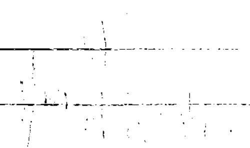
1) 

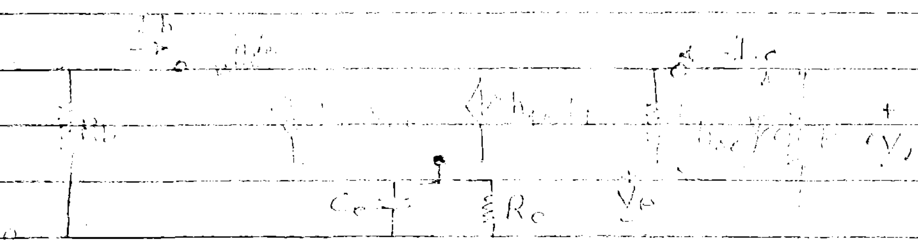
$h_{re} = h_{oe} = 0$

2) 

$h_{ie} = 0$







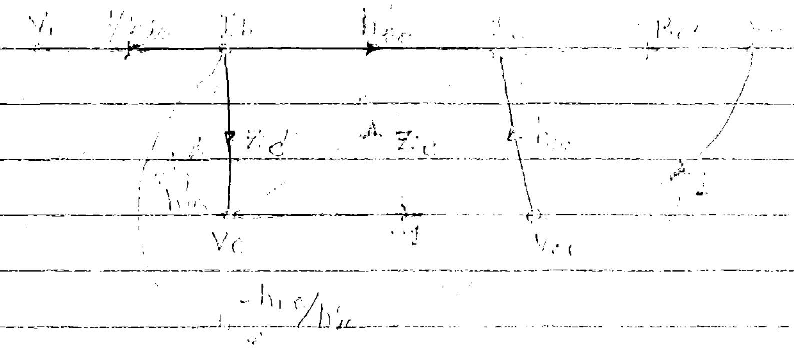
$V_2 = -R_{cL} I_c$

$I_c = h_{fe} I_b + h_{oe} V_{ce}$

$V_{ce} = V_2 - V_e$

$V_e = Z_e (I_b + I_c)$

$I_b = \frac{1}{h_{ie}} (V_1 - h_{re} V_{ce} - V_e)$

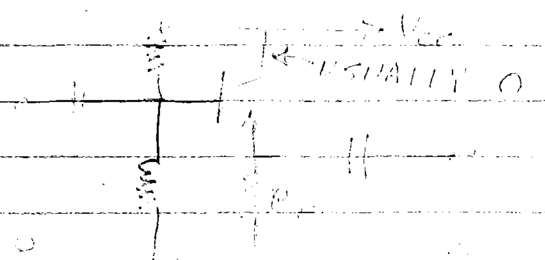


3-20-14

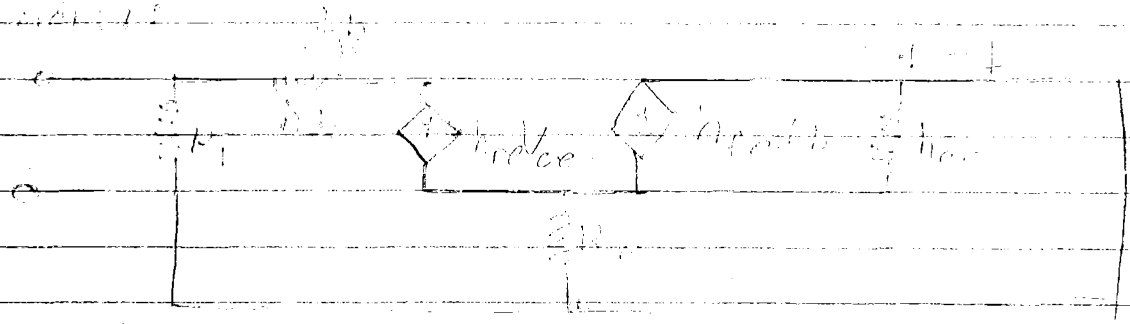
[illegible]

AND [illegible]

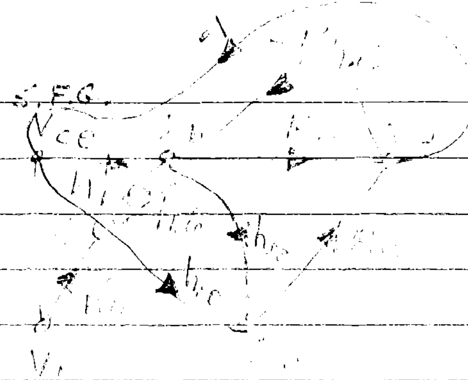
[illegible]



[illegible]



COMMON [illegible]



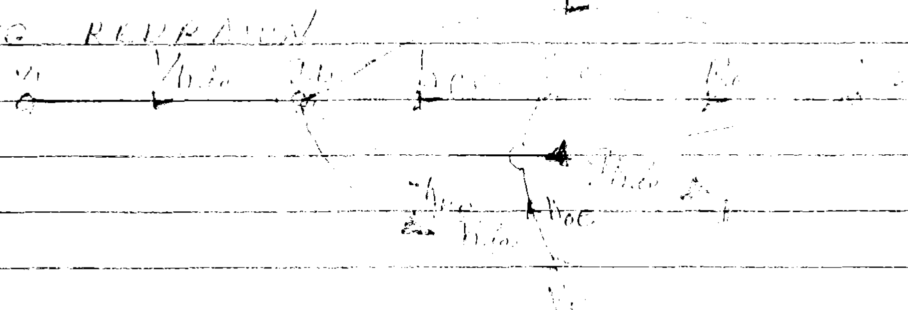
$V_1 = $ [illegible]

$I_b = \frac{1}{h_{ie}}($ [illegible] $)$

$I_c = h_{fe} I_b + V_{ce} h_{oe}$

$V_{ce} = -V_2$

SEC. REDRAWN [illegible]



$\Delta = 1 + h_{oe}R_e +$ [illegible] $h_{fe}R_e$ [illegible] $h_{fe}R_e$ [illegible]

$G_1 = \frac{h_{fe}R_e}{h_{ie}}$ [illegible]

$G_2 = \frac{R_e}{h_{ie}}$; $\Delta_2 = 1$

$A_V = $ [illegible] $(1+h_{oe})R_e$ [illegible] $h_{fe}R_e(1+h_{fe})$

$\approx$ [illegible] $(1+h_{fe})R_e$ [illegible]

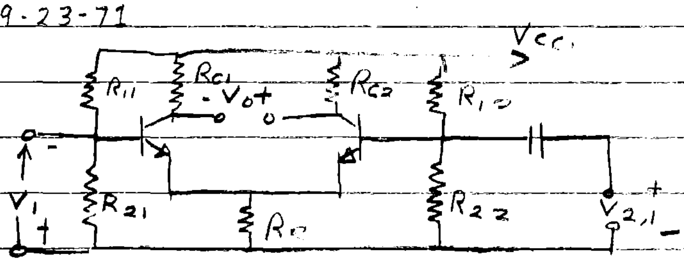
$= (1+h_{fe})R_e / (h_{ie} + (1+h_{fe})R_e)$

≈ 1

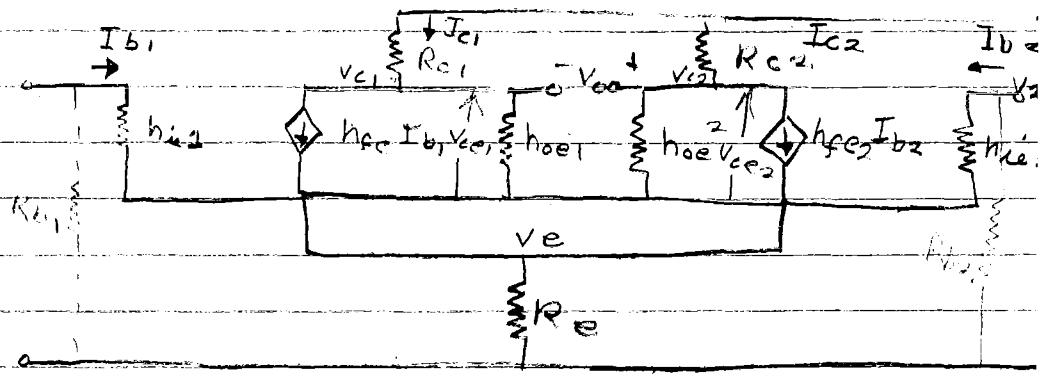
ASSUME HARD [illegible]

$Z_{in} = $ [illegible]

9-23-71



MODEL
$\Rightarrow h_{re}=0;$



$V_o = V_{c2} - V_{c1}$

$V_{c1} = -R_{c1} I_{c1}$

$V_{c2} = -R_{c2} I_{c2}$

$I_{c1} = h_{fe1} I_{b1} + h_{oe1} V_{ce1}$

$I_{c2} = h_{fe2} I_{b2} + h_{oe2} V_{ce2}$

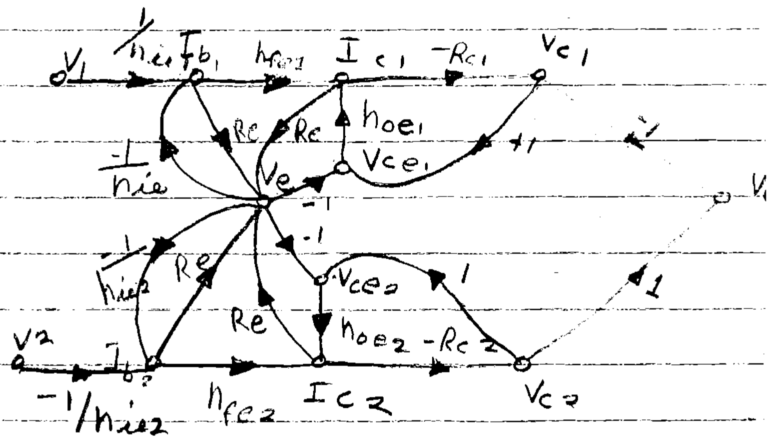
$V_{ce1} = V_{c1} - V_e$

$V_{ce2} = V_{c2} - V_e$

$V_e = R_e (I_{b1} + I_{b2} + I_{c1} + I_{c2})$

$I_{b1} = V_1 - V_e / h_{ie1}$

$I_{b2} = V_2 - V_e / h_{ie2}$



$$\Delta = 1 + \frac{R_e}{h_{ie1}} + \frac{h_{fe1} R_e}{h_{ie1}} + h_{oe1} R_e + h_{oe1} R_{c1}$$
$$+ \frac{R_e}{h_{ie2}} + \frac{h_{fe2} R_e}{h_{ie2}} + h_{oe2} R_e + h_{oe2} R_{c2}$$
$$+ {}^{-}h_{oe1} R_{c1} \left(\frac{-R_e}{h_{ie1}} - \frac{R_e}{h_{ie2}} - \frac{h_{fe2} R_e}{h_{ie2}} - h_{oe2} R_e \; h_{oe2} R_{c2} \right)$$
$$+ {}^{-}h_{oe2} R_e (\cdot h_{oe2} R_{c2})$$
$$+ \left(\frac{-h_{fe1} R_e}{h_{ie1}} \right) (-h_{oe2} R_{c2})$$
$$- \frac{R_e}{h_{ie1}} (-h_{oe2} R_{c2}) - \frac{R_e}{h_{ie2}} (-h_{oe2} R_{c2})$$
$$- \left[{}^{-}h_{oe} R_{c1} \left(\frac{-R_e}{h_{ie1}} \right) (-h_{oe2}) + (-h_{oe1} R_{c1}) \left(\frac{-R_e}{h_{ie2}} \right) (-h_{oe2} R_{c2}) \right]$$

$\frac{V_o}{V_1}$

$G_1 = h_{fe} R_{c1} / h_{ie1}$

$\Delta_1 = 1 + \frac{R_e}{h_{ie2}} + \frac{h_{fe} R_e}{h_{ie2}} + h_{oe2}(R_{c2} + R_e) + \frac{R_e}{h_{ie2}}(+ h_{oe2} R_{c2})$

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3-8

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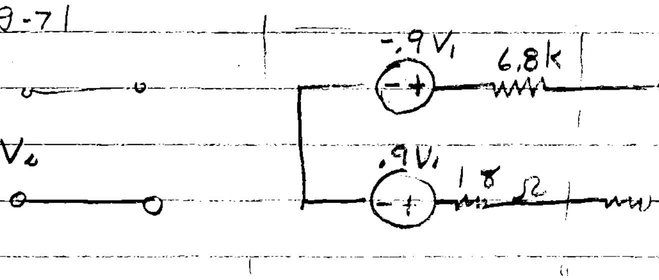
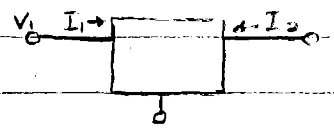
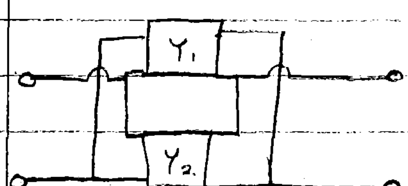


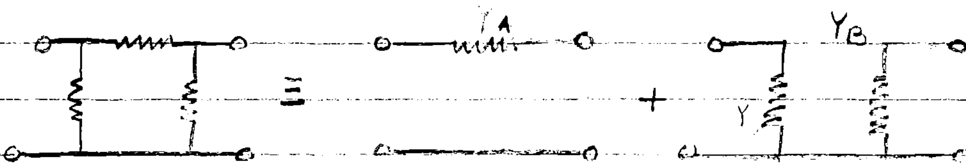


IN PARRALEL



$[Y_{eq}] = [Y_1] + [Y_2]$

EX:

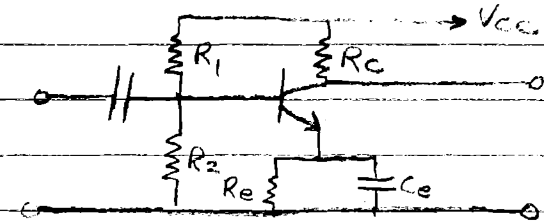


$Y_{eq} = Y_a + Y_b$

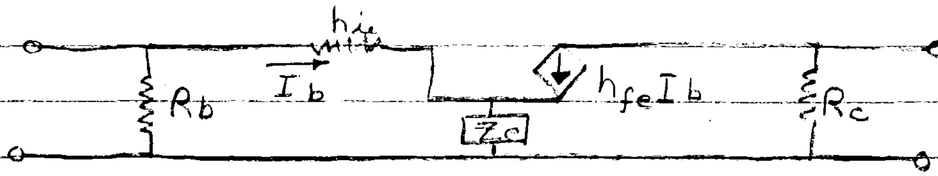
$$= \begin{bmatrix} Y_1 & -Y_1 \\ -Y_1 & Y_1 \end{bmatrix} + \begin{bmatrix} Y_2 & 0 \\ 0 & Y_3 \end{bmatrix} = \begin{bmatrix} Y_1 + Y_2 & -Y_1 \\ -Y & Y_1 + Y_3 \end{bmatrix}$$

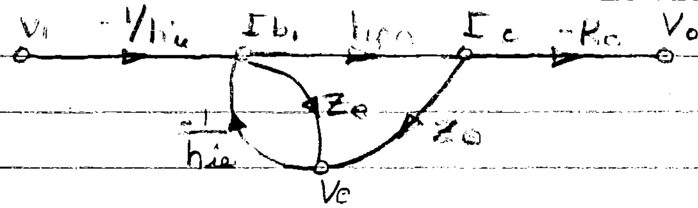
MAY ADD Z MATRICES FOR TWO TWO PORT NETWORKS IN SERIES

TRANSISTOR AMP (LOW FREQUENCY RESPONSE)



LET $h_{re} = h_{oe} = 0$





$$\frac{V_o}{V_i} = \frac{-h_{fe}R_c}{h_{ie}+(1+h_{fe})Z_e}$$

$$Z_e = R_e \| X_e = R_e/(1+j\,\omega/\omega_e) \ni \omega_e = \frac{1}{R_eC_e}$$

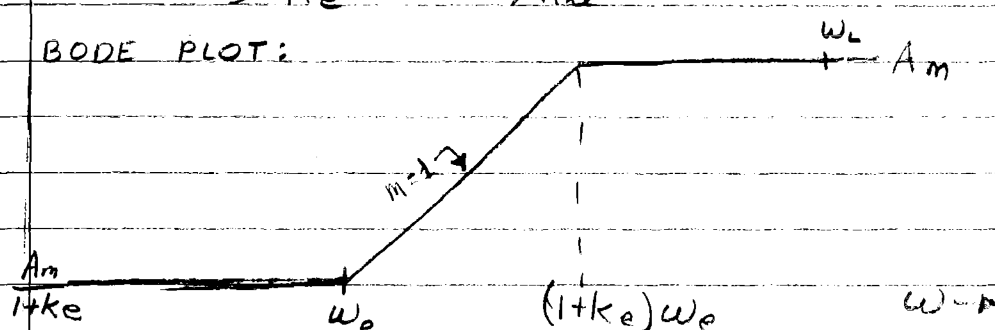
DEFINE A_m = MID FREQ GAIN $\ni Z_e = 0$

$$A_m = \frac{-h_{fe}R_c}{h_{ie}}$$

$$\therefore A_v = \frac{A_m}{1+\frac{h_{fe}}{h_{ie}}R_e\frac{1}{1+j\omega/\omega_e}} = \frac{A_m}{1+k_e}\;\frac{1+j\,\omega/\omega_e}{1+j\,\omega/[(1+k_e)\omega_e]}$$

$$\ni k_e = 1+h_{fe}/h_{ie}$$

BODE PLOT:



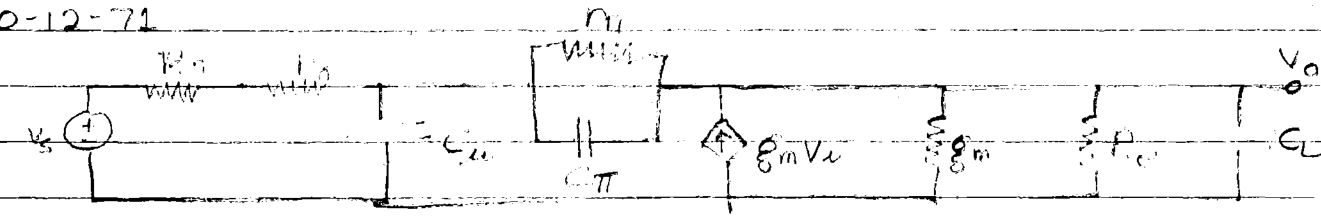
LOW FREQ. DESIGN

WANT AMP. "FLAT" TO ω_L

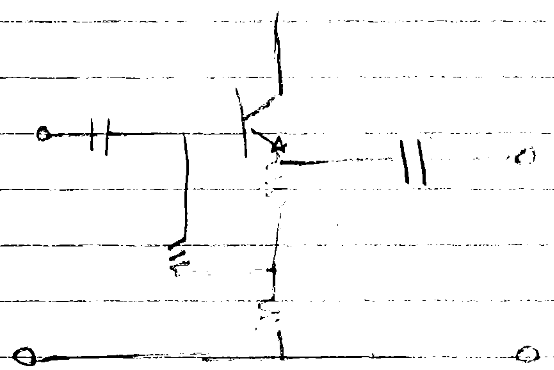
"FLAT" $\Rightarrow \omega_L = 10(1+K_e)\omega_e = \frac{10(1+K_e)}{R_e C_e}$

$\therefore C_e = \frac{10(1+K_e)}{R_e 2\pi f_L} \sim \frac{2 h_{fe}}{h_{ie} f_L}$

10-12-71



EMITTER FOLLOWER



FROM MODEL, NODE EQUATION YIELDS:

$V_o[g_\pi + g_m + G_o + j\omega(C_\pi + C_L)] = V_i(g_\pi + j\omega C_\pi) + g_m V_i$

$\Rightarrow \frac{V_o}{V_i} = \frac{g_m + g_\pi + j\omega C_\pi}{g_\pi + g_m + G_o + j\omega(C_\pi + C_L)} \cong \frac{g_m + j\omega C_\pi}{g_m + G_o + j\omega(C_\pi + C_L)}$

NEED V_i AS FUNCTION OF V_s

IN THE USEFUL RANGE OF FREQ. THE INPUT IMPEDANCE OF E.F. (S.F.) IS MUCH HIGHER THAN $R_s + R_x$

$$V_i \doteq V_s$$

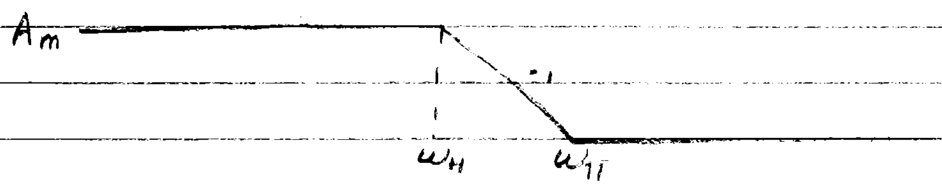
$$\frac{V_o}{V_s} = \frac{g_m}{g_m + G_L} \cdot \frac{1 + j\omega C_\pi / g_m}{1 + j\omega (C_\pi + C_L)/(g_m + G_L)}$$

$$= A_m \frac{1 + j\,\omega/\omega_\pi}{1 + j\,\omega/\omega_H}$$

$$\omega_\pi = g_m / C_\pi \doteq \omega_T$$

$$\omega_H = \frac{g_m + G_L}{C_\pi + C_L} = \frac{g_m}{C_\pi} \cdot \frac{1 + G_L/g_m}{1 + C_L/C_\pi} \doteq \frac{\omega_T}{1 + C_L/C_\pi}$$

BODE PLOT:



INPUT IMPEDANCE

$A_v \doteq A_m / (1 + j\,\omega/\omega_H)$ OVER USEFUL FREQ. RANGE

~~$I = -g_m V_i + V_o(g_m + G_L$ +~~

$$I = (V_i - V_o)(g_\pi + j\omega C_\pi)$$

$$Y = \frac{I}{V_i} = (g_\pi + j\omega C_\pi)\left(1 - \frac{A_m}{1 + j\,\omega/\omega_H}\right)$$

$$\frac{1 - A_m + j\,\omega/\omega_H}{1 + j\,\omega/\omega_H}$$

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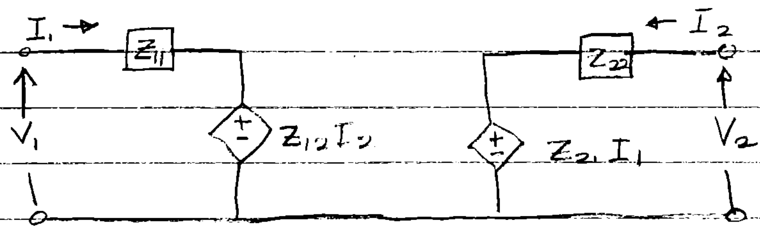
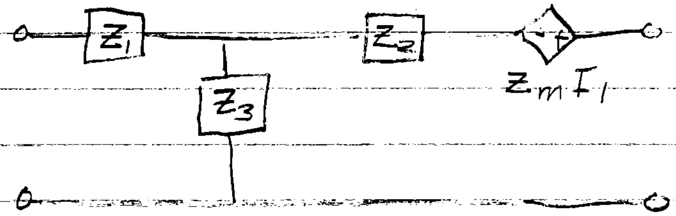
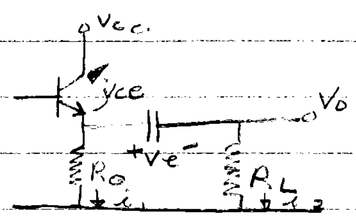




→ T FORM

WON'T WORK: CALL YZORZY (A, B, CD, A, B, C, D)

EMITTER FOLLOWER

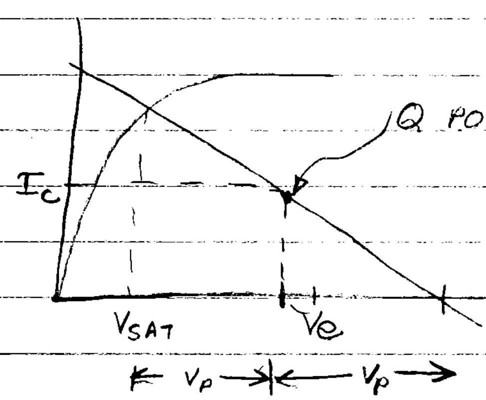


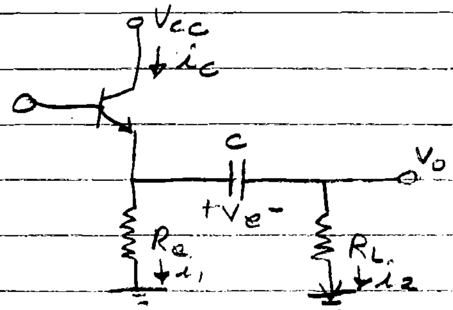
WANT TO DESIGN FOR A CERTAIN OUTPUT VOLTAGE (PEAK) ACROSS A GIVEN LOAD, R_L. LET V_p = PEAK OUTPUT VOLTAGE

AT CUTOFF, $V_o = -V_p$

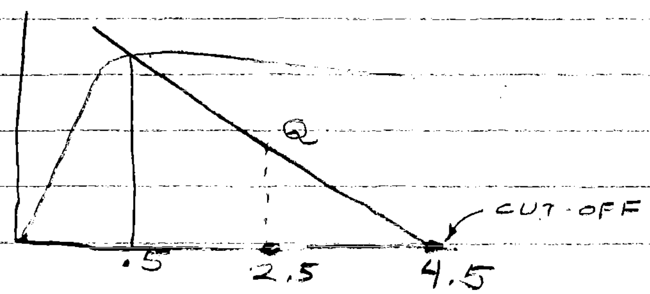
AT SATURATION, $V_o = +V_p$

QUIESCENT $V_o = 0$





LET $R_L = 50$ AND $V_p = 2\ V$ $(V_{CE_{SAT}} = .5\ V)$



AT CUT-OFF, $V_{OUT} = -V_p = -2\,V$; $i_c = 0$, $i_1 = -i_2$

$$\therefore \quad \frac{V_o + V_e}{R_e} = -\left(-V_p/R_L\right)$$

$$\Rightarrow \frac{-2 + V_e}{R_e} = +.04 \Rightarrow V_e = 2 + .04 R_e$$

$$\therefore V_e = \left(1 + \frac{R_e}{R_L}\right) V_p$$

AT SATURATION

$$V_o = V_p = 2V\ ; \quad \frac{V_{cc} - .5}{R_e} + .04 = \frac{2V_e}{R_e}$$

(with i_1, i_2, i_c marked over the three terms)

$$\Rightarrow V_{cc} = 2V_e - .04R_e + .5$$

$$\therefore V_{cc} = 2V_e - \frac{V_p}{R_L} R_e + V_{CE_{SAT}}$$

WANT $V_p = 2V$, $R_L = 50\Omega$, $V_{CE}(SAT) = .5V$

1) LET $R_e = 1k$

$\Rightarrow V_e = (1 + 20)2 = 42V$

$I_c = \frac{42}{1k} = 42\,mA$

$V_{cc} = 84 - 2.20 + .5 = 44.5V \Rightarrow V_{CE} = 2.5$

2) LET $R_e = 500\Omega$

$\Rightarrow V_e = 22V$

$V_{cc} = 24.5\ V$

$$V_{CE} = V_p + V_{CE(SAT)}$$

SLOPE OF DOP = $\frac{-1}{R_L'}$ ∋ R_L' = A.C. RESISTANCE (EQ)

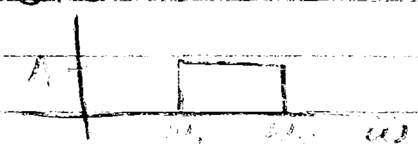
R_L' = PARRALELL EQUIVALLENT OF R_L AND AMP OUTPUT IMPEDANCE

10-[illegible]

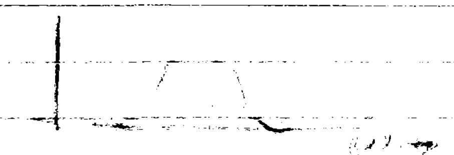
TUNED AMPLIFIERS

BAND PASS CHARACTERISTIC

IDEAL BAND PASS:



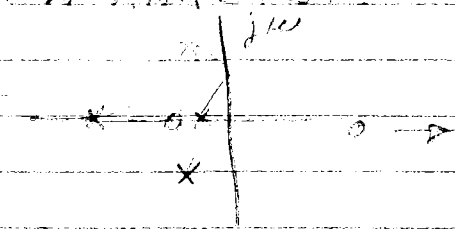
REALLY

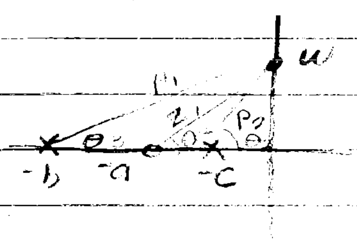


POLE, ZERO PATTERN ANALYSIS

$A_v(s) = \frac{P(s)}{Q(s)}$

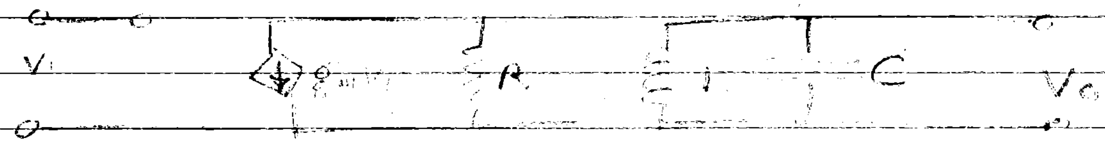
$= K \frac{(s+a)}{(s+b)(s+c)}$





$|A_v(\omega_1)| = K \frac{Z_1}{P_1 P_2}$

$\angle A_v(\omega_1) = \theta_1 - (\theta_2 + \theta_3)$



$$V_o = -g_m V_1 \frac{1}{\frac{1}{R} + sC + \frac{1}{sL}}$$

$$\frac{V_o}{V_1} = A_v(s) = \frac{-g_m}{C} \frac{s}{s^2 + \frac{1}{RC}s + \frac{1}{LC}}$$

$$= \frac{-g_m}{C} \frac{s}{s^2 + 2\alpha s + \omega_0^2} \quad \alpha = \frac{1}{2RC},\ \omega_0^2 = \frac{1}{LC}$$

$$A_v(s) = \frac{-g_m}{C} \frac{s}{s^2 + 2\alpha s + \omega_0^2} \quad \underbrace{\omega_0^2 - \alpha^2}_{\beta^2 = \omega_0^2 - \alpha^2}$$

$$= \frac{-g_m}{C} \frac{s}{(s+\alpha)^2 + \beta^2}$$

$$= \frac{-g_m}{C} \frac{s}{(s+\alpha+j\beta)(s+\alpha-j\beta)}$$

β MAY BE REAL, IMAGINARY, OR ZERO

β REAL $\Rightarrow \omega_0 > \alpha$

β ZERO $\Rightarrow \omega_0 = \alpha$

β IMAG $\Rightarrow \omega_0 < \alpha$

CONSIDER β REAL $\Rightarrow$ COMPLEX [illegible]

SPECIAL CASES

$\omega = \omega_0$

$$A_{v_0} = A_v(j\omega_0) = \frac{-g_m}{C} \frac{j\omega_0}{-\omega_0^2 + 2\alpha j\omega_0 + \omega_0^2}$$

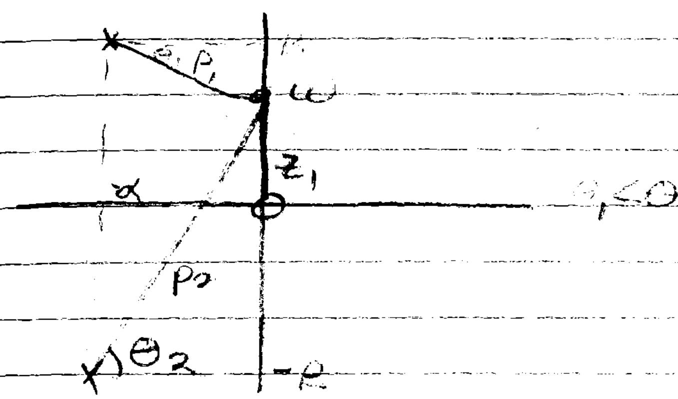
$$= \frac{-g_m}{C} \cdot \frac{1}{(1/RC)} = -g_m R$$

SPECIAL CASE

MAX (A_v) 1) WHAT IS IT?

2) WHERE DOES IT OCCUR

POLE ZERO PATTERN

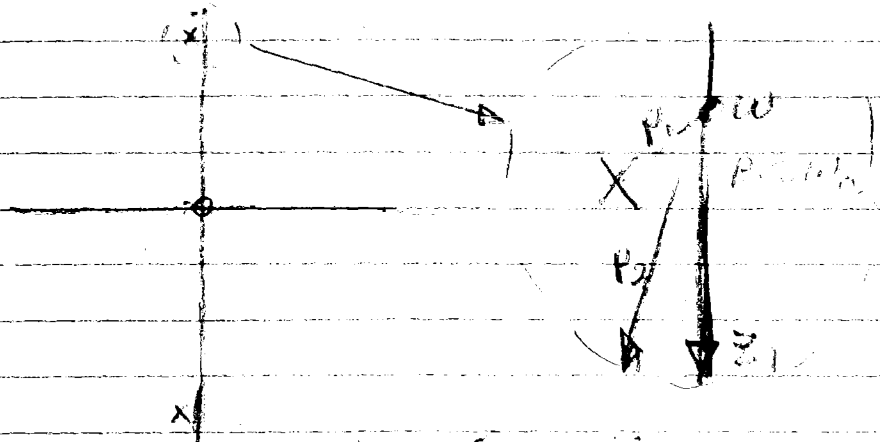


$A_v(j\omega) = \frac{-g_m}{C} \frac{Z_1\angle 90°}{(P_1\angle\theta_1)(P_2\angle\theta_2)}$

$|A_v| = \frac{g_m}{C}\frac{Z_1}{P_1 P_2}$; $\angle A_v = 90° - (\theta_1 + \theta_2) + 180°$

SPECIAL CASE - "NARROW BAND APPROXIMATION"

$\omega_0 \gg \alpha$ ONLY INTERESTED IN ω NEAR ω_0



$A_v = \frac{g_m}{C}\frac{Z_1}{P_1 P_2}$

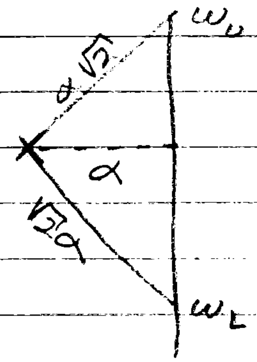
$Z_1 \approx \omega$; $P_2 \approx 2\omega$, $\omega \approx \omega_0$ $\therefore A_v = \frac{g_m}{C}\frac{\omega}{\omega 2 P_1}$

$$A_v = \frac{g_m}{2 P_1 C}$$

MAXIMUM $|A_v| = \frac{g_m}{2\alpha C} = g_m R$

FREQ WHERE $|A_v|$ IS MAX $= \omega_M = \omega_0$

BANDWIDTH



$\omega_U \doteq \omega_0 + \alpha$

$\omega_L \doteq \omega_0 - \alpha$

$BW = \omega_U - \omega_L = 2\alpha = \frac{1}{RC}$

$Q = \frac{\omega_0}{B.W.} = \frac{\omega_0}{1/RC} = \sqrt{\frac{R^2C}{L}} \left(\frac{\omega_0^2 C}{\omega_0^2 C}\right)$

$= \omega_0 RC$

$= R / \frac{1}{\omega_0 C} = R/X_C$

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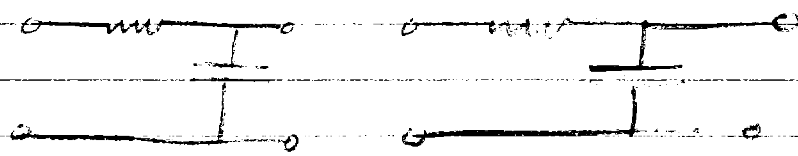
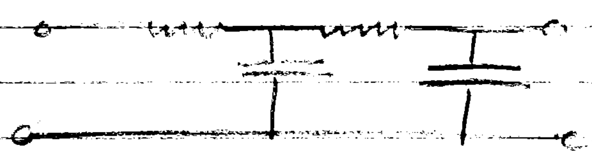
FOURTH HOMEWORK PROBLEM



$H_1(f) = \frac{1}{1 + j\frac{f}{318.3}} = H_2(f)$

$\Rightarrow H(f) = \frac{1}{\left(1 + j\frac{f}{318.3}\right)^2}$



$\frac{V_3}{V_1}$: $V_2(G_1 + G_2 + sC_1) - V_3G_2 = G_1V_1$

$-V_2G_2 + V_3(G_2 + sC_2) = 0$

$= \frac{1}{2.5 \times 10^{-7} s^2 + 1.05 \times 10^{-3} s + 1}$

$= \frac{1}{\left(1 + j\frac{\omega}{2140}\right)\left(1 + j\frac{\omega}{1460}\right)}$

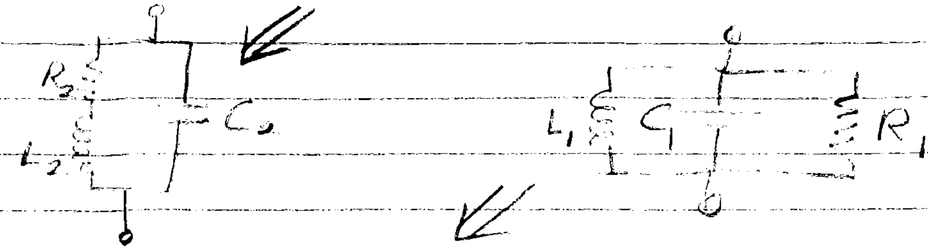
$= \frac{1}{\left(1 + j\frac{f}{232.3}\right)\left(1 + j\frac{f}{436.1}\right)}$

REDUE; $R_1 = R_2 = 1K$

$C_1 = C_2 = .5\ \mu F$

1, 2, & 4 IN CHAPT 15 (TUESDAY)

PRACTICAL ANTI-RESONANT CIRCUIT



$$Z = \frac{1}{C_1} \frac{s}{s^2 + \frac{1}{R_1 C_1} s + \frac{1}{L_1 C_1}} = \frac{1}{C_1} \frac{s}{s^2 + 2\alpha_1 s + \omega_0^2}$$

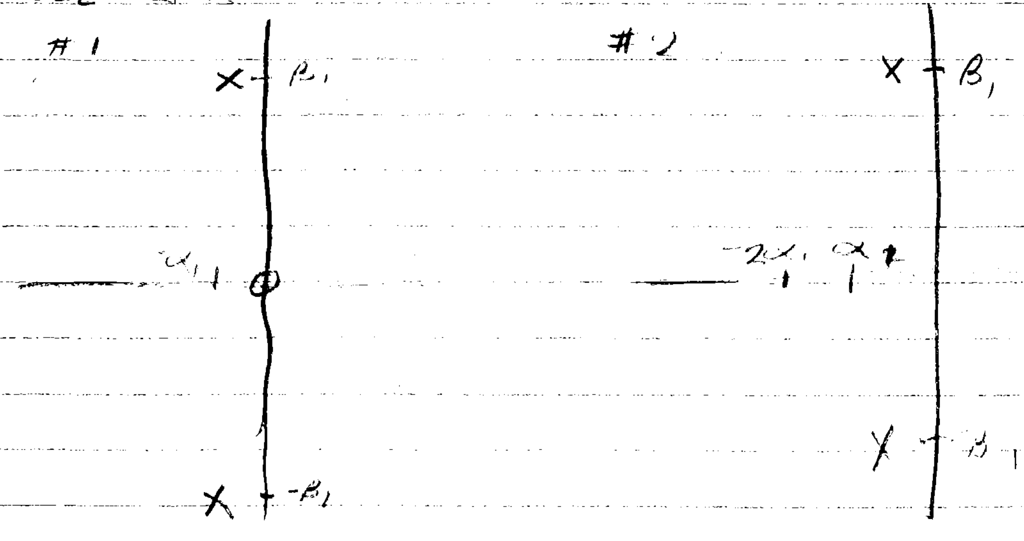
$$Z_{HA} = \frac{\frac{1}{C_2 s_2}(R_2 + s L_2)}{\frac{1}{C_2 s_2} + R_2 + s L_2}$$

$$= \frac{R + sL}{1 + RCs + s^2 LC}$$

$$= \frac{1}{C} \frac{s + R/L}{s^2 + Rs/L + 1/LC}$$

$$= \frac{1}{C} \frac{s + 2\alpha}{s^2 + 2\alpha s + \omega_0^2}$$

POLE ZERO



IF $\omega_{01} >> \alpha_1$, $\omega_{02} >> \alpha_2$ (NARROWBAND APPROXIMATIONS IN EFFECT (CONSIDERING VALUES OF ω_0)

FOR EQUIVALENCE:

$C_1 = C_2$; $\omega_{01} = \omega_{02} \Rightarrow L_1 = L_2$; $\alpha_1 = \alpha_2 \Rightarrow \frac{1}{2R_1C_1} = \frac{R_2}{L_1}$

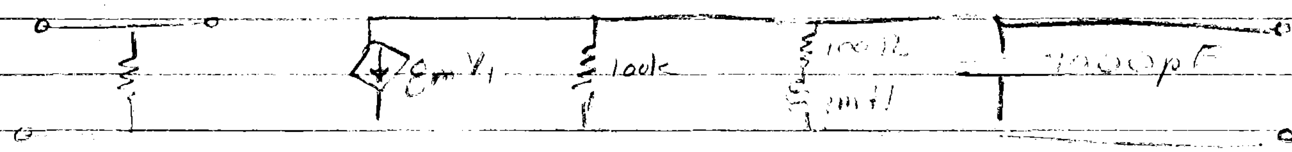
$\omega_{01} = \omega_2$

$\omega_0 >> R_2/L_2$

$\omega_{02} L_2 >> R_2$

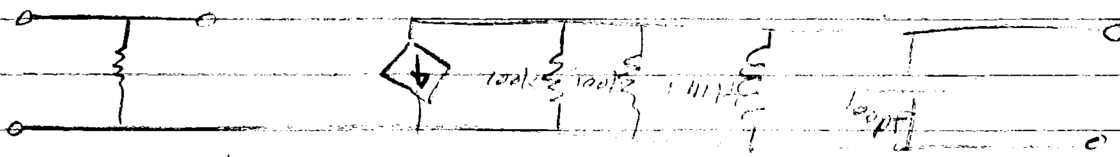
$\frac{\omega_0 L_2}{R_2} >> 1$

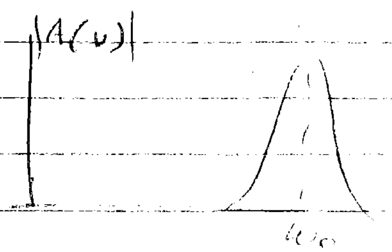
$\Rightarrow Q >> 1$



$\omega = \sqrt{LC}^{-1} = 500$ KHZ

$\alpha = R/2L = \frac{200}{.002} = 50{,}000$ /sec

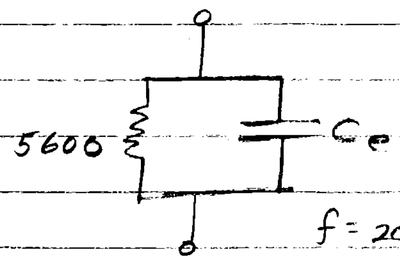




11-71

20 HZ $C \simeq 169 \mu F$ (100)

200 HZ $C \simeq 60, 80$



$f = 20\ HZ$

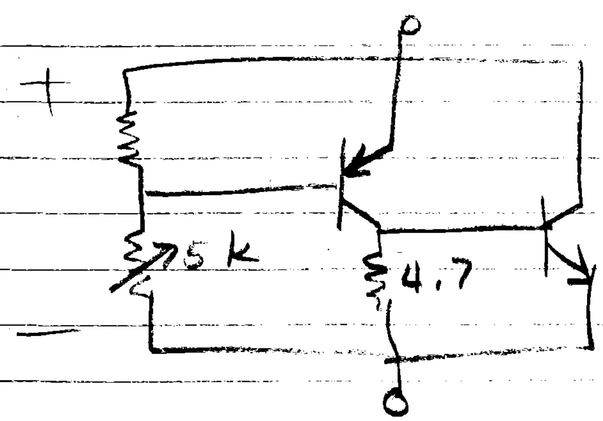
RULE OF [thumb] ; MAKE $X_{ce} \doteq .05 R_e$ (VERY SMALL COMP W R_e)

$$\Rightarrow C_e = \frac{1}{40\pi(280)} = 28.3 \mu F$$

FIND MAX PWR. GAIN IN PROB. # 3

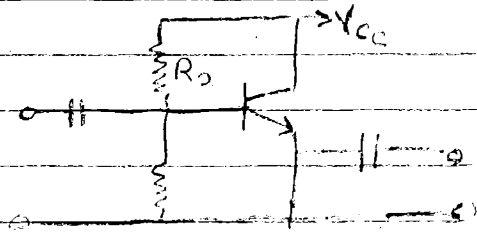
(Pg 516)

VARIABLE ZENOR DIODE



AMP TYPES

EMITTER FOLLOWER

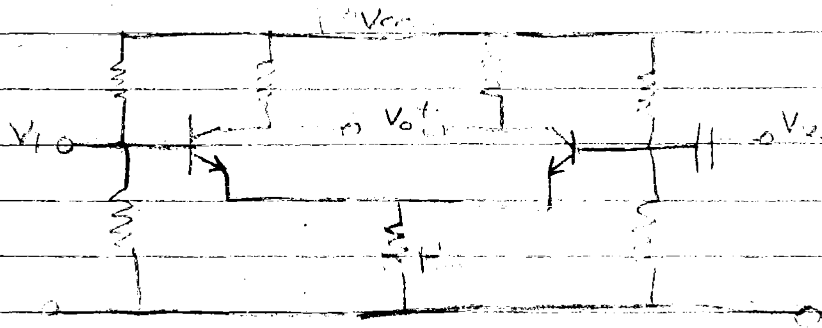


$A_V \sim 1$

HI Z_{IN}

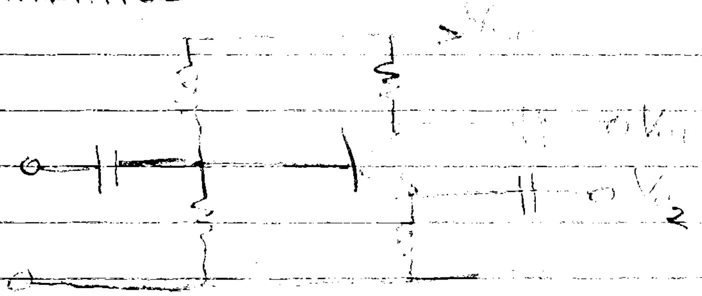
LOW Z_{OUT}

DIFFERENTIAL AMPLIFIER



IF $V_1 = V_2$, $V_0 = 0$

PARAPHASE



A_1 IS 180° FROM A_2

Z_{OUT} LOW

Z_{IN} HI

BOB MARKS

Electrical Engineering Dept.
Rose-Hulman Institute of Technology
Terre Haute, Indiana

EE 363A Electronic Circuits
Test no. 3
Closed books, 50 minutes

84

1. Evaluate the gain of the signal flow graph shown, X_o/X_i.

$$\Delta = 1 - [BH + CI + GIH + DJ + EK] + [BHDJ + BHEK + CIEK + GIHEK]$$

$G_1 = ABCDEF \qquad \Delta_1 = 1$

$G_2 = AGDEF \qquad \Delta_2 = 2$

$$\Rightarrow \frac{X_o}{X_i} = \frac{ABCDEF + AGDEF}{\Delta}$$

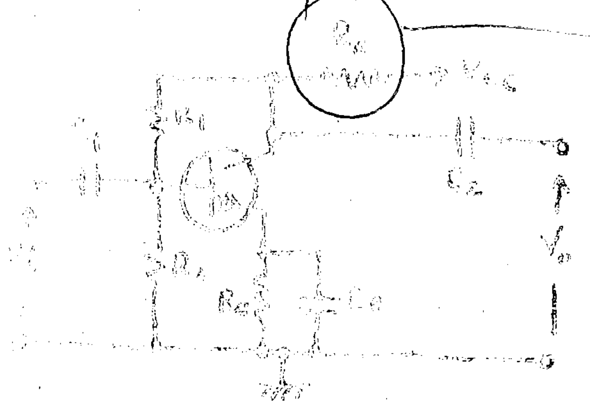
$$\frac{X_o}{X_i} = \frac{ABCDEF + AGDEF}{1 - [BH + CI + GIH + DJ + EK] + [BHDJ + BHEK + CIEK + GIHEK]}$$

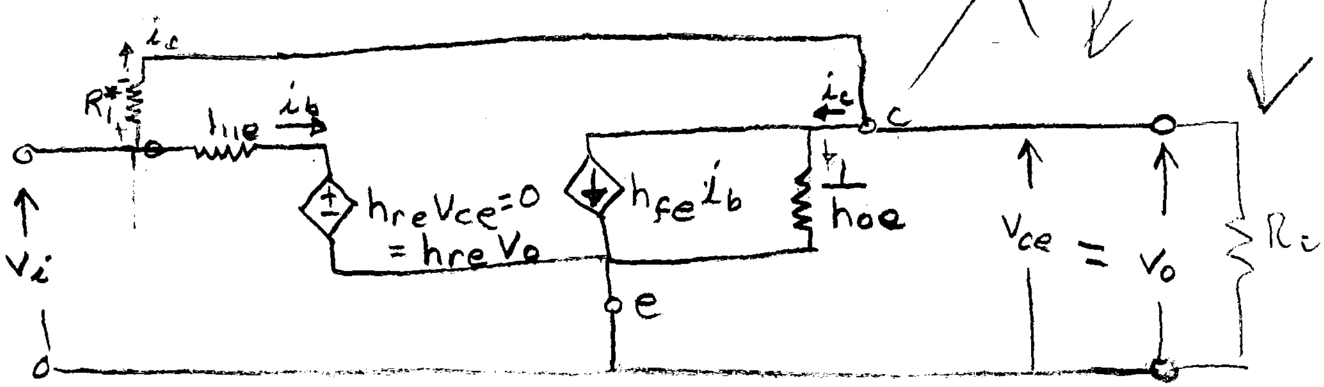
10

2. Draw the signal flow graph for the circuit shown. Do not evaluate the gain.

Assume $h_{re} = 0$, C_1, C_2, C_E are "LARGE"

FYI: R_1 and R_2 are not in parallel!





$V_o = (i_c - h_{fe} i_b)\frac{1}{h_{oe}}$

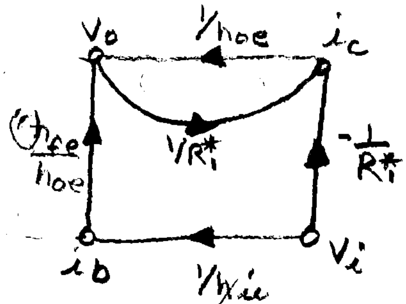
$i_b = (V_i - h_{re}V_o)\frac{1}{h_{ie}}$

$i_c = \frac{(V_o - V_i)}{R_i^*} - \frac{V_o}{R_c}$

$\Delta = 1 - \left(\frac{1}{R_1 h_{oe}} + \frac{h_{fe} h_{re}}{h_{ie} h_{oe}}\right)$

$G_1 = \frac{-h_{fe}}{h_{oe} h_{ie}}$ $\Delta_1 = 1$

$G_2 = \frac{1}{R h_{oe}}$ $\Delta_2 = 0$



8

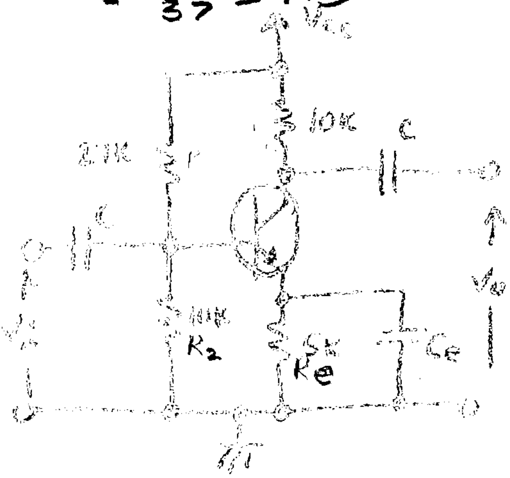
3. Given is the equation for the gain of a common emitter transistor amplifier. Use this equation to find the gain of the amplifier shown below. For the transistor assume $h_{fe} = 99$, $h_{re} = 0$, $h_{oe} = 1/100k$ mhos. $= 10^{-5} S = 10^{-2} mS$

In particular find two gains for the amplifier at two different frequencies: (a) at a high frequency where the emitter bypass capacitor is effectively bypassing, and (b) at a low frequency where the emitter bypass capacitor can be considered an open circuit. NOTE: Give the gain both as a voltage ratio and in dB. $h_{ie} = 2200\Omega$

$$A_v = \frac{h_{oe} R_c Z_e - h_{fe} R_c}{h_{ie}[1 + h_{oe}(Z_e + R_c)] + (1 + h_{fe}) Z_e - \sout{(1+h_{fe}) h_{re} Z_e}} \quad + h_{oe} R_c Z_e - \sout{h_{fe} R_c h_{re}}$$

$R_c = 27 \parallel 10$

$= \frac{270}{37} = 7.3$



NOTE: C's are "large"

AT HIGH FREQ, $Z_{ce} = \frac{1}{j 2\pi C} \rightarrow 0$

$\Rightarrow Z_e = Z_{ce} \parallel R_e = 0$

$$\therefore A_{v_{HI}} = \frac{-h_{fe} R_c}{h_{ie}[1 + h_{oe} R_c]}$$

$$= \frac{-(99)(7.3)}{(2.2)[1 + 7.3 \times 10^{-2}]}$$

$$= \frac{-722}{(2.2)(1.07)} = -306$$

$A_v = 306$

$A_v db = 20 \log_{10} A_v$

$= (20)(2)(.486) = 19.5$ db (W 180° PHASE SHIFT)

← (BACK OF SECOND SHEET)

7

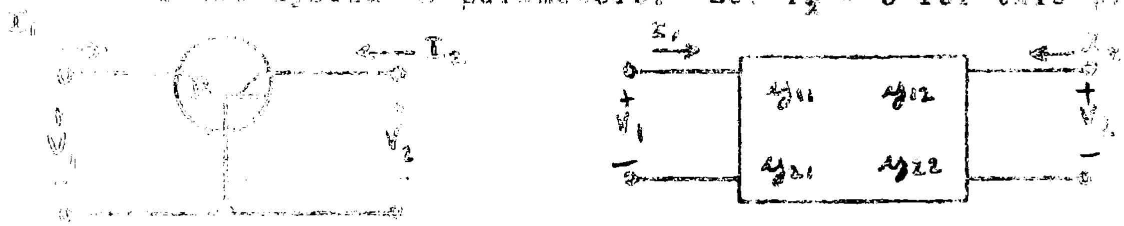
BOB MARKS

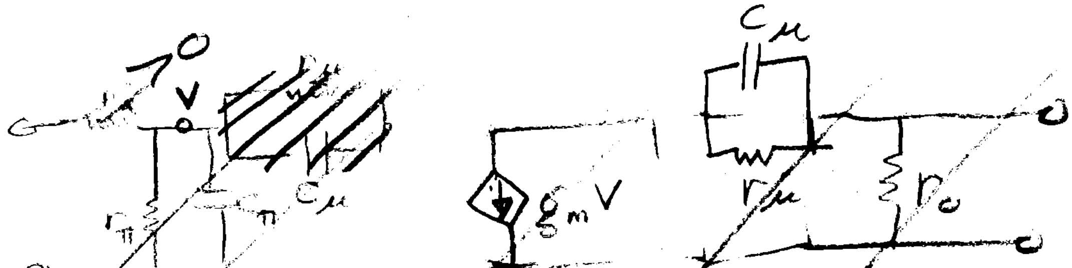
Rose-Hulman Institute of Technology
Terre Haute, Indiana
November 11, 1971

EE 363 - Electronics Circuits
Test No. 2
Closed books, 50 minutes

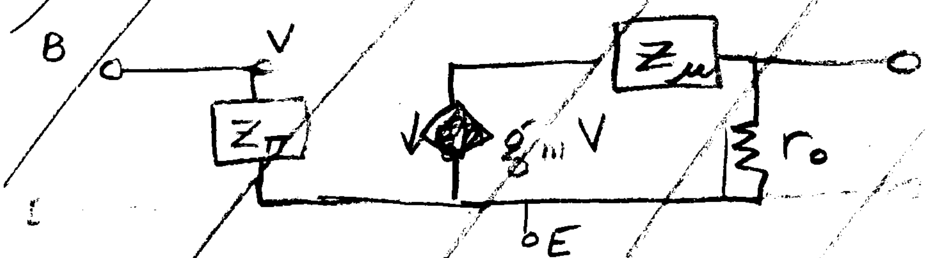
57

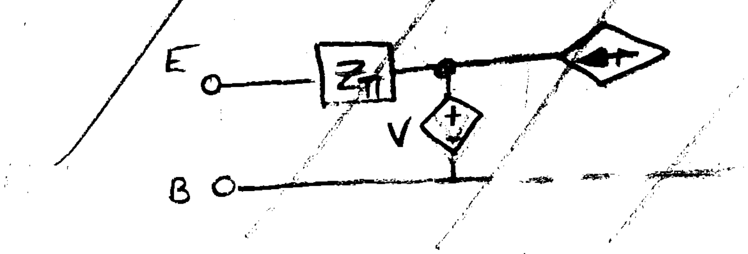
1. Compute the common base Y-matrix for a transistor in terms of the hybrid-π parameters. Let $r_x = 0$ for this problem.





$$Z_\pi = \frac{r_\pi * \frac{1}{sC_\pi}}{r_\pi + \frac{1}{sC_\pi}} \; ; \; Z_\mu = \frac{r_\mu \frac{1}{sC_\mu}}{r_\mu + \frac{1}{sC_\mu}}$$

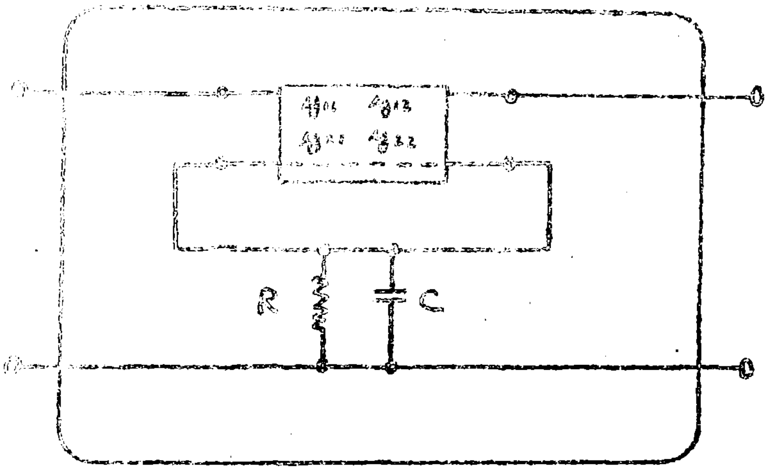




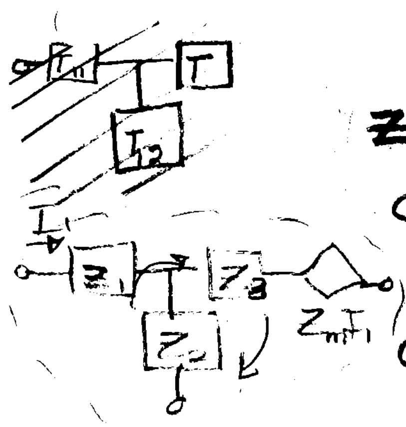
'OER

1

for the 2 port shown. Assume that the y-parameters for the two-port in the box are already computed as Y11, Y12, Y21, Y22. Let the radian frequency be W.



$$Z_0 = R \| \frac{1}{sC} = \frac{R\frac{1}{sC}}{R+\frac{1}{sC}} = \frac{R}{sCR+1}$$



```
S = CMPLX(0,W)
CALL YZØRZY(Y(1,1),Y(1,2),Y(2,1),Y(2,2),
     Z(1,1),Z(1,2),Z(2,1),Z(2,2))
      (Z TO ZT)
CALL ZTØZT(Z(1,1),Z(1,2),Z(2,1),Z(2,2),
     Z1,Z2,Z3,ZM)
Z2 = Z2 + R/(S*C*R+1.)
CALL ZTTØZ(Z1,Z2,Z3,ZM,
     Z(1,1),Z(1,2),Z(2,1),Z(2,2))
CALL YZØRZY(Z(1,1),Z(1,2),Z(2,1),Z(2,1),
     Y(1,1),Y(1,2),Y(2,1),Y(2,1))
```

(Z(2,2), Y(2,2), Z1, Z2, Z3 CMPLX)

9.5

The amplifier voltage gain has the form:

$$A_v(s) = \frac{10^9}{(s+100+j500)(s+100-j500)} = \frac{10^9}{(s+10^2)^2+(500)^2}$$

$\alpha = 10^2$
$\beta = 500$

Find:

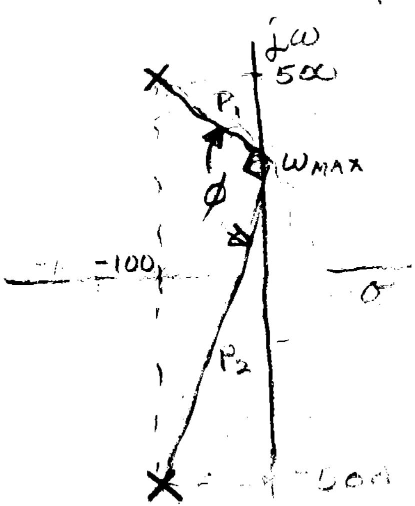
a) A_{max}

b) W_{max}, the frequency where A_{max} occurs.

c) Bandwidth.

d) The gain at d-c, A_0.

e) Sketch $|A_v|$ vs. frequency.



a) A_{MAX} occurs when $P_1 \perp P_2$

$|A(j\omega)| = \frac{10^9}{P_1 P_2}$

AREA OF $\Delta = \frac{1}{2} P_1 P_2 \sin\phi = \beta\alpha = 5\times10^4$

@ $\phi = 90°$; $\sin\phi = 0$

$\Rightarrow P_1 P_2 = 10^5 \Rightarrow |A|_{MAX} = 10^4$

b) $\omega_{MAX}^2 = \beta^2 - \alpha^2$

$= (24\times10^4) \Rightarrow \omega_{MAX} = 4.9\times10^2 \frac{RAD}{SEC}$

c) $W_U^2 = \omega_{MAX}^2 + 2\alpha\beta$

$= 24\times10^4 + 10\times10^4 = 34\times10^4 \Rightarrow \omega_U = 5.83\times10^2 \frac{RAD}{SEC}$

$\omega_L^2 = 14\times10^4 \Rightarrow \omega_L = 3.74\times10^2 \frac{RAD}{SEC}$

$B.W. = \omega_U - \omega_L = (5.83 - 3.74)\times10^2$

$= 209 \frac{RAD}{SEC}$

d) $A_0 = A_v(0) = 10^9/(\sqrt{26})10^2$

$= \frac{10^7}{5.1} = .196\times10^7$

6

Part (e)

(A) High Q in a tuned amplifier means the complex conjugate poles are close to the $j\omega$-axis.
False or true.

(B) A good differential voltage amplifier will have zero output voltage if both inputs are the same.
False or true.

(C) Since an emitter follower amplifier has a voltage gain less than unity, you can't use it to make an oscillator.
False or true.

(D) The power gain of an amplifier is at half its maximum value at a frequency where the voltage gain is 0.707 times its maximum value.
False or true.

(E) Cascading of identical non-interacting amplifiers results in a gain higher than that of one stage and a bandwidth lower than that of one stage.
False or true.

BW: $B_0\sqrt{2^n-1}$ ~~>0~~
$\sqrt{2^n-1} > 0$

0

[illegible]

SOLUTIONS

Problems set [illegible]

2. $A_v = \dfrac{[illegible]}{[illegible]}$

[illegible]

at $f = 1000$ Hz $\qquad Z_e = \dfrac{R_e}{1 + j\omega R_e C_e} = \dfrac{4300}{1 + j\,[illegible]}$

$= \dfrac{4300}{1 - j\,255.3} = \dfrac{4300}{255.3 \angle 89.8} = 16.8 \angle -89.8 \ \Omega$

$= .05 - j\,16.8 \ \Omega$

$A_v = \dfrac{2 \times 10^{-6} \times 10^{9} \times 16.8 \angle -89.8 - 70 \times 10^{4}}{2000\left[1 + 2 \times 10^{-5}\left(10^{4} + 16.8 \angle -89.8\right)\right] + 71 \times 16.8 \angle -89.8 + 2 \times 10^{-5} \times 10^{4} \times 16.8 \angle -89.8 \ [illegible]}$

$= \dfrac{3.18 \angle -89.8 - 70 \times 10^{4}}{2000 + 1192 \angle -89.8 + 3.18 \angle -89.8 + 4.71}$

$= \dfrac{-7 \times 10^{5}}{2000 - j\,1192 - j\,3.2 + 4.71} = \dfrac{-7 \times 10^{5}}{2005 - j\,1195} = [illegible]$

[illegible]

On $f = 60\,Hz$

$$Z_e = \frac{4700}{1 + j2\pi \times 60 \times 4700 \times 4 \times 10^{-5}} = \frac{4700}{1 + j70.87}$$

$$= \frac{4700}{709 \angle 89.2^\circ} = 66.31 \angle -89.2^\circ$$

$$A_v = \frac{2 \times 10^{-5} \times 10^{4} \times 66.31 \angle -89.2^\circ - 70 \times 10^{4}}{2000\left[1 + 2 \times 10^{-5}\left(10^{4} + 66.31 \angle -89.2^\circ\right)\right] + 71 \times 66.31 \angle -89.2^\circ + 2 \times 10^{-5} \times 10^{4} \times 66.31 \angle -89.2^\circ \ldots}$$

$$= \frac{-70 \times 10^{+4}}{2400 + 4708 \angle -89.2^\circ + 13.26 \angle -89.2^\circ - 70}$$

$$= \frac{-70 \times 10^{4}}{2400 - 70 + 65.9 - j4720} = \frac{-70 \times 10^{4}}{2396 - j4722} = \frac{-7 \times 10^{5}}{5295 \angle -63.1^\circ}$$

$$= \boxed{133.7 \angle 244.4^\circ}$$

$$\frac{[illegible]}{h_{ie}(1+h_{oe}R_E)+R_E(1+h_{fe})(1-h_{re})}$$

$$\frac{10^{4}(251)}{2000(1+10^{-?}\times 2\times 10^{3})+10^{4}(251)} \approx$$

$\frac{G_R V_1 \text{ to } V_2}{G_R V \text{ to } I_{sc}}$

$$\frac{2.51\times 10^{6}}{2200+2.51\times 10^{6}} = \boxed{.999}$$

$$\frac{1+h_{oe}R_E}{h_{ie}(1+h_{oe}R_E)+R_E(1-h_{re})(1+h_{fe})} = \frac{2}{2.5\times 10^{6}}$$

$(\ldots\times 10^{?})(\ldots)(\ldots) = 1.25\times 10^{5} \parallel 4.3\times 10^{?}$ [illegible]

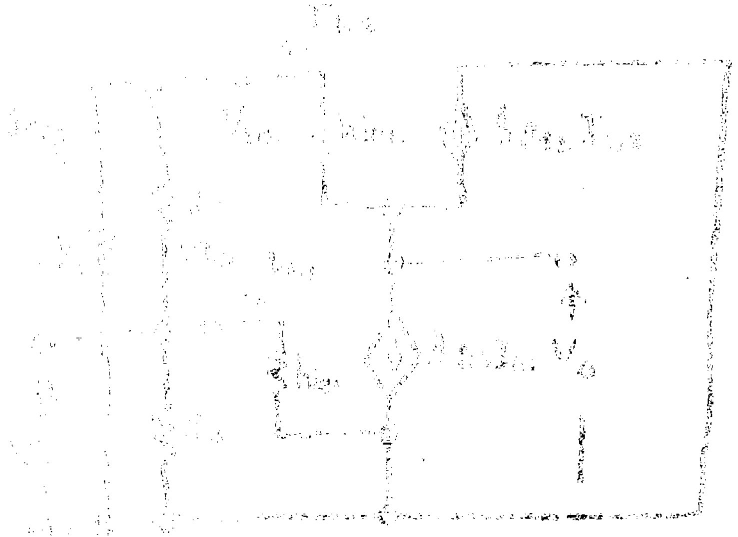
$$\frac{[illegible]\times 1000}{[illegible]\times 10^{6}} = \frac{2\times 10^{3}}{2.5\times 10^{6}} = [illegible]$$

[illegible] Second connected

(4) $R_E \parallel 1000 = 2308\ldots$ [illegible]

$$\frac{[illegible]}{[illegible]} = \frac{[illegible]}{2052+5.14\times 10^{6}} = [illegible]$$

$[illegible] = 558\ldots = \boxed{[illegible]}$



$$V_o = V_{b2} - h_{ie2} I_{b2}$$

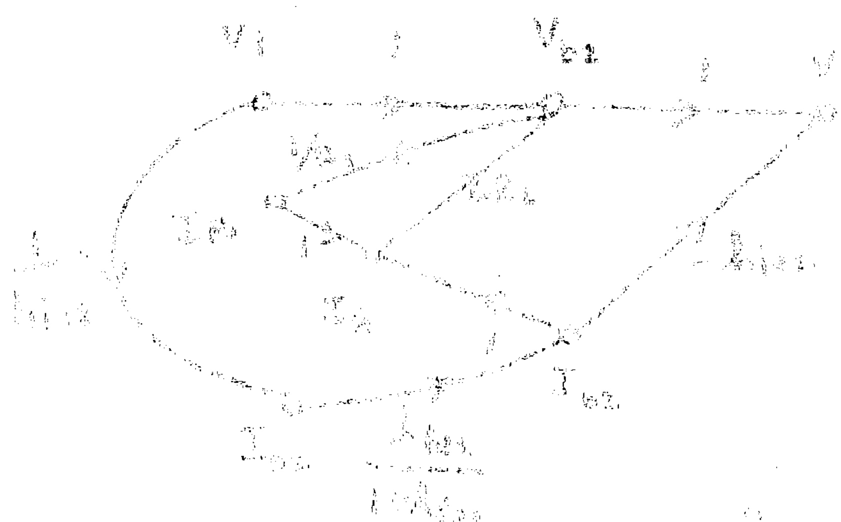
$$V_{b2} = V_i - R_2 I_A$$

$$I_A = I_B + I_{b1}$$

$$I_B = \frac{V_{b2}}{R_1}$$

$$I_{b2} = \frac{h_{fe2}}{1 + h_{fe2}} I_{b1}$$

$$I_{b1} = V_i / h_{ie1}$$



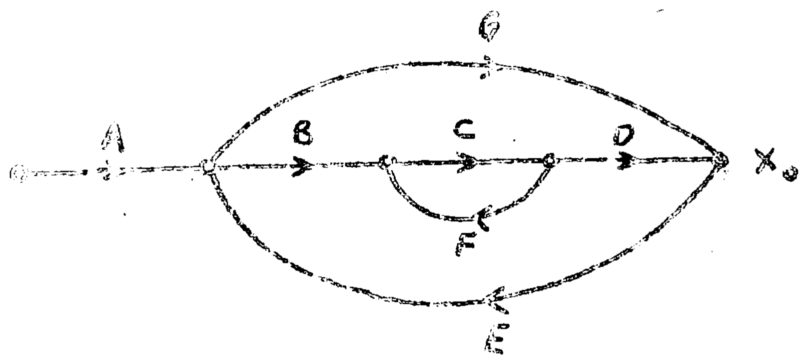
$$\frac{V_o}{V_i} = \frac{1 + \dfrac{h_{fe2}}{1 + h_{fe2}}\left(R_2 - \dfrac{h_{ie2}}{h_{ie1}}\right)}{1 + R_2 / R_1}$$

BOB MARKS
9-27-71

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana
September 27, 1971

EE363A - Electronic Circuits
Quiz 3" no. 2
Closde books, 10 minutes.

Evaluate the gain expression for the path from X_i to X_o for the signal flow graph shown.



$\Delta = 1 - [CF + BCDE + GE] + GECF$

$G_1 = AG \quad \Delta_1 = 1 - CF$

$G_2 = ABCD \quad \Delta_2 = 1$

$$\Rightarrow \frac{X_o}{X_i} = \frac{AG(1-CF) + ABCD}{1 - [CF + BCDE + GE] + GECF}$$

10/10

Bob Martz

Electrical Engineering Dept.
Rose-Hulman Inst. of Tech.
Terre Haute, Ind.
October 11, 1971

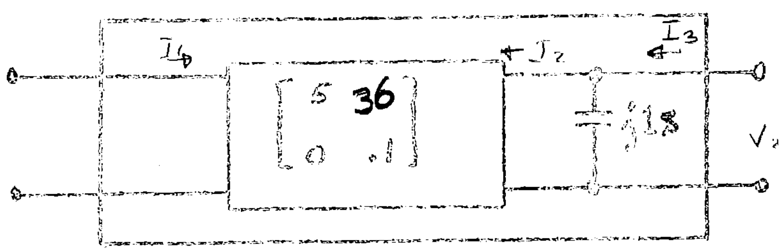
25

EE 363A - Electronic Circuits
Quiz No. 3
Closed books, 10 minutes

The y-parameters for the two-port shown are

$y_{11} = 5S \quad y_{21} = 36S \quad y_{12} = 0 \quad y_{22} = .10S.$

Give the y-parameters for the complete 2-port including the capacitor.



$I_3 = I_2 + jsV_3$
$= I_2 + jsV_2$

want y-parameters for this.

$\begin{matrix} I_1 \\ I_2 \end{matrix} = \begin{bmatrix} 5 & 36 \\ 0 & .1 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad \begin{bmatrix} 5 & 36 \\ 0 & .1 \end{bmatrix} + \begin{bmatrix} & \\ & 1 \end{bmatrix} =$

$\begin{bmatrix} I_1 \\ I_3 \end{bmatrix} = \begin{bmatrix} 5 & 36 \\ & \end{bmatrix} \begin{bmatrix} V_1 \\ V_3 \end{bmatrix}$

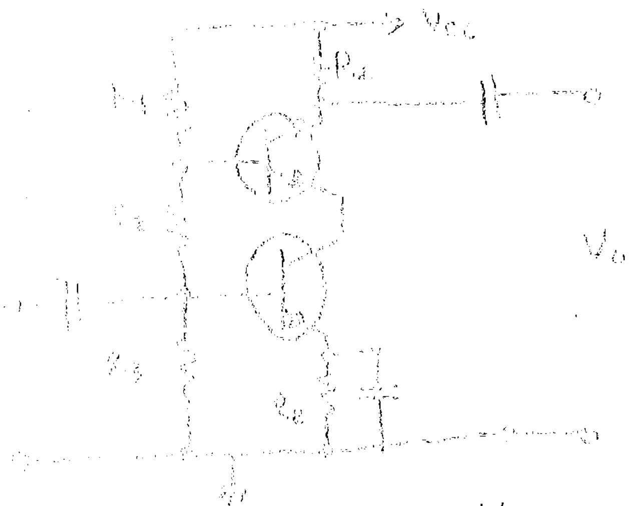
BOB MARKS

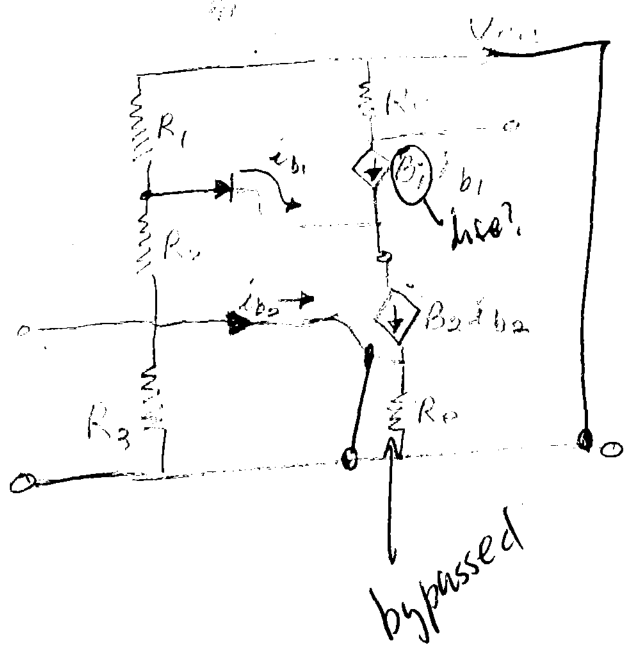
Electrical Engineering Dept.
Rose-Polman Institute
Terre Haute, Indiana
September 20, 1971

(60)

EE365 - Electronic Circuits
Quiz no. 1
Closed books. 30 minutes.

Draw the equivalent small signal AC circuit for the amplifier shown. Use the h-parameter model. Assume that all capacitors are short circuits to signal. Note:-Assume $h_{re} = 0$.





h_{ie_1} missing

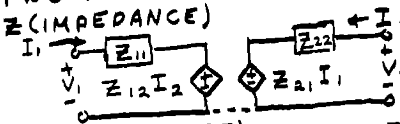
h_{ie_2} missing

h_{oe} missing

ECCTS: TEST 2 PLUG SHEET

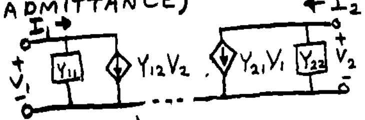
I) TWO PORT NETWORKS

1) Z (IMPEDANCE)



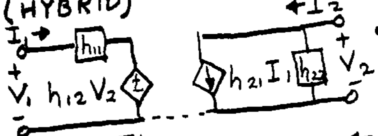
$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

2) Y (ADMITTANCE)



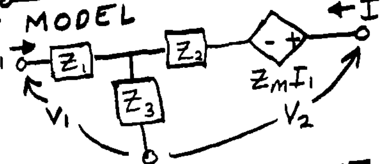
$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

3) h (HYBRID)

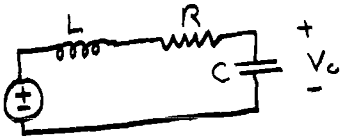


$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

4) ZT MODEL



II) ANTIRESONANT CIRCUIT: V_s



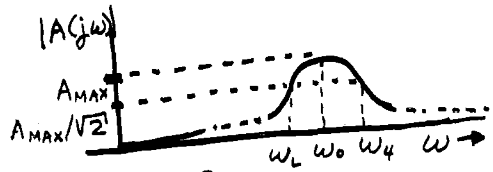
$Q_0 = \frac{\omega_{MAX}}{BW} = \omega_0 RC$

$A(s) = \frac{\omega_0^2}{(s+\alpha)^2 + \beta^2}$

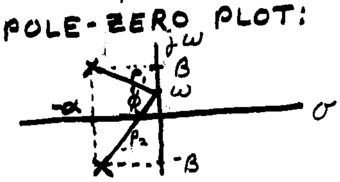
$\omega_0^2 = 1/LC$

$\alpha = R/2L$

$\beta^2 = \omega_0^2 - \alpha^2$



POLE-ZERO PLOT:



$|A(j\omega)| = \omega_0^2/P_1P_2$

$|A(j\omega)|_{\omega_{MAX}} = |A(j\omega)|_{MAX} = \frac{\omega_0^2}{2\alpha\beta}$; $\omega_{MAX}^2 = \beta^2 - \alpha^2$ (@ $\phi = 90°$)

$\frac{1}{2}$ PWR ω; $\phi = 45°, 135°$

$A(j\omega) = A(s) = (\omega_0^2 \sin\phi)/2\alpha\beta = \omega_0^2/(\omega_0^2 - \omega^2 + j2\alpha\omega)$

$\Rightarrow |\omega_0^2 - \omega^2 + j2\alpha\omega|^2 = 2(2\alpha\beta)^2$ @ $\frac{1}{2}$ PWR

$\therefore \omega_U^2 = \omega_{MAX}^2 + 2\alpha\beta$; $\omega_L^2 = \omega_{MAX}^2 - 2\alpha\beta$

FOR HI Q_0; $\beta >> \alpha$; $\omega_0 \sim \beta \sim \omega_{MAX} \Rightarrow BW \cong R/L$

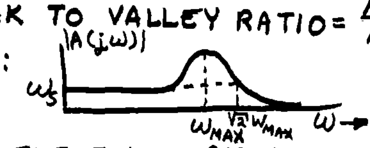
III) MAXIMALLY FLAT GAIN (ANTIRESONANT CIRCUIT) MAYBE

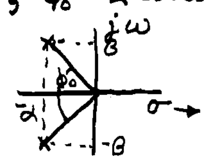
A_P = PEAK GAIN = $\omega_0^2/2\alpha\beta$ (FROM $A(j\omega) = \frac{\omega_0^2}{2\alpha\beta}\sin\phi$)

A_0 = VALLEY GAIN = $|A(s)|_{s=0}$

PEAK TO VALLEY RATIO = $\frac{A_P}{A_V} = \frac{1}{\sin\phi_0}$; $\phi_0 = 2\,\mathrm{atan}\,\beta/\alpha$

FOR $\phi_0 > 90°$:





FOR $\phi_0 < 90°$, THERE WILL BE NO PEAK (PTVR = 1)

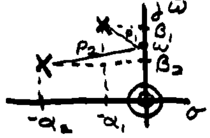
FOR $\phi_0 = 90°$, AMPLIFIER IS MAXIMALLY FLAT

$\alpha = \beta \Rightarrow \phi_0 = 90°$

$\omega_0^2 - \alpha^2 = \alpha^2 \Rightarrow L = \frac{1}{2}R^2C$:

IV) TUNED STAGES

1 DOUBLE TUNED



$\alpha_1 = \frac{1}{2}/R_1C_1$ ($R_1 = R_o \| R_s$)

$\omega_{o1}^2 = 1/L_1C_1$

$\alpha_2 = 1/2R_2C_2$

$\omega_{o2}^2 = 1/L_2C_2$

~~FOR FIRST STAGE~~

FOR SECOND STAGE

$A_V = \frac{-g_m}{C}\frac{s}{s^2 + \frac{1}{RC}s + \frac{1}{LC}}$

$K = g_m/R_2C_1C_2 \Rightarrow A(j\omega) = A(s) = \frac{Ks^2}{(s^2 + 2\alpha_1 s + \omega_{o1}^2)(s^2 + 2\alpha_2 s + \omega_{o2}^2)}$

FOR $\beta_2 >> \alpha_2$; $\beta_1 >> \alpha_1$; $|A(j\omega)| = \frac{K}{4}\frac{1}{P_1P_2}$

IF THE TWO POLES COINCIDE, AMP IS "SYNCHRONOUSLY TUNED"

(CONTINUED)

n SYNCHRONOUSLY TUNED STAGES

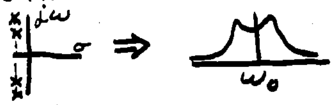
$BW_n = B_0\sqrt{2^{1/n}-1} \ni B_0 = 2\alpha$

$A_p = \frac{K/4}{\alpha^n}$

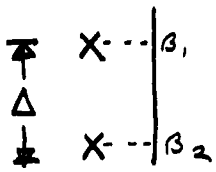
FOR $\frac{1}{2}$ PWR. FREQ.

$p^2 = 2^{1/n}\alpha^2 ;\ p^2 = \alpha^2 + (\Delta\omega)^2$

NON - SYNCHRONOUSLY TUNED AMPLIFIERS

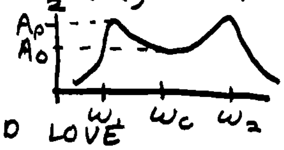


(STAGGERED TUNING)



FOR $\frac{\Delta}{2} \geq \alpha$, $A_p = \frac{\alpha R_1 g_m R_2}{\Delta R_S}$

$\frac{\Delta}{2} < \alpha$, ONLY 1 PEAK



$\frac{A_p}{A_0} = \frac{1}{\sin\phi_0}$

V) PLUGS TO KNOW AND LOVE

$Q_0 = \frac{\omega_{MAX}}{BW} = \omega_0 RC$ [illegible] (TANK)

$A(s) = \frac{\omega_0^2}{(s+\alpha)^2 + \beta^2}$ (TANK)

$\omega_0^2 = 1/LC$

$\alpha = R/2L$ (SERIES) $= \frac{1}{2RC}$ (SHUNT)

$\beta^2 = \omega_0^2 - \alpha^2$

$\omega^2_{MAX} = \beta^2 - \alpha^2$

$\omega_U^2 = \omega^2_{MAX} + 2\alpha\beta$

$\omega_L = \omega^2_{MAX} - 2\alpha\beta$

HI Q $\Rightarrow$ $BW = R/L$

$A_p = \omega_0^2/2\alpha\beta$

$A_0 = A(s)|_{s=0}$

$PTVR = A_p/A_0 = \frac{1}{\sin\phi_0}$

$\phi_0 = 2\,\mathrm{atan}\,\beta/\alpha$ ($\phi_0 > 90° \Rightarrow$ PEAK)

FOR FLAT $L = \frac{1}{2}R^2C$

$BW_n = 2\alpha\sqrt{2^{1/n} - 1.}$ (FOR HI Q)

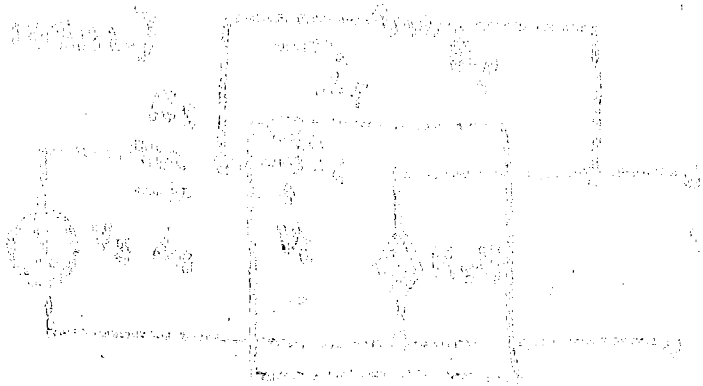
$K = g_m/R_2C_1C_2$

$A_p = K/4\alpha^n$

$p^2 = 2^{1/n}\alpha^2 ;\ p^2 = \alpha^2 + (\Delta\omega)^2$

Operational Amplifier

(contd.)



$A_v = 10^4$

$-10 \le v_o \le 10^V$

$\therefore v_i \approx 0$

Assume $i_n = 0$

$$i_s = \frac{v_s - v_i}{R_s} = \frac{v_s}{R_s}$$

$$i_f = \frac{v_i - v_o}{R_f} = -\frac{v_o}{R_f}$$

$i_s = i_f$

$$\frac{v_s}{R_s} = -\frac{v_o}{R_f}$$

$$\boxed{\frac{v_o}{v_s} = -\frac{R_f}{R_s}}$$

Gain of Amp. with feedback

$$A_{vf} = \boxed{\frac{R_f}{R_s}}$$

Since "zero" output impedance of R_f ...

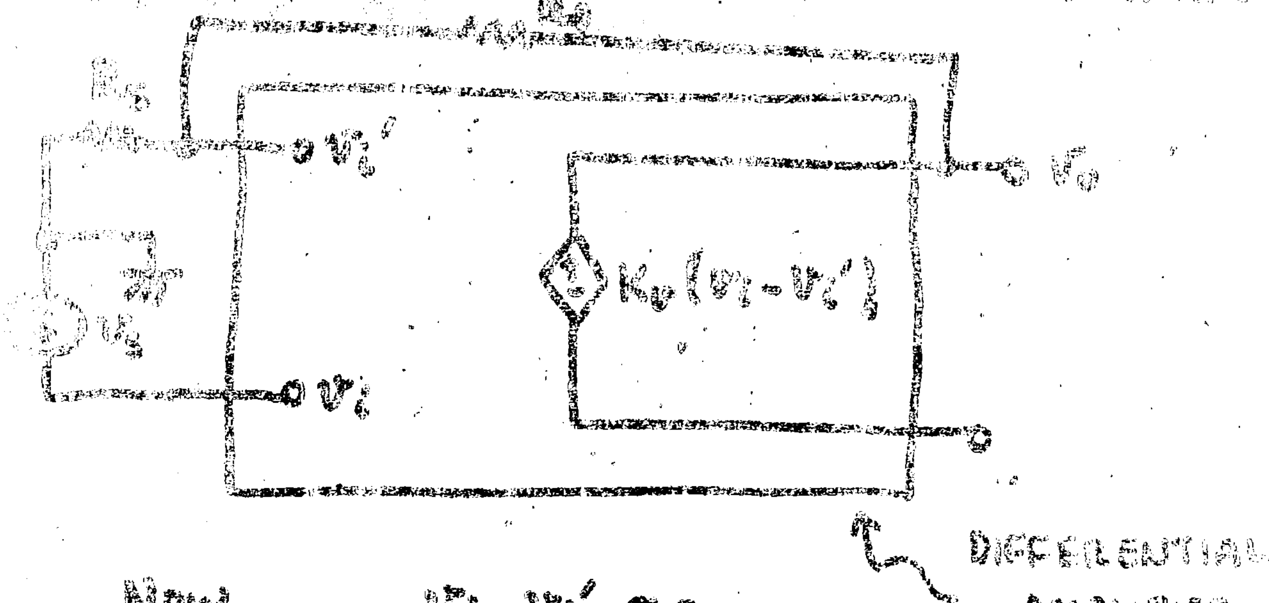
The node where v_i appears is called a summing junction.

$R_i = 10^6\ \Omega$ $R_o = 50\ \Omega$ $A_v = 10^5$

EE, 8BW

11.16.71.2

NON-INVERTING OPERATIONAL AMPLIFIER



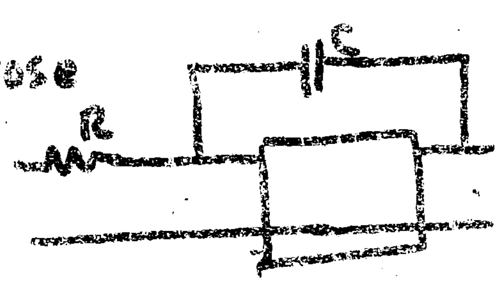
Now $\quad v_i - v_i' \approx 0$

$$v_i \approx v_i'$$

$$v_i' = \frac{R_s}{R_s + R_f} \cdot V_o = V_s$$

$$\frac{V_o}{V_s} = \boxed{1 + \frac{R_f}{R_s}}$$

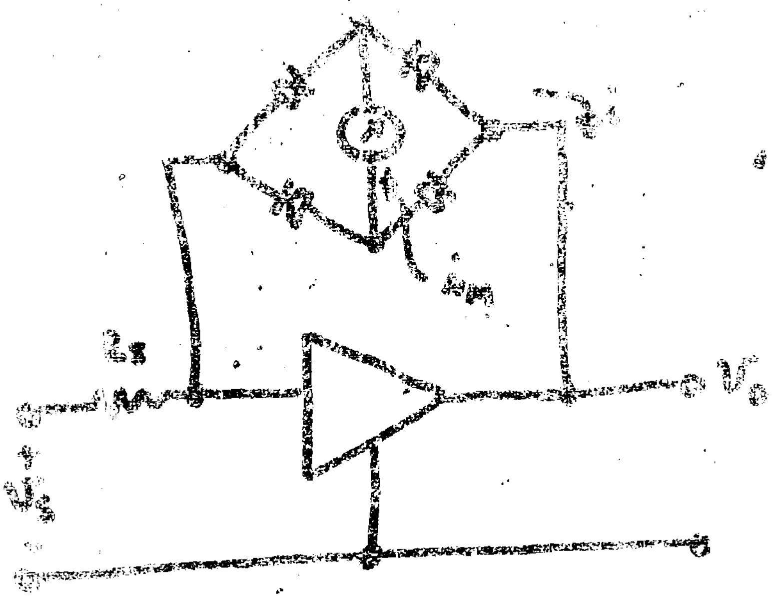
Suppose



$$\frac{V_o(s)}{V_s(s)} = \frac{-\frac{1}{sC}}{R} = \boxed{-\frac{1}{RCs}}$$

THIS FIGURE IS NOT [illegible]

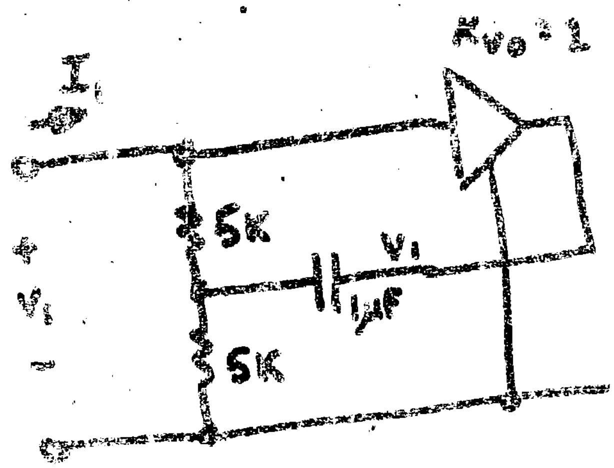
A-C VOLTMETER USING OP AMP.

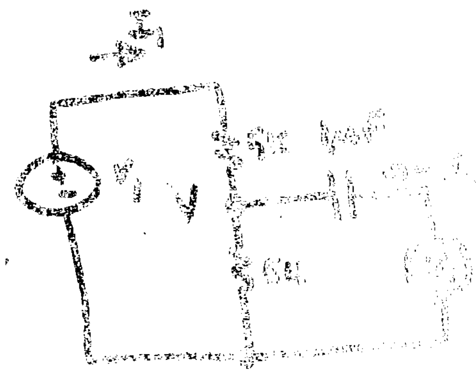


$I = \dfrac{V_s}{R_s}$

$I_M = \left|\dfrac{V_s}{R_s}\right|$

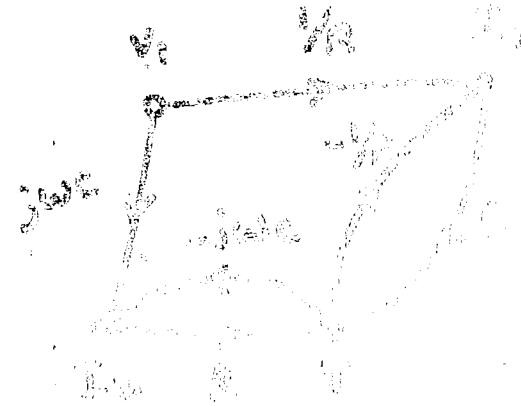
NOTE: I_M NOT
DEPENDENT ON
OF THE DIODES.





$I_1 = \dfrac{V_1 - V}{R}$ $\quad V = R(I_1 + I_2)$

$I_2 = j\omega C(V_1 - V)$



$$\frac{I_1}{V_1} = \frac{\frac{1}{R}\left(1 + j\omega RC\right) + \left(-j\omega C\right)}{1 - \left(-1 - j\omega RC\right)} = 2 + j\omega RC$$

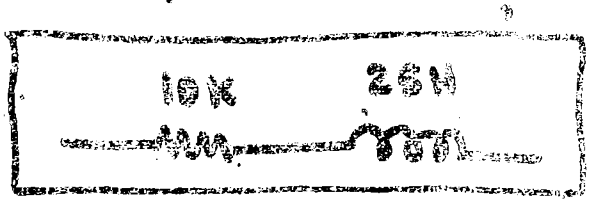
$$= \frac{\frac{1}{R} + j\omega C - j\omega C}{2 + j\omega CR}$$

$$\frac{V_1}{I_1} = Z_{in} = 2R + j\omega R^2 C$$

$C = 1\mu F \quad R = 5K$

$$Z_{in} = 10K + j\omega \left(5 \times 10^3\right)^2 \times 10^{-6}$$

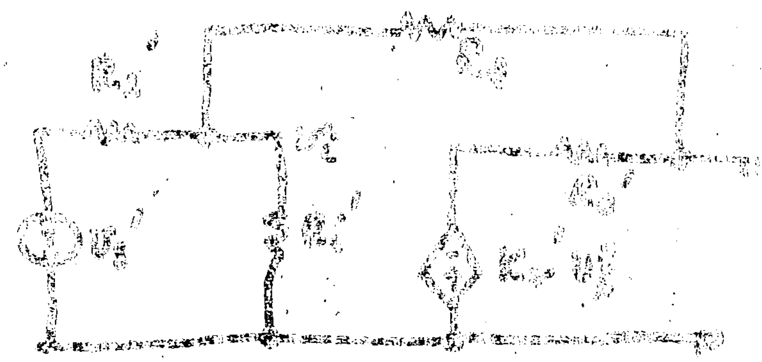
$$= \boxed{10{,}000 + j\omega 25}$$

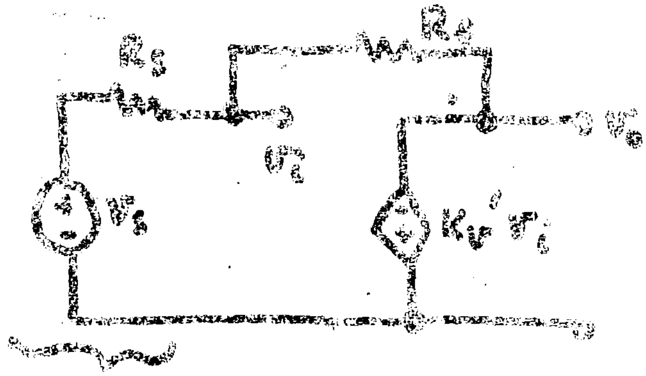
$=$ 

THIS INPUT IMPEDANCE IS INDUCTIVE

$$Q \;@\; 1000\text{ Hz} = \frac{25 \times 1000 \times 6.28}{10^4} = 15.7$$

EFFECTS OF NEGATIVE FEEDBACK





T.T.

$$v_o = K_v' v_i$$

$$v_i = \frac{R_f}{R_s + R_f} v_s - \frac{R_s}{R_s + R_f} v_o$$

$$\frac{R_f}{R_f + R_s} = \alpha \qquad \frac{R_s}{R_s + R_f} = \beta$$

$$\alpha = 1 - \beta$$

Normally $\beta \ll 1$

$\alpha \approx 1$

$$v_i = \alpha v_s - \beta K_v' v_i$$

$$v_o = \frac{-\alpha K_v' v_s}{1 + \beta K_v'} = -K_v v_s$$

$$K_v = \frac{\alpha K_v'}{1 + \beta K_v'}$$

TERMINOLOGY:

K_F' = OPEN LOOP GAIN (NO FEEDBACK)

β = FEED BACK RATIO*

$\beta K_F' = K_L$ = LOOP GAIN

$1+\beta K_F' = F$ = RETURN DIFFERENCE

K_F = CLOSED LOOP GAIN.

*AMOUNT OF VOLTAGE FED BACK TO INPUT FROM V_O.

$K_F < K_F'$ — THIS IS THE PRICE YOU PAY, REDUCTION IN GAIN.

SELF CALIBRATION

MAKING K_F RELATIVELY INDEPENDENT OF K_F'

$K_F' \gg 1 \Rightarrow K_F \doteq \boxed{\frac{1}{\beta}}$

$$K_F = \frac{\alpha K_F'}{1+\beta K_F'}$$ LET $K_F' \to K_F' + \Delta K_F'$

$$K_F + \Delta K_F = \frac{\alpha(K_F' + \Delta K_F')}{1+\beta(K_F' + \Delta K_F')}$$

[illegible]

[illegible]

$$\frac{\Delta K_p}{K_p} = \frac{1}{1+\beta(K_p^0+\Delta K_p^0)} \cdot \frac{\Delta K_p^0}{K_p^0} \quad [illegible]$$

[illegible] β is small [illegible]

Then $$\frac{\Delta K_p}{K_p} \approx \frac{\Delta K_p^0}{K_p^0}$$

$$K_m^0 = \text{Maximum}\{K_p^0\}$$

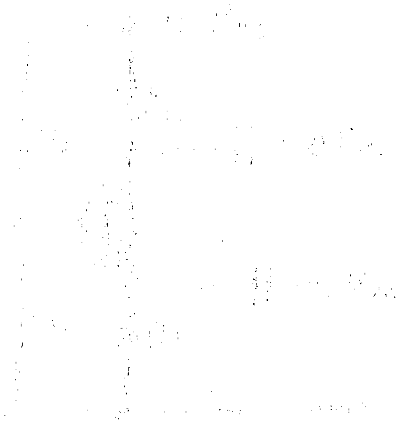
$$K_m = \frac{\alpha K_m^0}{1+\beta K_m^0}$$

So $K_p^0 \to \infty$ $\quad K_p \to \frac{\alpha}{\beta}$

$$\Delta K_p = \frac{\alpha}{\beta} - K_m$$

$$\Delta K_p = \frac{\alpha}{\beta} - \frac{\alpha K_m^0}{1+\beta K_m^0} = \boxed{\frac{K_m}{\beta K_m^0}}$$

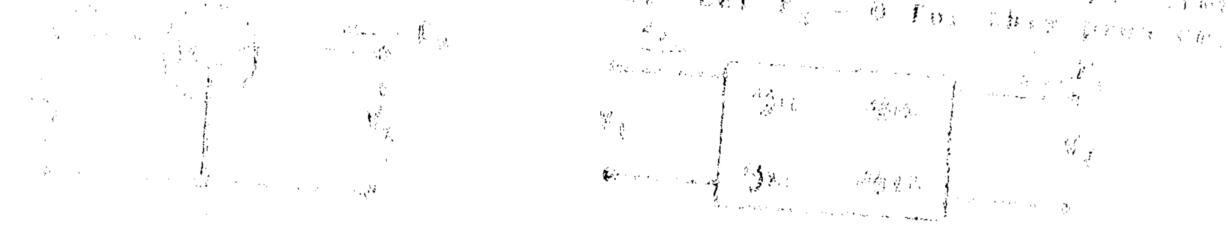
$$\max\left\{\frac{\Delta K_p}{K_m}\right\} = \frac{1}{\beta K_m^0}$$



[illegible]
[illegible]
[illegible]

EE 368 - Electronic Circuits
Test No. 2
Closed Book, 50 minutes

[illegible] the common base y-matrix for a transistor in terms of the hybrid-π parameters. Let $r_x = 0$ for this problem.

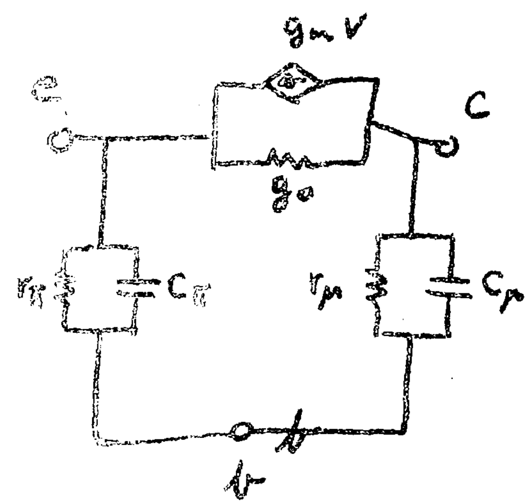


Solution

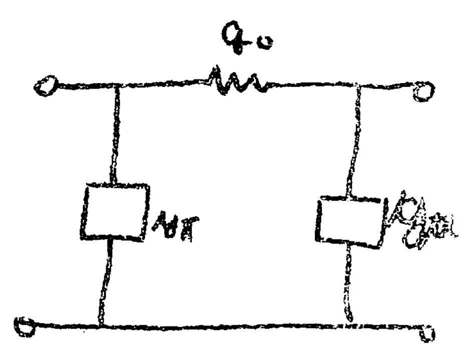
$g_o = \frac{1}{r_o}$

$y_\pi = \frac{1}{r_\pi} + j\omega C_\pi$

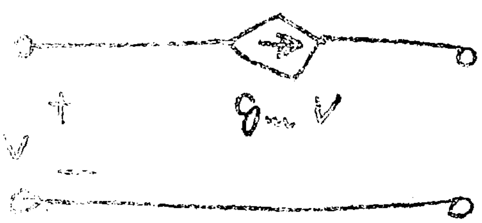
$y_\mu = \frac{1}{r_\mu} + j\omega C_\mu$



=



$$\begin{bmatrix} y_\pi + g_o & -g_o \\ -g_o & y_\mu + g_o \end{bmatrix}$$

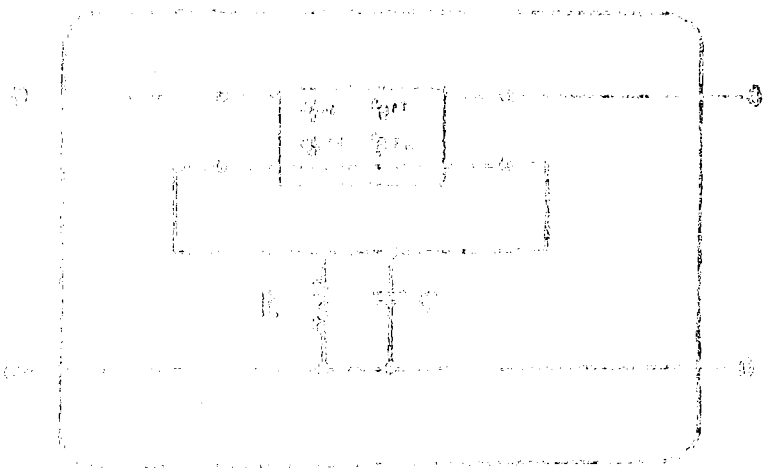


$$\begin{bmatrix} g_m & 0 \\ -g_m & 0 \end{bmatrix}$$

adding gives

$$Y = \begin{bmatrix} y_\pi + g_o + g_m & -g_o \\ -g_o - g_m & y_\mu + g_o \end{bmatrix}$$

[illegible] in the [illegible] system which will compute the y parameters for the 2 port shown. Assume that the y parameters for the two-port in the box are already computed as Y11, Y12, Y21, Y22. Let the radian frequency be W.



SOLUTION

```
CALL YZØRZY(Y11,Y12,Y21,Y22,Z11,Z12,Z21,Z22)
CALL ZTØZT(Z11,Z12,Z21,Z22,Z1,Z2,Z3,ZM)
Z3 = Z3 +1./CMPLX(1.0/R,W*C)
CALL ZTTØZ(Z1,Z2,Z3,ZM,Z11,Z12,Z21,Z22)
~~CALL YZØRZY(Y11,Y12,Y21,Y22,Z~~
CALL YZØRZY(Z11,Z12,Z21,Z22,Y11,Y12,Y21,Y22)
```

here they are

$$A(s) = \frac{10^9}{(s+100+j500)(s+100-j500)}$$

Find:

a) A_{max}

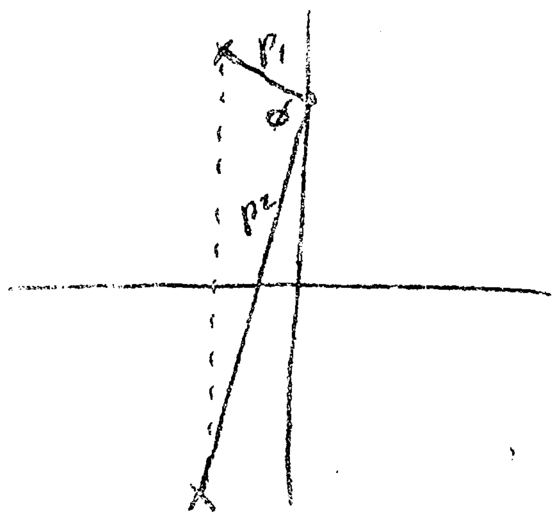
b) ω_{max}: the frequency where A_{max} occurs.

c) Bandwidth.

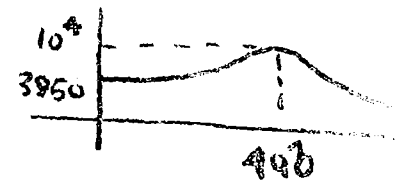
d) The gain at d-c, A_0

e) Sketch $|A_v|$ vs. frequency.

SOLUTION



$$|A_v| = \frac{10^9}{p_1 p_2}$$



$$\frac{1}{2} p_1 p_2 \sin\phi = \alpha\beta$$

$$A_v = \frac{10^9}{2\alpha\beta} \sin\phi$$

$$|A_v|_{max} = A_{max} = \frac{10^9}{2 \cdot 100 \cdot 500} = \frac{10^9}{10^5} = \boxed{10^4}$$

(b) $$\omega_{MAX} = \sqrt{\beta^2 - \alpha^2} = \sqrt{500^2 - 100^2} = 100\sqrt{24}$$

$$= 200\sqrt{6} = 200 \times 2.45 = \boxed{490 \ \frac{rad}{sec}}$$

(c) $$BW = 2\alpha = \boxed{200 \ \frac{rad}{sec}}$$

(d) $$A_0 = \frac{10^9}{100^2 + 500^2} = \frac{10^9}{10^4(1+25)} = \frac{10^5}{26} = \boxed{3850}$$

[illegible]
[illegible]
False or true.

(B) A good differential voltage amplifier will have zero output voltage if both inputs are the same.
False or true.

(C) Since an emitter follower amplifier has a voltage gain less than unity, you can't use it to make an oscillator.
False or true.

(D) The power gain of an amplifier is at half its maximum value at a frequency where the voltage gain is 0.707 times its maximum value.
False or true.

(E) Cascading of identical non-interacting amplifiers results in a gain higher than that of one stage and a bandwidth lower than that of one stage.
False or true.

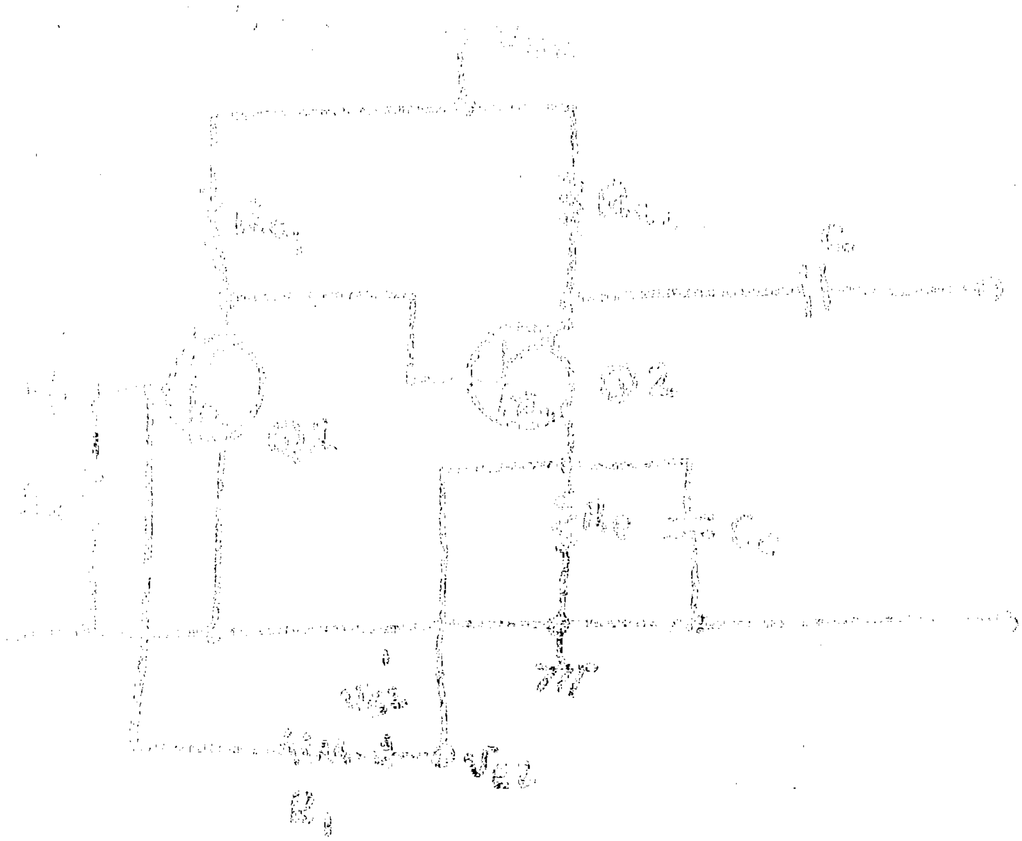
(A) TRUE

(B) TRUE

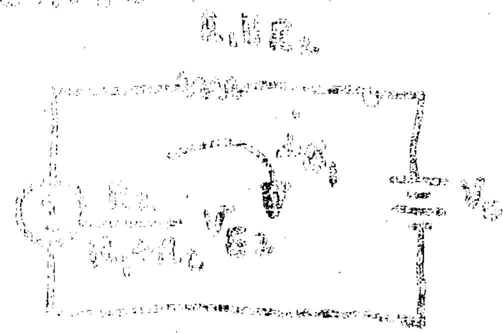
(C) FALSE

(D) FALSE

(E) TRUE



CIRCUIT FOR BASE OF Q1



$$\frac{V_{E_2}}{1+R_1/R_2} = V_0 + \frac{R_1}{1+R_1/R_2}\, i_{B_1}$$

$$V_{E_2} = V_0\left(1+\frac{R_1}{R_2}\right) + R_1 i_{B_1}$$

V_{E_2} is well stabilized if $\left(1+\frac{R_1}{R_2}\right)V_0 \gg R_1 i_{B_1}$

EX 4.3
11.4.11.3

$$V_{CE_1} = V_{BE2} + V_O$$

$$V_{CE_2} = V_{CC} - R_{C_2} i_{C_2} - V_{BE2}$$

$$i_{C_2} \approx \frac{V_{BE2}}{R_2}$$ so these quantities are static

FIND i_{C_1}

$$V_{CC} = V_{BE2} + V_O + R_{C1} i_{C1}$$

$$= V_O\left(1 + \frac{R_1}{R_2}\right) + R_1 i_{B1} + V_O + R_{C1} i_{C1}$$

$$V_{CC} = \left(2 + \frac{R_1}{R_2}\right) V_O + \left(\frac{R_1}{\beta_1} + R_{C1}\right) i_{C1}$$

$$\boxed{i_{C1} = \frac{V_{CC} - \left(2 + \frac{R_1}{R_2}\right) V_O}{R_{C1} + \frac{R_1}{\beta_1}}}$$

if $R_{C1} >> \frac{R_1}{\beta_1}$

$$\boxed{i_{C1} \doteq \frac{1}{R_{C1}}\left[V_{CC} - \left(2 + \frac{R_1}{R_2}\right) V_O\right]}$$

THIS IS INDEPENDENT OF β

[illegible]

V_o [illegible]

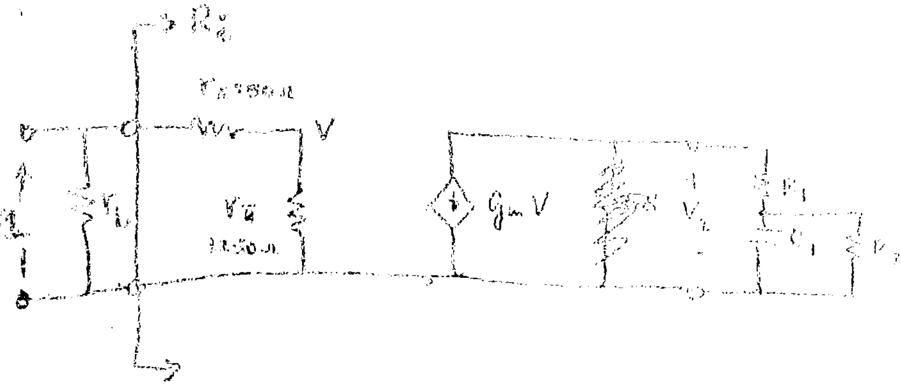
[illegible] 119K

[illegible] 36K

[illegible] 12.7K

Angelo
459.14.12

$$r_\pi = \frac{\beta}{40 I_c} = \frac{50}{40} = 1.25\ k\Omega$$



$$r_i = r_x + r_\pi = 1250 + 50 = \boxed{1300\ \Omega}$$

$$V_2 = -g_m V \left(R_1 + \frac{1}{\frac{1}{R_2} + sC_1} \right), \quad V = \frac{1250}{1300} V_1$$

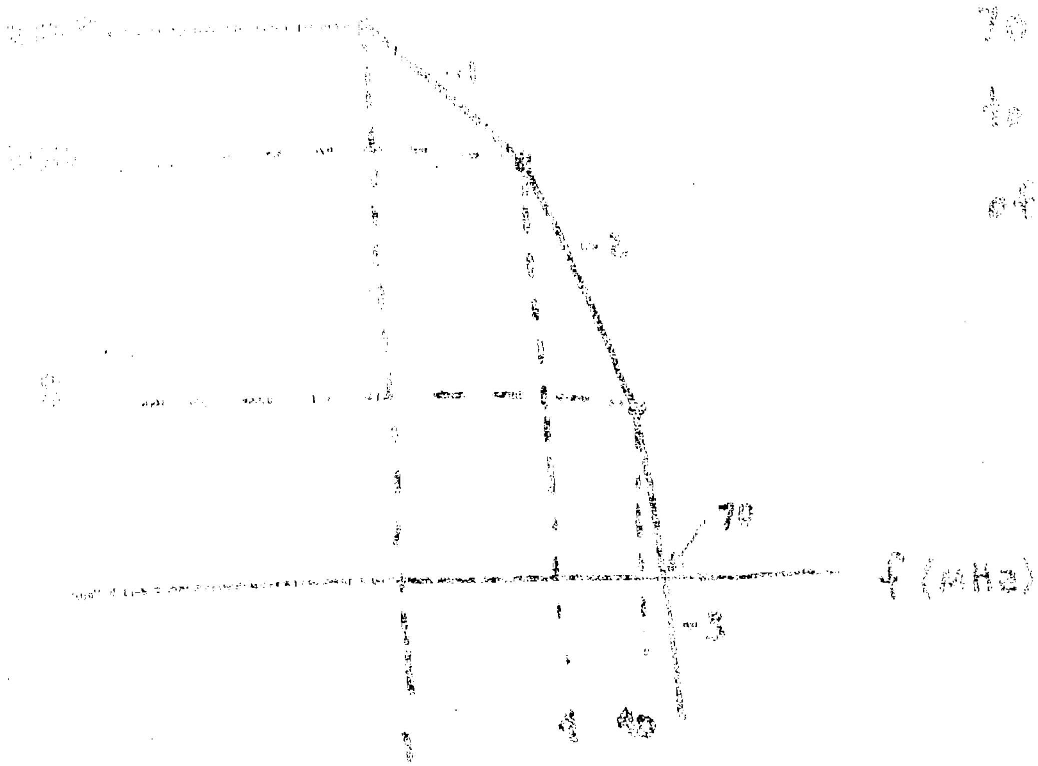
$$\frac{V_2}{V_1} = K \left(R_1 + \frac{1}{\frac{1}{R_2} + sC_1} \right) = K \left(R_1 + \right.$$

$$= K \frac{R_1\left(\frac{1}{R_2} + sC_1\right) + 1}{\frac{1}{R_2} + sC_1} = K \frac{\frac{R_1}{R_2} + sC_1R_1 + 1}{\frac{1}{R_2} + sC_1}$$

$$= K \frac{1 + \frac{R_1}{R_2}}{\frac{1}{R_2}} \cdot \frac{1 + \frac{sC_1R_1}{1 + R_1/R_2}}{1 + sC_1R_2} = K' \frac{1 + j\frac{\omega}{\omega_1}}{1 + j\frac{\omega}{\omega_2}}$$

$$\boxed{\omega_1 = \frac{1 + R_1/R_2}{R_1C_1}} \qquad \boxed{\omega_2 = \frac{1}{R_2C_1}}$$

Convert to Barry-preferred form of Bode:



70 dB corresponds to voltage gain of 3100

$$A(j\omega) = -3100 \frac{1}{\left(1+j\frac{f}{1}\right)\left(1+j\frac{f}{4}\right)\left(1+j\frac{f}{40}\right)}$$

Poles at

$s = -2\pi \ \frac{\text{Mrad}}{\text{sec}}$

$s = -8\pi \ \frac{\text{Mrad}}{\text{sec}}$

$s = -80\pi \ \frac{\text{Mrad}}{\text{sec}}$

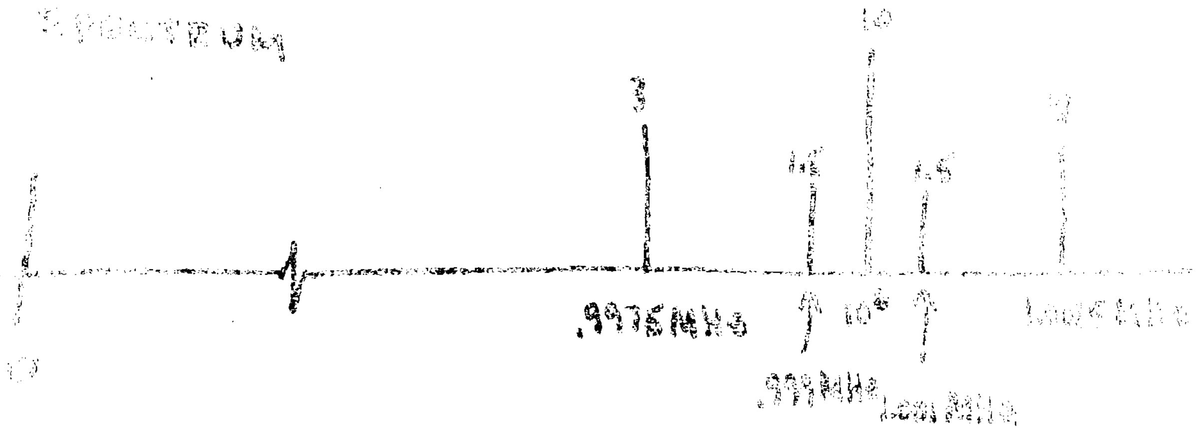
$$v = \left[10 + 3 \cos 2000\pi t + 6 \cos 5000\pi t\right] \cos 2\pi \cdot 10^6 t$$

$$= 10 \cos 2\pi \cdot 10^6 t + 3 \cos 2000\pi t \cos 2\pi \cdot 10^6 t + 6 \cos 5000\pi t \ldots$$

$$= 10 \cos 2\pi \cdot 10^6 t + 1.5 \cos 2\pi(10^6 + 10^3)t + 1.5 \cos 2\pi(10^6 - 10^3)t$$

$$+ 3 \cos 2\pi(10^6 + 2500)t + 3 \cos 2\pi(10^6 - 2500)t$$

SPECTRUM



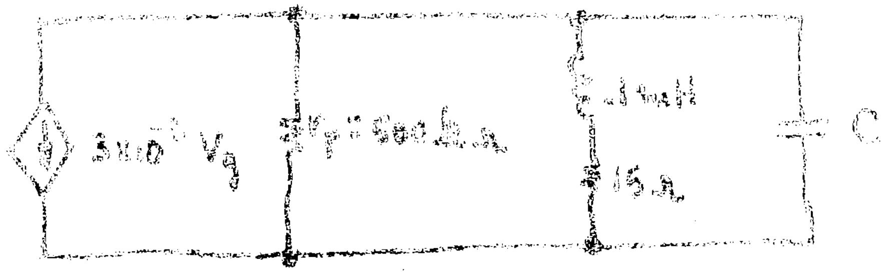
[illegible]

Highest audio frequency [illegible] [illegible] [illegible]

[illegible] [illegible] to the [illegible] [illegible]) is [illegible] [illegible]. [illegible]

[illegible] [illegible] of the [illegible] [illegible] [illegible] [illegible] [illegible],

[illegible] [illegible] [illegible] of [illegible] [illegible] [illegible] the [illegible] [illegible]



(a) $\frac{1}{LC} = \omega_0^2 = 10^{14}$. $C = \frac{1}{10^{14} L} = \frac{1}{10^{14} \times 10^{-4}}$

$= 10^{-10}\,F = \boxed{100\,pF}$

(b) $R_p = \frac{L}{C R_s} = \frac{10^{-4}}{10^{-10} \cdot 15} = \frac{10^{6}}{15} = .0667 \times 10^{6}$

$= 66.7\,K$

$r_p \parallel R_p = \frac{500 \times 66.7}{566.7} = 58.9\,k\Omega$

$\alpha = \frac{1}{2RC}$

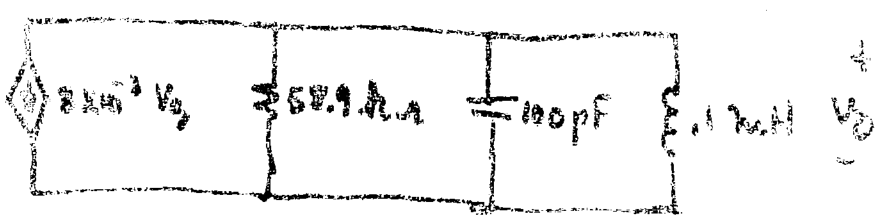
$= 8.5 \times 10^{4}$

$\alpha^2 = 72.2 \times 10^{8}$

$\omega_0^2 >> \alpha^2$.

CHECK THIS

Equivalent cct.



A_0 = gain at resonance

$\frac{V_0}{V_g} = A_0 = -3 \times 10^{-3} \times 58.9 \times 10^{3} = \boxed{-176.7}$

$BW = \frac{1}{RC} = \frac{1}{58.9 \times 10^{3} \times 10^{-10}} = \frac{100}{58.9} \times 10^{5} = 1.7 \times 10^{5}\ \frac{rad}{sec}$

[illegible]

$\alpha = \frac{R}{2L} = \frac{6.6}{2\times10^{-6}} = 3.3\times10^{6}\ s^{-1}$

$\omega_0^2 = \frac{1}{LC} = 1.09[illegible]\times10^{17}$, $\omega_0 = 3.300[illegible]\times10^{8}$, f_0 = [illegible]

$\beta = \sqrt{\omega_0^2 - \alpha^2} = 3.3000[illegible]\times10^{8}\ s^{-1}$

$\max\{A_v\} = \frac{\omega_0^2}{2\alpha\beta} =$ **50.006**

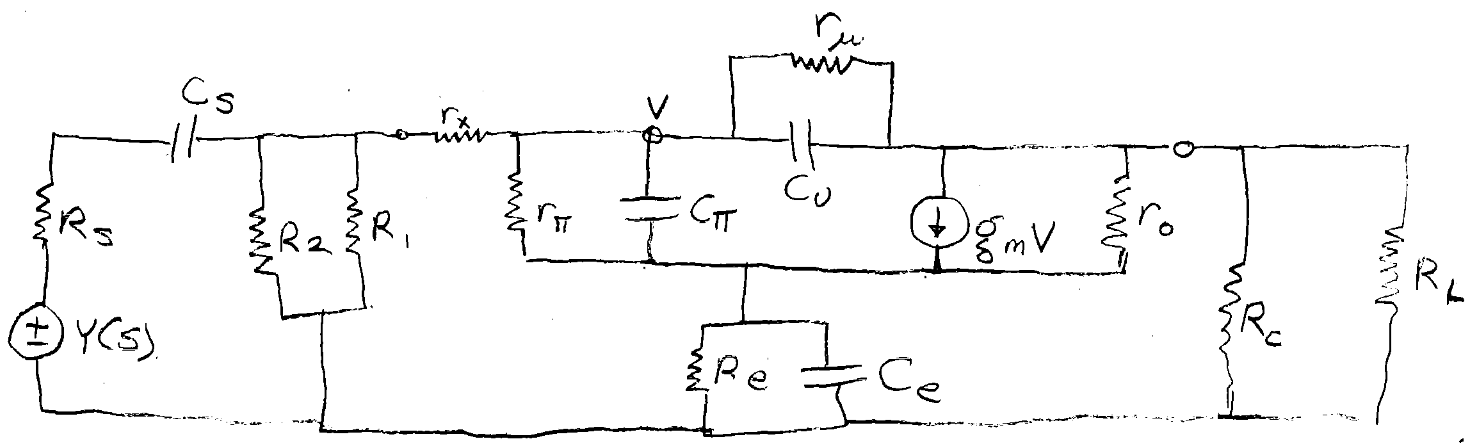
$\omega_{max} = \sqrt{\beta^2 - \alpha^2} = 3.30007[illegible]\times10^{8}$, f_{max} = 52.5[illegible] MHz

$Q_0 = \frac{\omega_0 L}{R} =$ **50.0037**

$\omega_L = \sqrt{\omega_{max}^2 - 2\alpha\beta} =$, f_L = 51.9[illegible] MHz

$\omega_U = \sqrt{\omega_{max}^2 + 2\alpha\beta} =$, f_U = 53.0[illegible] MHz

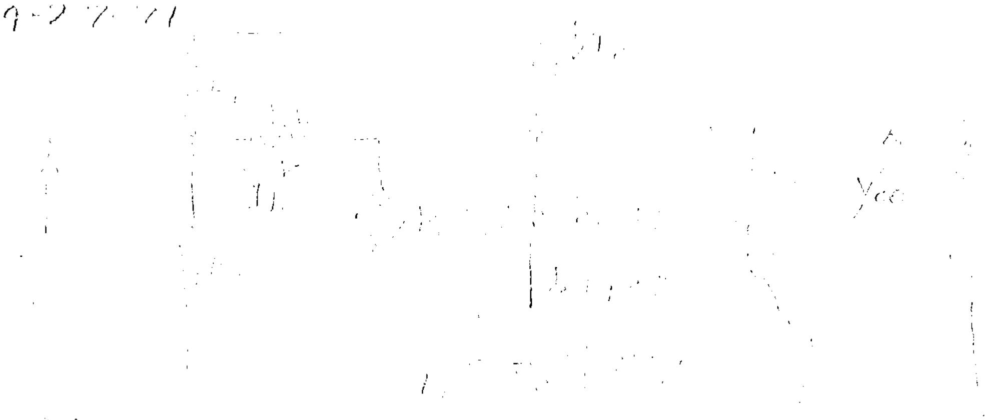
$A_v = \frac{1/\omega_0 C}{R} = \frac{1}{\omega_0 RC} = Q_0 =$ 50.0037



Cs
Rs
Y(s)
R2
R1
rx
rπ
V
Cπ
rμ
Cμ
gmV
ro
Re
Ce
Rc
RL

2.5/6

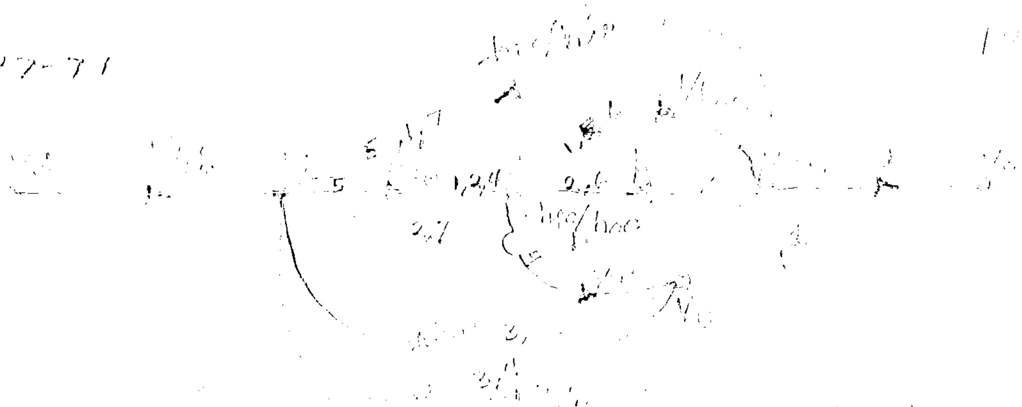
9-27-71



[illegible]

9-22-71

1-1)



[illegible]

$= X\!\!\!/\ 5.41$

$h_{ie} = 2k$ $R_1 = 27k$

$h_{re} = 10^{-4}$ $R_2 = 10k$

$h_{fe} = 70$ $R_L = 10k$

$h_{oe} = 200\,m\mho$

Z_{C_1} @ 2,000 Hz

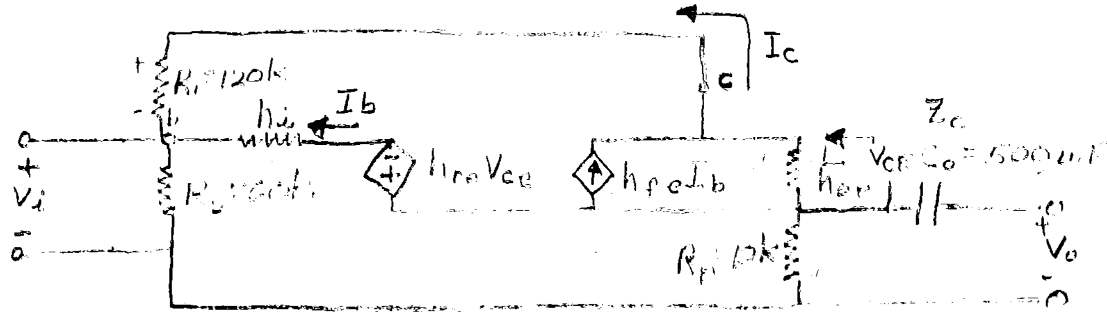
$X_c = \frac{1}{2\pi \times 2 \times 10^3 \times [illegible] \times 10^{-6}} = \frac{-j}{160\pi \times 10^{-3}} = \frac{-j}{160\pi} \times 10^{-3}\ k\Omega$

$Z_{C_1} = X_c \| R_0 = \frac{\left(\frac{-j}{160\pi}\right)(4.7)}{4.7 - \frac{j}{160\pi}} = \frac{.0094 \angle -90^\circ}{4.7 \angle 0^\circ} = .00198\ \Omega$

(-15)

9-27-71

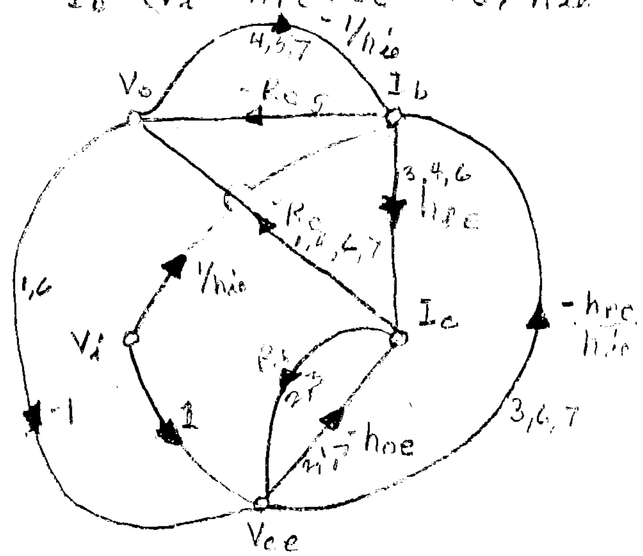
1-2)



$V_o = -R_e(I_b + I_c)$ $\qquad$ $V_{ce} = R_1 I_c + V_i - V_o$

$I_c = h_{fe} I_b - h_{oe} V_{ce}$

$I_b = (V_i - h_{re} V_{ce} - V_o)\frac{1}{h_{ie}}$



$\Delta = 1 + \Big[h_{oe} R_e + h_{oe} R_1 + \frac{h_{re} h_{fe} R_1}{h_{ie}} + \frac{-h_{re} R_1}{h_{ie}} + \frac{R_e}{h_{ie}} + \frac{h_{fe} R_e h_{re}}{h_{ie}} + \frac{h_{re} [illegible]}{h_{ie}}$
$\quad - \frac{h_{oe} R_1 R_e}{h_{ie}} \Big]$

$G_1 = \frac{-R_e}{h_{ie}}$; $\Delta_1 = 1 + h_{oe} R_1$

$G_2 = +h_{fe} R_e$; $\Delta_2 = 1$

$G_3 = \frac{R_e h_{re}}{h_{ie}}$; $\Delta_3 = 1$

$$A_v = \frac{V_o}{V_i} = \frac{-R_e + h_{ie}(1 + h_{oe} R_1) + h_{fe} h_{ie} R_e + R_e h_{re}}{h_{ie}(1 + h_{oe}(R_e + R_1)) + h_{re} h_{fe} R_1 - h_{re} R_1 - R_1 + h_{fe} R_e h_{re} + h_{fe} R_e - h_{oe} R_1 R_e}$$

BOB MAR[illegible]

9-27-71

$G_1 = \frac{h_{fe}}{h_{ie}}$ $\Delta_1 = 1$

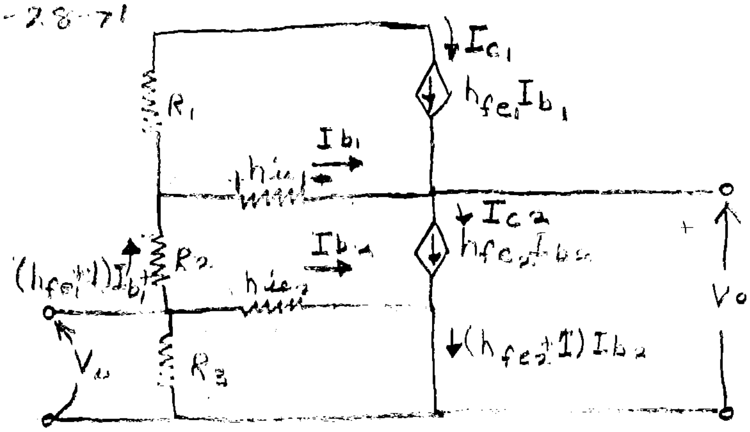
$G_2 = -1/h_{ie}$ $\Delta_2 = 1 + h_{oe}R_1$

$$G_m = \frac{h_{ie}(1 + h_{oe}(R_2 + R_1)) + h_{fe} \ldots - h_{oe}R_1 \ldots}{h_{ie} - 1 - h_{oe}R_1}$$

(2)

9-28-71

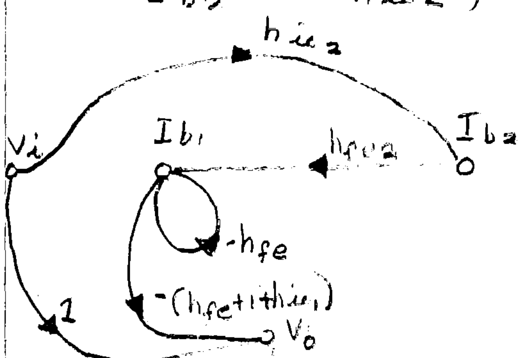
1-3)



$I_{b_1} = h_{fe_2} I_{b_2} - h_{fe_1} I_{b_1} \Rightarrow I_{b_1}(1+h_{fe_1}) = h_{fe} I_{b_2}$

$V_o = -(h_{fe_1}+1) R_2 I_{b_1} - h_{ie_1} I_{b_1} + V_i$

$I_{b_2} = V_i / h_{ie2}$;



$\Delta = 1 + h_{fe}$

$G_1 = 1 \qquad \Delta_1 = 1 + h_{fe}$

$G_2 = -h_{ie2} h_{fe_2} (h_{fe} + h_{ie} + 1)$; $\Delta_2 = 1$

$$A_v = \frac{V_o}{V_i} = \frac{(1+h_{fe_1}) - h_{ie2} h_{fe2} (h_{fe} + h_{ie} + 1)}{(1 + h_{fe})}$$

Table 5-3 Two-port Matrices

1. *Impedance matrix* $[z_{ij}]$ $\qquad \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$

   $\Delta_z = z_{11}z_{22} - z_{12}z_{21}$ $\qquad$ For reciprocal circuits $z_{12} = z_{21}$

2. *Admittance matrix* $[y_{ij}]$ $\qquad \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$

   $\Delta_y = y_{11}y_{22} - y_{12}y_{21}$ $\qquad$ For reciprocal circuits $y_{12} = y_{21}$

3. *Hybrid matrix* $[h_{ij}]$ $\qquad \begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$

   $\Delta_h = h_{11}h_{22} - h_{12}h_{21}$ $\qquad$ For reciprocal circuits $h_{12} = -h_{21}$

4. *Hybrid matrix* $[g_{ij}]$ $\qquad \begin{bmatrix} I_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ I_2 \end{bmatrix}$

   $\Delta_g = g_{11}g_{22} - g_{12}g_{21}$ $\qquad$ For reciprocal circuits $g_{12} = -g_{21}$

5. $(ABCD)$ *matrix* $\qquad \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$

   $\Delta_A = AD - BC$ $\qquad$ For reciprocal circuits $\Delta_A = 1$

6. $(\mathfrak{ABCD})$ *matrix* $\qquad \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \begin{bmatrix} \mathfrak{A} & \mathfrak{B} \\ \mathfrak{C} & \mathfrak{D} \end{bmatrix} \begin{bmatrix} V_1 \\ -I_1 \end{bmatrix}$

   $\Delta_{\mathfrak{A}} = \mathfrak{AD} - \mathfrak{BC}$ $\qquad$ For reciprocal circuits $\Delta_{\mathfrak{A}} = 1$

7. *Scattering matrix* $[S_{ij}]$ $\qquad \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$

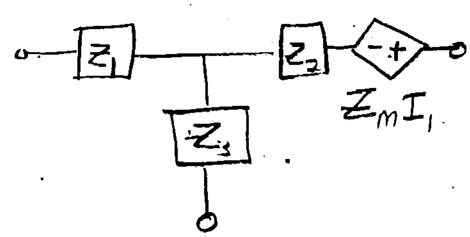
   $\Delta_S = S_{11}S_{22} - S_{12}S_{21}$ $\qquad$ For reciprocal circuits $S_{12} = S_{21}$

8. *Transmission scattering matrix* $[T_{ij}]$ $\qquad \begin{bmatrix} b_1 \\ a_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a_2 \\ b_2 \end{bmatrix}$

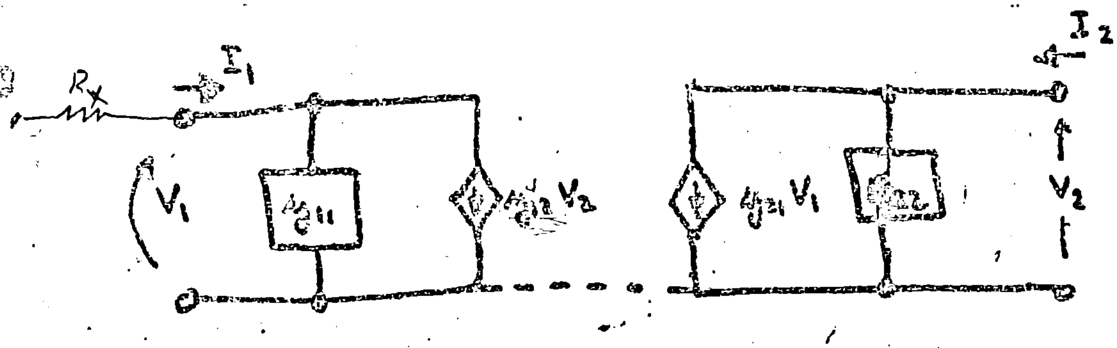
   $\Delta_T = T_{11}T_{22} - T_{12}T_{21}$ $\qquad$ For reciprocal circuits $\Delta_T = 1$ (for $R_1 = R_2$)

EQUIVALENT CIRCUITS

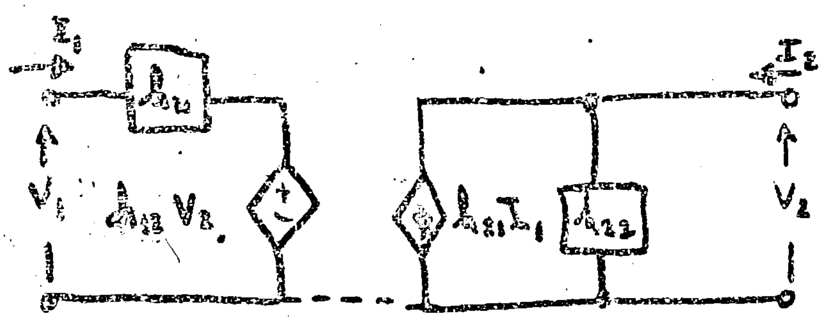
z-parameters



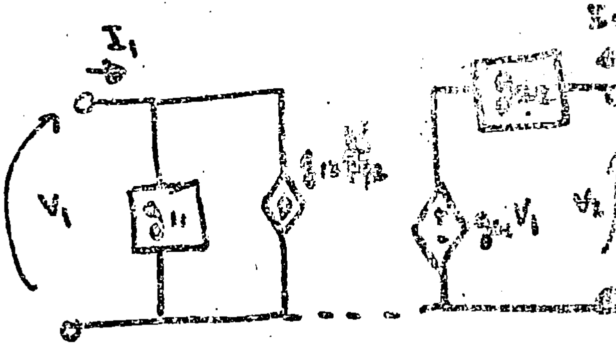
y-parameters



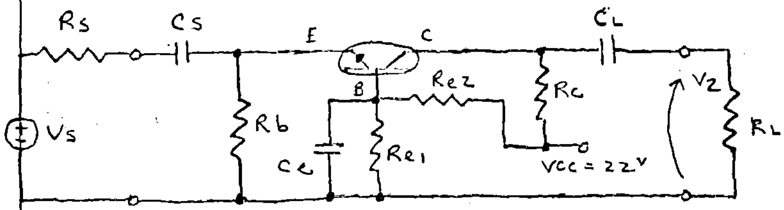
h-parameters



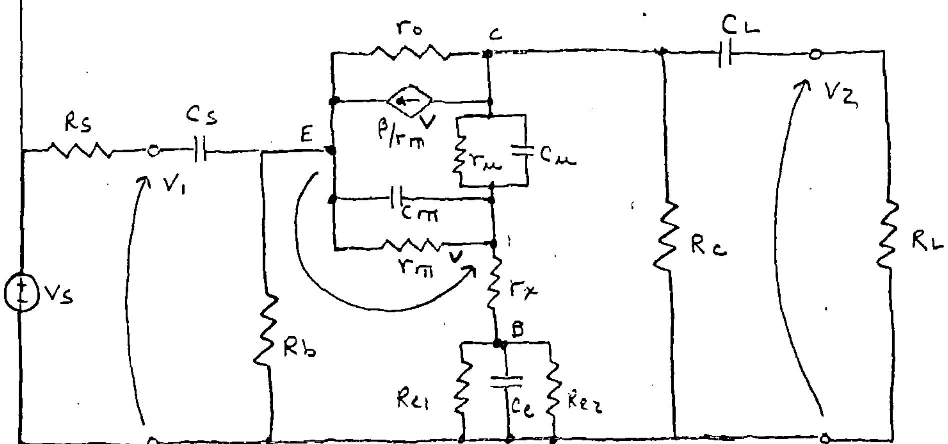
g-parameters



NO EQUIVALENT CIRCUIT EXISTS FOR ABCD AND $\mathcal{ABCD}$.



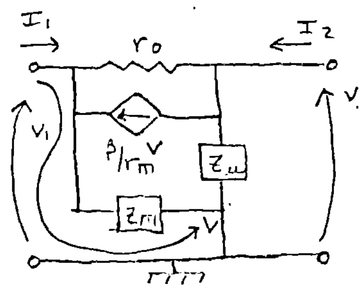
small signal - high frequency model



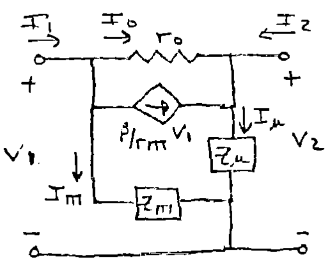
Let $Z_\mu = r_\mu \,||\, C_\mu$

$Z_\pi = r_\pi \,||\, C_\pi$

1)



but $V = -V_1$ so =>



then => $V_2 = I_\mu Z_\mu$ | $V_1 = V_2 + I_o r_o$ | $V_1 = I_\pi Z_\pi$

$\therefore\ I_\mu = V_2 / Z_\mu$ | $I_o = \dfrac{V_1 - V_2}{r_o}$ | $I_\pi = V_1 / Z_\pi$

and $I_1 = I_o + \beta/r_\pi V_1 + I_\pi$ | $I_2 = I_\mu - I_o - \beta/r_\pi V_1$

$\therefore\ I_1 = \dfrac{V_1 - V_2}{r_o} + \beta/r_\pi V_1 + V_1/Z_\pi$ | $I_2 = V_2/Z_\mu + \dfrac{V_2 - V_1}{r_o} - \beta/r_\pi V_1$

so =>

$$I_1 = V_1(g_o + \beta g_\pi + Y_\pi) + V_2(-g_o)$$

$$I_2 = V_1(-g_o - \beta g_\pi) + V_2(Y_\mu + g_o)$$

These are the 2-port network Y parameters for this part

y-> $Y = \begin{bmatrix} g_o + \beta g_\pi + Y_\pi & -g_o \\ -g_o - \beta g_\pi & Y_\mu + g_o \end{bmatrix}$ $\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$

1) $Y \to Z \to Z_T$

$Z_3 = Z_3 + r_x + Z_e$

$Z_T \to Z \to Y$

$Y_{11} = Y_{11} + G_B$

$Y_{22} = Y_{22} + G_C$

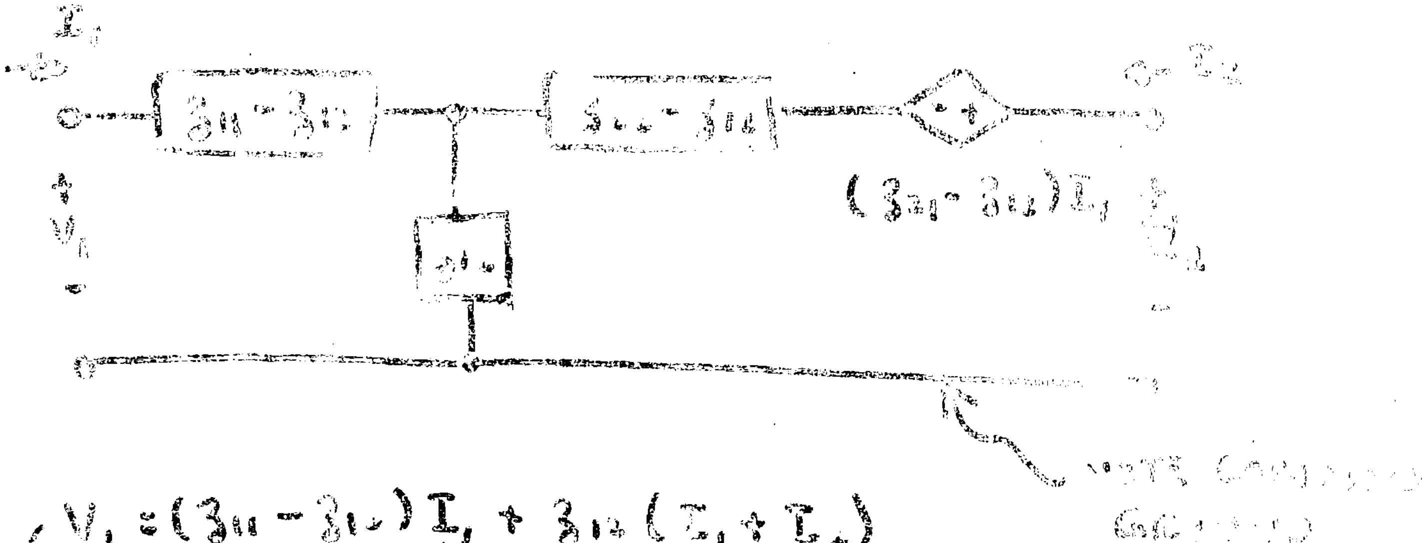
$Y \to Z$

$Z_{11} = Z_{11} + C_S$

$Z_{22} = Z_{22} + C_L$

that's it.

ALTERNATE (T-) FORM OF Z-PARAMETERS



$$V_1 = (z_{11} - z_{12}) I_1 + z_{12} (I_1 + I_2)$$

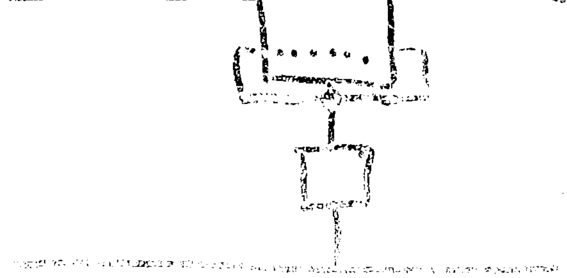
$$V_2 = (z_{21} - z_{12}) I_1 + (z_{22} - z_{12}) I_2 + z_{12} (I_1 + I_2)$$

$$V_1 = z_{11} I_1 + z_{12} I_2$$

$$V_2 = z_{21} I_1 + z_{22} I_2$$

THE USUAL Z-PARAMETER EQUATIONS

THIS FORM IS USED IF YOU HAVE AN AMPLIFIER LIKE THIS



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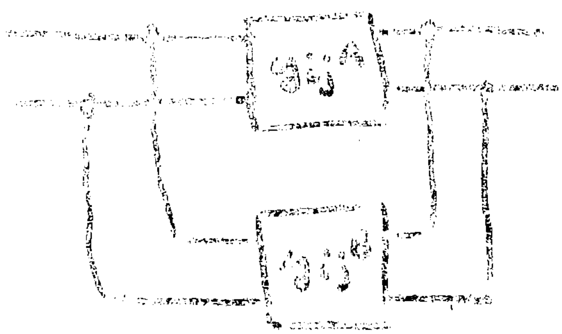
10.6.71.2

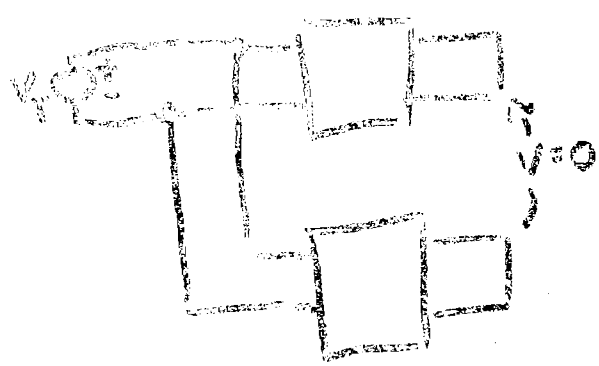
INTERCONNECTIONS OF TWO-PORTS:

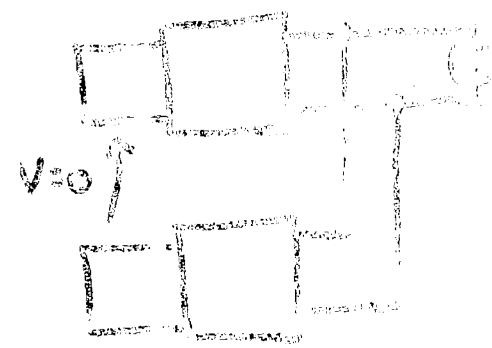
Shunt-shunt configuration



$$y_{ij} = y_{ij}^A + y_{ij}^B$$

VALIDITY TEST FOR SHUNT-SHUNT CONNECTION





NOTE: IF THE 2 TWO-PORTS HAVE COMMON GROUND TERMINAL BETWEEN INPUT & OUTPUT, THE TESTS ARE MET.

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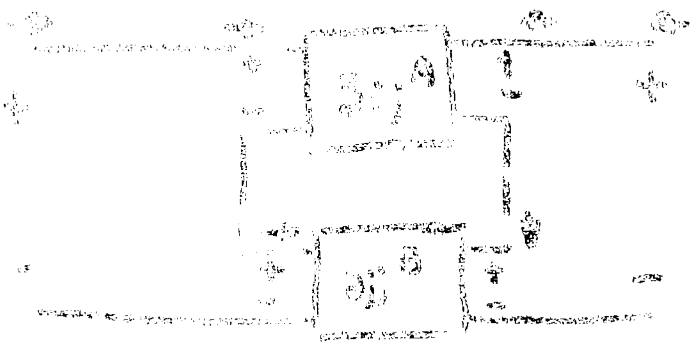
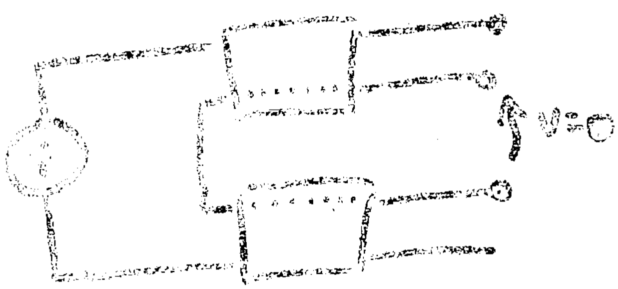
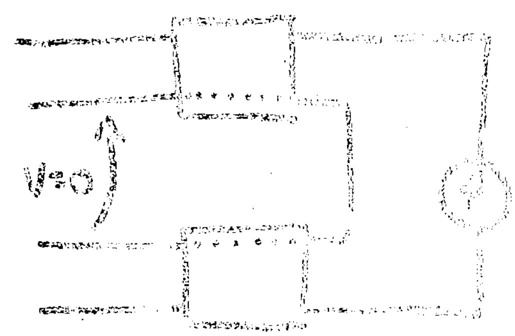
Series-series configuration



$$z_{ij}^{T} = z_{ij}^{A} + z_{ij}^{B}$$

VALIDITY TESTS

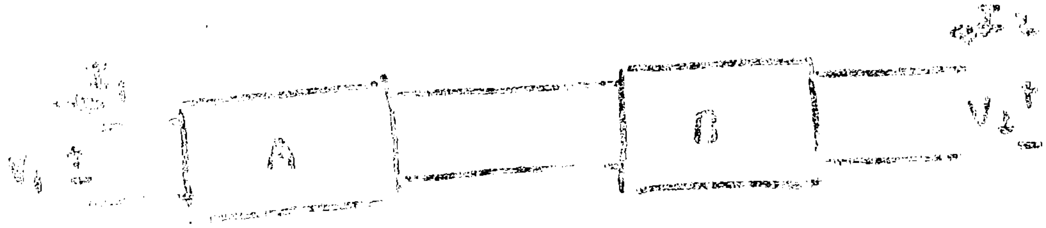




COMMON GROUNDS AS SHOWN IN DOTTED LINES WILL INSURE TESTS ARE MET.

[illegible]
[illegible]

CASCADE CONNECTION



$$[ABCD] = \begin{bmatrix} A^A & B^A \\ C^A & D^A \end{bmatrix} \times \begin{bmatrix} A^B & B^B \\ C^B & D^B \end{bmatrix}$$

DEFINITIONS OF POWER GAINS

$$A_p = \underline{\text{power gain}} = \frac{P_o}{P_{in}} = \frac{|V_2|^2 \, Re\{Y_L\}}{|V_1|^2 \, Re\{Y_{in}\}}$$

Transducer power gain

$$A_{pT} = \frac{P_o}{\text{Power available from source}} = \frac{P_o}{\dfrac{|I_s|^2}{4 Re\{Y_s\}}}$$

Available power gain

$$A_{pA} = \frac{\text{Power available from 2-port}}{\text{Power available from source}} = \frac{\dfrac{|I_N|^2}{4 Re\{Y_N\}}}{(\quad)}$$

I_N, Y_N ARE NORTON'S EQUIVALENT [illegible] OUTPUT PORT.

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10.30.03

INSERTION POWER GAIN

$A_{PI} = \dfrac{P_o}{P_o'}$ $\quad P_o'$ = power into load without 2-port being used.

$$P_o' = \left| \frac{V_s}{Z_s + Z_L} \right|^2 Re\{Z_L\}$$

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10.4.71.4

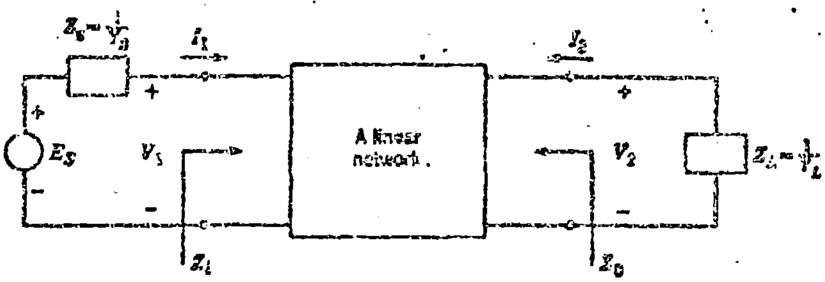


Fig. 3-12

Table 3-3 Gain and Impedance Relations

	$[z_{ij}]$	$[y_{ij}]$	$[g_{ij}]$	$[h_{ij}]$	$\begin{bmatrix} A & B \\ C & D \end{bmatrix}$	$\begin{bmatrix} \mathcal{A} & \mathcal{B} \\ \mathcal{C} & \mathcal{D} \end{bmatrix}$
Z_i	$\frac{\Delta_z + z_{11}Z_L}{z_{22} + Z_L}$	$\frac{y_{22} + Y_L}{\Delta_y + y_{11}Y_L}$	$\frac{g_{22} + Z_L}{\Delta_g + g_{11}Z_L}$	$\frac{\Delta_h + h_{11}Y_L}{h_{22} + Y_L}$	$\frac{AZ_L + B}{CZ_L + D}$	$\frac{\mathcal{D}Z_L + \mathcal{B}}{\mathcal{C}Z_L + \mathcal{A}}$
Z_o	$\frac{\Delta_z + z_{22}Z_s}{z_{11} + Z_s}$	$\frac{y_{11} + Y_s}{\Delta_y + y_{22}Y_s}$	$\frac{\Delta_g + g_{22}Y_s}{g_{11} + Y_s}$	$\frac{h_{11} + Z_s}{\Delta_h + h_{22}Z_s}$	$\frac{DZ_s + B}{CZ_s + A}$	$\frac{\mathcal{A}Z_s + \mathcal{B}}{\mathcal{C}Z_s + \mathcal{D}}$
$A_i = -\frac{I_2}{I_1}$	$\frac{z_{21}}{z_{22} + Z_L}$	$\frac{-y_{21}Y_L}{\Delta_y + y_{11}Y_L}$	$\frac{g_{21}}{\Delta_g + g_{11}Z_L}$	$\frac{-h_{21}Y_L}{h_{22} + Y_L}$	$\frac{1}{D + CZ_L}$	$\frac{\Delta_a}{\mathcal{A} + \mathcal{C}Z_L}$
$A_v = \frac{V_2}{V_1}$	$\frac{z_{21}Z_L}{\Delta_z + z_{11}Z_L}$	$\frac{-y_{21}}{y_{22} + Y_L}$	$\frac{g_{21}Z_L}{g_{22} + Z_L}$	$\frac{-h_{21}}{\Delta_h + h_{11}Y_L}$	$\frac{Z_L}{B + AZ_L}$	$\frac{\Delta_a}{\mathcal{B} + \mathcal{D}Z_L}$

THIS TABLE GIVES FORMULAS FOR CALCULATING INPUT AND OUTPUT IMPEDANCE AND CURRENT AND VOLTAGE GAINS.

POWER GAIN MAY BE GOTTEN:

$$P_o = |I_2|^2 \, Re\{Z_L\}$$

$$P_{in} = |I_1|^2 \, Re\{Z_i\}$$

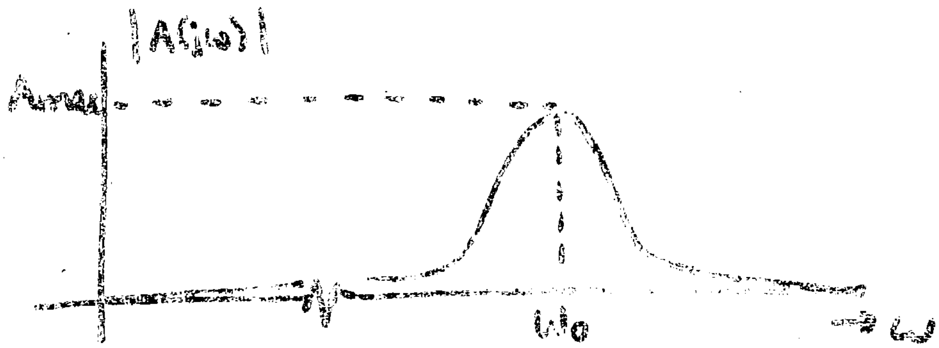
$$A_p = \frac{P_o}{P_{in}} = \frac{|I_2|^2}{|I_1|^2} \cdot \frac{Re\{Z_L\}}{Re\{Z_i\}} = |A_i|^2 \, Re\{Z_L\} / Re\{Z_i\}$$

11.1, 11.1)

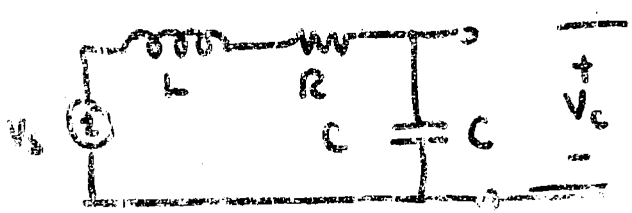
$$\frac{\omega_{max}}{BW} = \frac{\omega_0}{1/RC}$$

$$= \omega_0 RC = Q_0 \text{ of ANTIRESONANT CKT.}$$

The frequency response



Consider: Very PRACTICAL



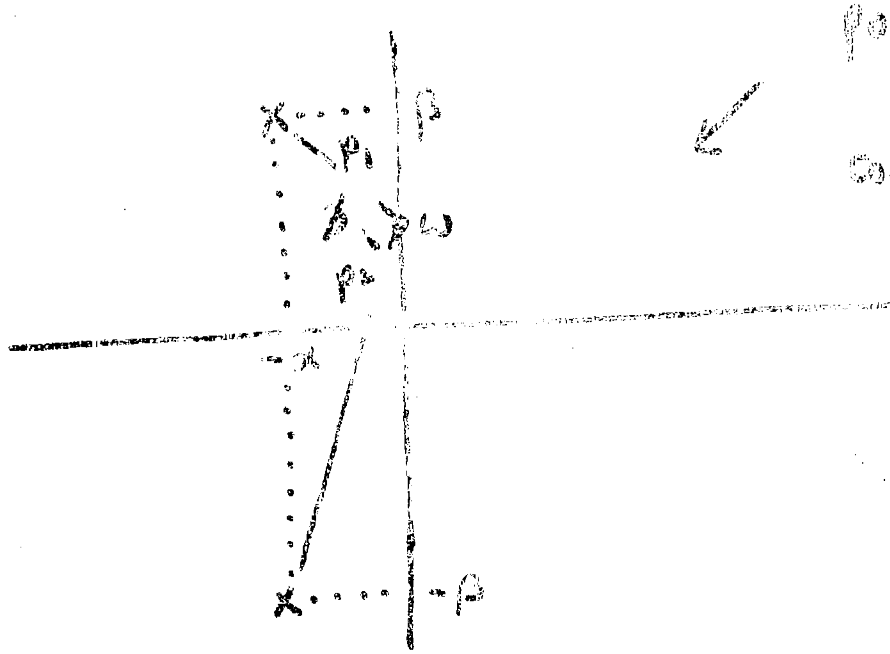
$$\frac{V_c}{V_s} = \frac{\frac{1}{sC}}{\frac{1}{sC} + R + sL} = \frac{1}{s^2LC + RCs + 1}$$

$$= \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{LC}}$$

$$A(s) = \omega_0^2 \frac{1}{s^2 + \frac{R}{L}s + \left(\frac{R}{2L}\right)^2 + \omega_0^2 - \left(\frac{R}{2L}\right)^2}$$

$\left(\frac{R}{2L}\right) = \alpha$; $\omega_0^2 - \left(\frac{R}{2L}\right)^2 = \beta^2$

$$= \omega_0^2 \frac{1}{(s+\alpha)^2 + \beta^2}$$



pole-zero pattern in complex conj. case, i.e. $\omega_0^2 > \left(\frac{R}{2L}\right)^2$

$$|A(j\omega)| = \omega_0^2 \frac{1}{(p_1 p_2)}$$

The triangle has area $= \frac{1}{2} p_1 p_2 \sin\theta$

$= \alpha\beta$

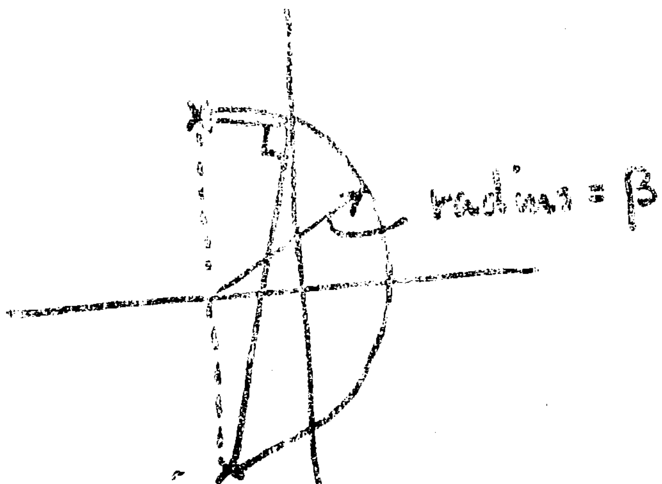
$$\therefore \frac{1}{p_1 p_2} = \frac{\sin\theta}{2\alpha\beta}$$

EE 3?3
[illegible]

$$|A(j\omega)| = \omega_0^2 \frac{\sin\phi}{2\alpha\beta}$$

Thus we may maximize $|A|$ by maximizing $\sin\phi$

$(\sin\phi)_{max}$ occurs when $\phi = 90°$



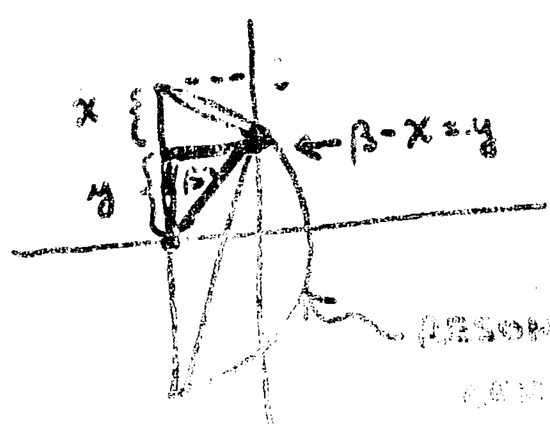
$$|A(j\omega)|_{max} = \boxed{\frac{\omega_0^2}{2\alpha\beta}} \stackrel{?}{=} Q_0$$ ← CHECK THIS

Where does this occur?

$\omega_{MAX} = \beta - x = y$

$$\boxed{\omega_{max} = \sqrt{\beta^2 - \alpha^2}}$$

$$= \sqrt{\omega_0^2 - 2\alpha^2}$$



RESONANT PEAKING CIRCLE

CENTER AT $-\alpha$

RADIUS = β

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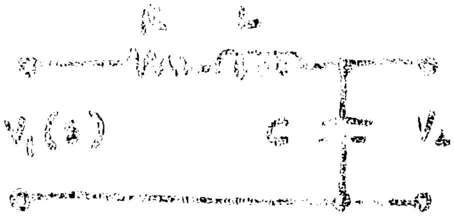
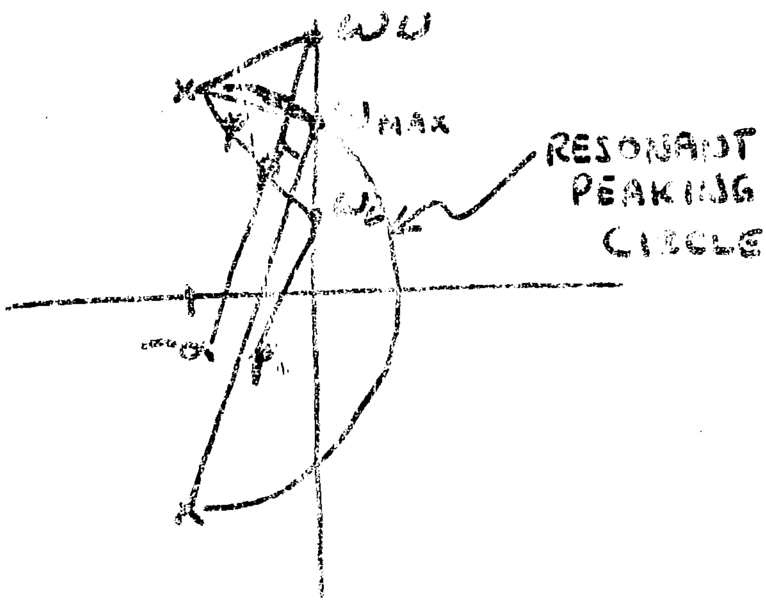
11.1.70.9



$$\frac{V_2(s)}{V_1(s)} = H(s) = \frac{\omega_0^2}{(s+\alpha)^2+\beta^2}$$

$$\alpha = \frac{R}{2L} \qquad \beta = \sqrt{\omega_0^2 - \alpha^2}$$



$$\omega_{MAX} = \sqrt{\omega_0^2 - 2\alpha^2}$$

ω_P

START HERE

FIND ½ POWER FREQUENCIES.

$$|A(j\omega)| = \frac{\omega_0^2}{2\alpha\beta} \sin\phi$$

ω_U OCCURS WHEN $\phi =$ ~~120°~~ 135° ←

ω_L " " $\phi =$ ~~30°~~ 45° ←

$$H(s) = \frac{\omega_0^2}{(s+\alpha)^2+\beta^2} = \frac{\omega_0^2}{s^2+2\alpha s+\omega_0^2}$$

$$H(j\omega) = \frac{\omega_0^2}{\omega_0^2-\omega^2+j2\alpha\omega}$$

AT THE HALF POWER FREQUENCIES

$$\left|\omega_0^2-\omega^2+j2\alpha\omega\right|^2 = 2(2\alpha\beta)^2$$

$$(\omega_0^2-\omega^2)^2+4\alpha^2\omega^2 = 8\alpha^2\beta^2$$

$$\omega^4-2\omega_0^2\omega^2+\omega_0^4+4\alpha^2\omega^2-8\alpha^2\beta^2=0$$

$$x=\omega^2$$

$$x^2+x(4\alpha^2-2\omega_0^2)+\omega_0^4-8\alpha^2\beta^2=0$$

$$\beta^2 \uparrow \; \omega_0^2-\alpha^2$$

$$x^2-2(\omega_0^2-2\alpha^2)x+\omega_0^4-8\alpha^2(\omega_0^2-\alpha^2)=0$$

$$x^2-2(\omega_0^2-2\alpha^2)x+\omega_0^4-8\alpha^2\omega_0^2+8\alpha^4=0$$

$$x^2-2(\omega_0^2-2\alpha^2)x+\omega_0^4-4\alpha^2\omega_0^2+4\alpha^4-4\alpha^2(\omega_0^2-\alpha^2)=0$$

$$\left[x-(\omega_0^2-2\alpha^2)\right]^2-4\alpha^2\beta^2=0$$

[illegible]

$$\left[x - \omega_{max}^2\right]^2 - (2\alpha\beta)^2 = 0 \qquad \leftarrow \omega_0^2 - 2\alpha^2$$

$$\left(a^2 - b^2 = (a-b)(a+b) \right)$$

$$\left[x - \omega_{max}^2 - 2\alpha\beta\right] \cdot \left[x - \omega_{max}^2 + 2\alpha\beta\right] = 0$$

$\therefore$

$$x = \omega_{max}^2 + 2\alpha\beta \qquad\qquad x = \omega_{max}^2 - 2\alpha\beta$$

$$\boxed{\omega_U^2 = \omega_{max}^2 + 2\alpha\beta} \qquad \boxed{\omega_L^2 = \omega_{max}^2 - 2\alpha\beta}$$

SPECIAL CASE, $\beta \gg \alpha$ $\quad \omega_0 \approx \beta \approx \omega_{max}$

$$\omega_U^2 \doteq \omega_0^2 + 2\alpha\omega_0$$

$$\omega_U \doteq \omega_0\sqrt{1 + \frac{2\alpha}{\omega_0}} \qquad \omega_L \doteq \omega_0\sqrt{1 - \frac{2\alpha}{\omega_0}}$$

$$\doteq \omega_0\left(1 + \frac{\alpha}{\omega_0}\right) = \omega_0 + \alpha \qquad \doteq \omega_0\left(1 - \frac{\alpha}{\omega_0}\right)$$

$$BW \doteq 2\alpha = 2\left(\frac{R}{2L}\right) = \boxed{\frac{R}{L}} \leftarrow \text{APPROXIMATION}$$

GOOD IN "H[illegible]" CASE.

[illegible]

[illegible]

Special case of two comp. conj. poles...

called the **MAXIMALLY FLAT** gain characteristic

$$A(j\omega) = \frac{\omega_0^2 \sin\phi}{2\alpha\beta} = A_p \sin\phi$$

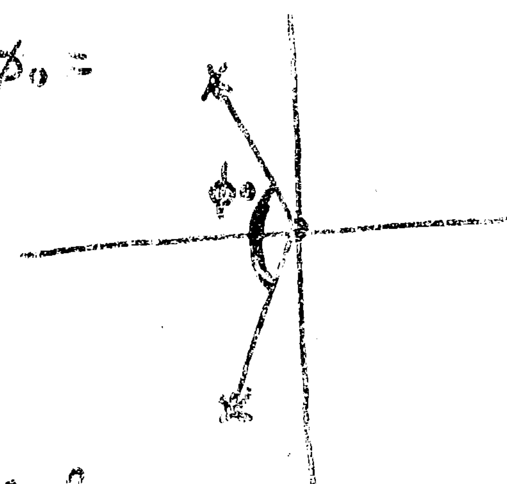
↑ peak gain value

PEAK-TO-VALLEY RATIO:

$$\boxed{\frac{A_p}{A_0} = \frac{1}{\sin\phi_0}}$$

$A_0 = |A(s=0)|$ gain at DC

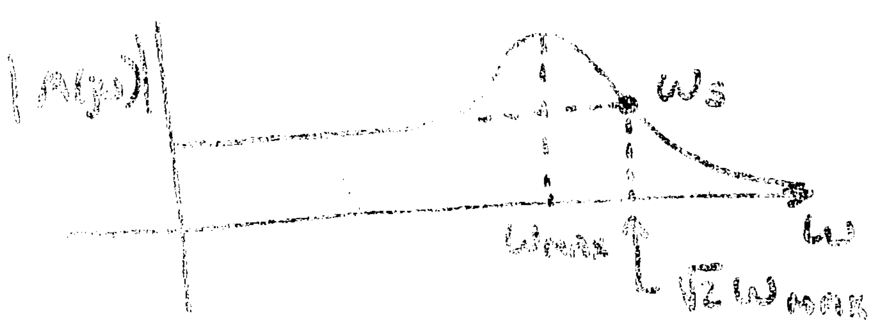
$\phi_0 =$



$$\boxed{\tan\frac{\phi_0}{2} = \frac{\beta}{\alpha}}$$

Peak occurs only if

$\phi_0 >$ 90°



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THERE WILL BE NO PEAK, i.e., $\frac{A_p}{A_0} = 1$ IF

$\phi_0 \leq 90°$

$\phi_0 = 90°$

UNDER THESE CONDITIONS, THE AMPLIFIER IS SAID TO BE MAXIMALLY FLAT. (BUTTERWORTH)

$\alpha = \beta$

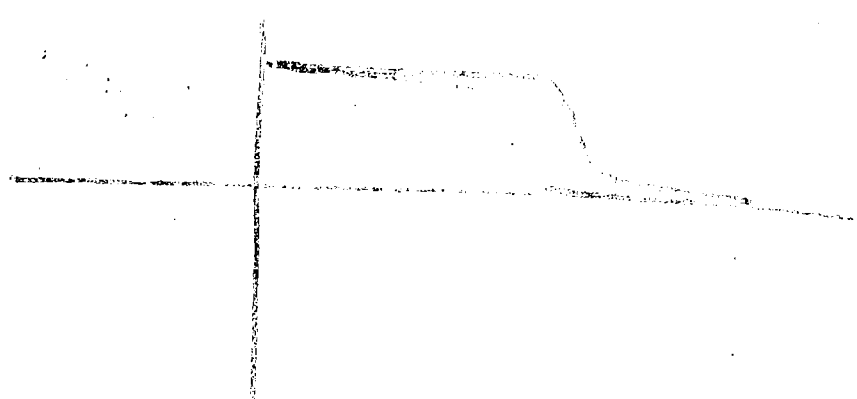
$$\omega_0^2 - \alpha^2 = \alpha^2$$

$$\omega_0^2 = 2\alpha^2$$

$$\frac{1}{LC} = 2\left(\frac{R}{2L}\right)^2$$

$$\frac{1}{LC} = \frac{R^2}{2L^2}$$

$$\boxed{L = \frac{1}{2}R^2C}$$ ← CONDITIONS FOR MAXIMALLY FLAT RESPONSE.



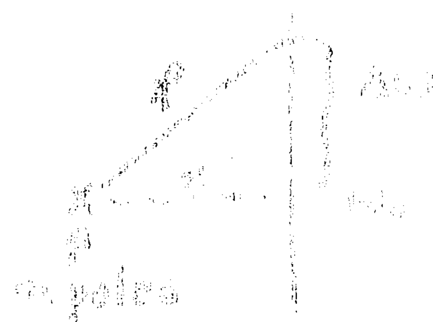
[illegible]

[illegible]

[illegible]

[illegible]

[illegible]



[illegible] (any frequency)

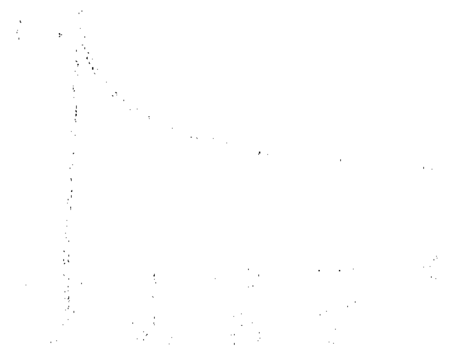
[illegible]

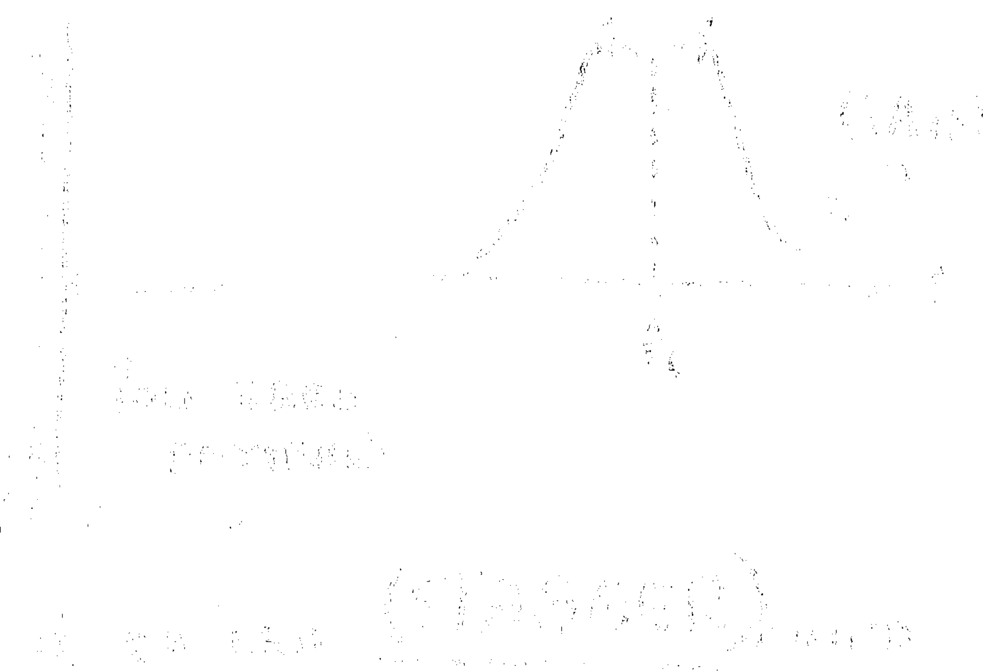
[illegible]

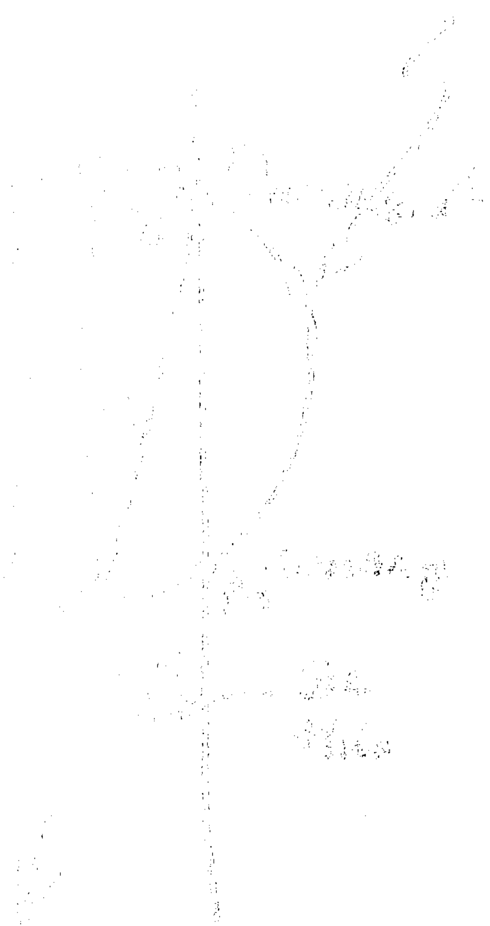
[illegible]

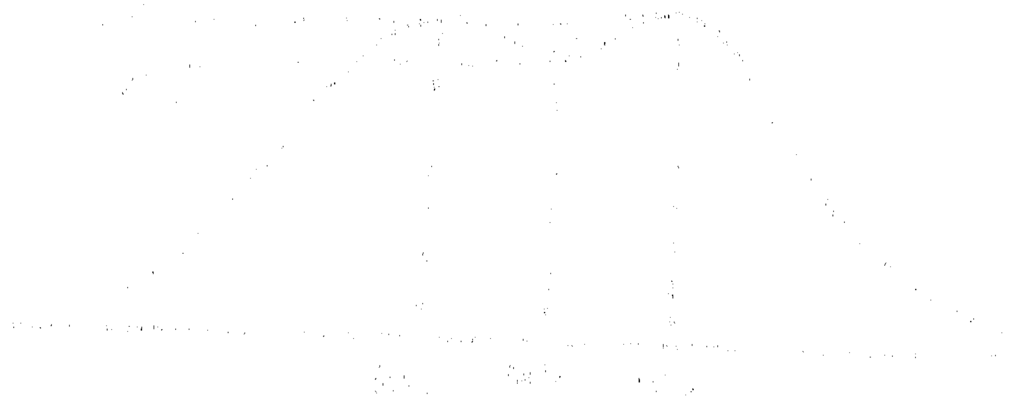
[illegible]

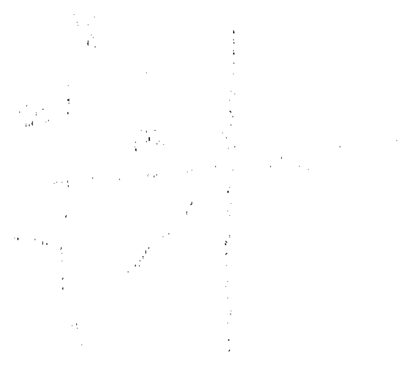
Bandwidth [illegible]











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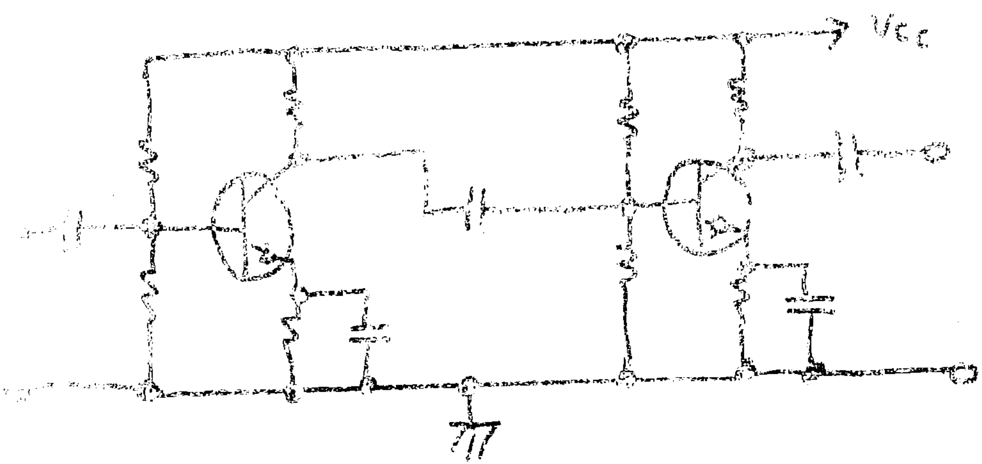
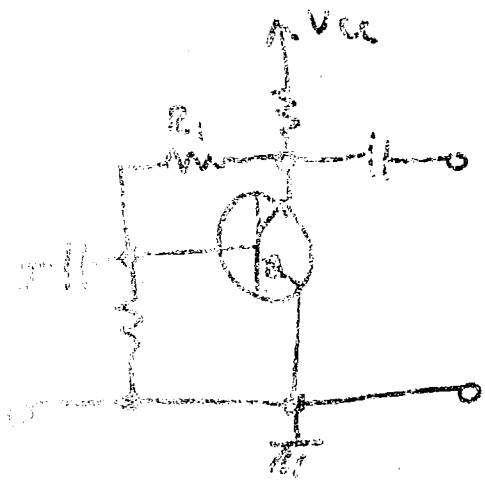
TWO-STAGE BJT AMPLIFIER, R-C COUPLED

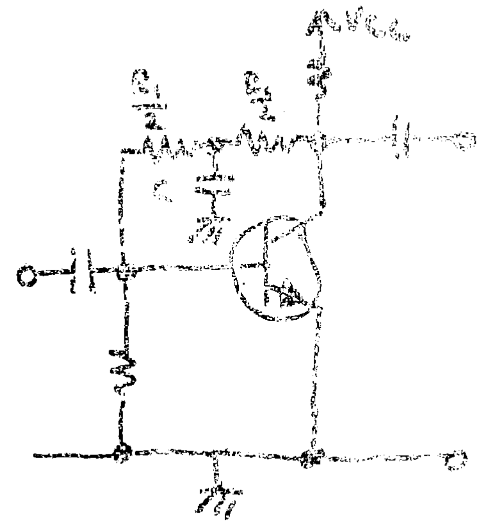


13 COMPONENTS

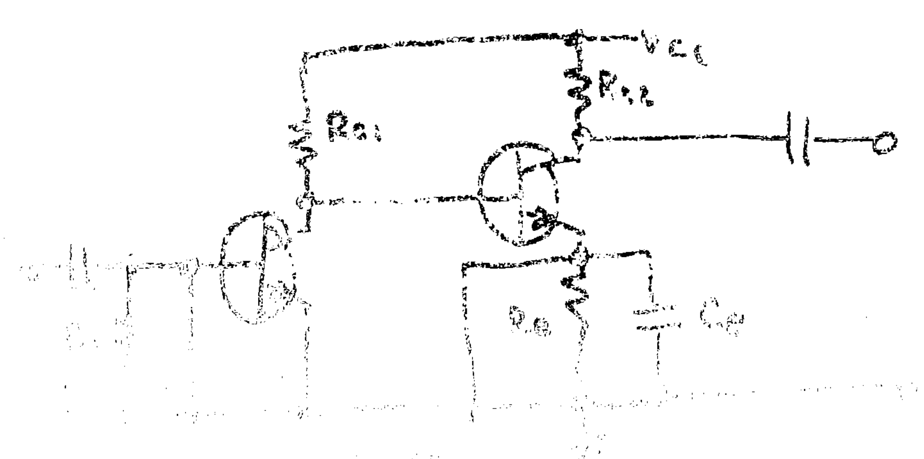
A STAGE MAY BE STABILIZED LIKE THIS



=>



DIRECT COUPLED



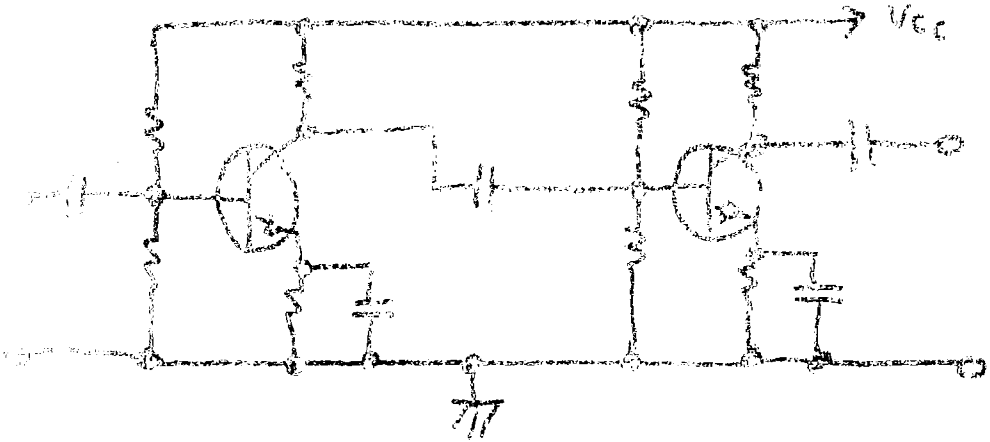
8 COMPONENTS

R1 may be

[illegible]

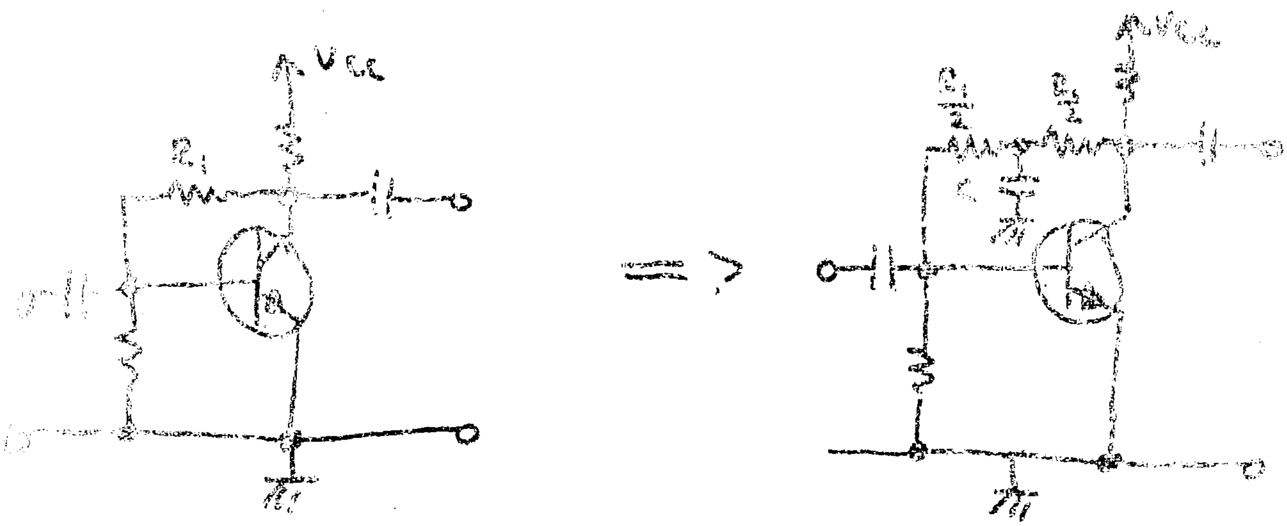
EE 363
11.9.71.1

TWO-STAGE BJT AMPLIFIER, R-C COUPLED

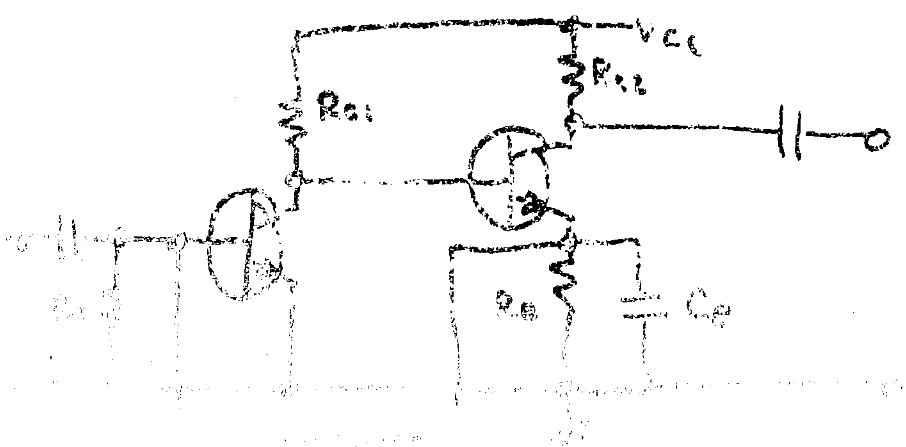


13 COMPONENTS

A STAGE MAY BE STABILIZED LIKE THIS

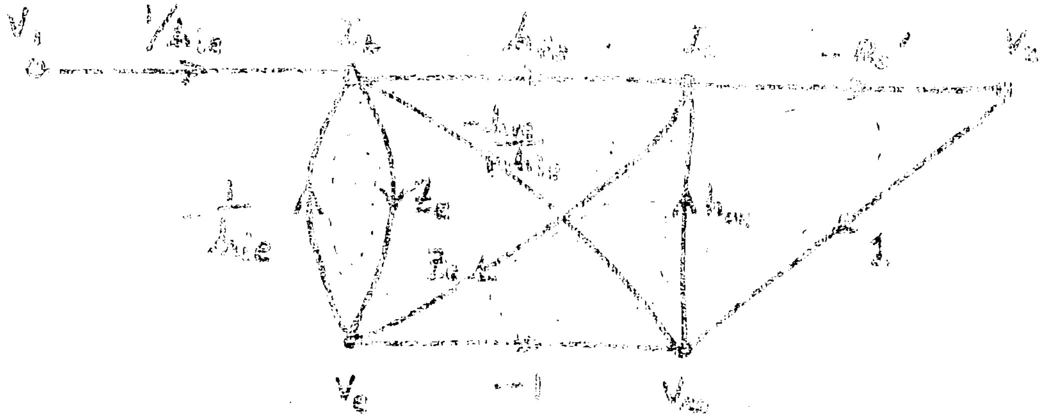


DIRECT COUPLED



8 COMPONENTS

R1 may be



$$\Delta = 1 + h_{oe}R_c' + \frac{Z_e}{h_{ie}} + h_{oe}Z_e + \frac{h_{fe}Z_e}{h_{ie}} - \frac{h_{fe}R_c h_{re}}{h_{ie}} - \frac{h_{fe}R_c' h_{re}}{h_{ie}}$$

$$- \frac{h_{re}Z_e}{h_{ie}} + \left(\frac{-Z_e}{h_{ie}}\right)\left(\frac{-h_{oe}R_c'}{1}\right)$$

$$\frac{V_1}{V_2} = \frac{1}{\Delta}\left[\frac{-h_{fe}R_c'}{h_{ie}} + \frac{h_{oe}R_c' Z_e}{h_{ie}}\right]$$

$$A_v = \boxed{\frac{h_{oe}R_c' Z_e - h_{fe}R_c'}{h_{ie}\left[1 + h_{oe}(Z_e + R_c')\right] + (1 + h_{fe})Z_e - (1 + h_{fe})h_{re}Z_e + h_{oe}R_c' Z_e - h_{fe}R_c' h_{re}}}$$

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9.15.71.2

APPROX VOLTAGE GAIN BASED ON h_{ie} AND h_{fe}

$$A_v \doteq \frac{-h_{fe} R_L}{h_{ie} + (1 + h_{fe}) Z_E}$$

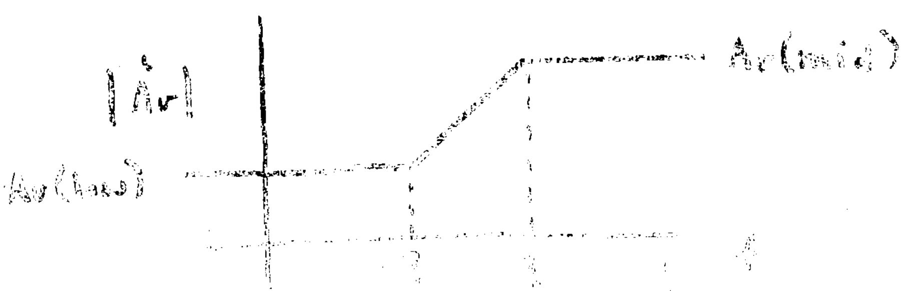
LOW FREQUENCY APPROX GAIN $Z_E = R_E$

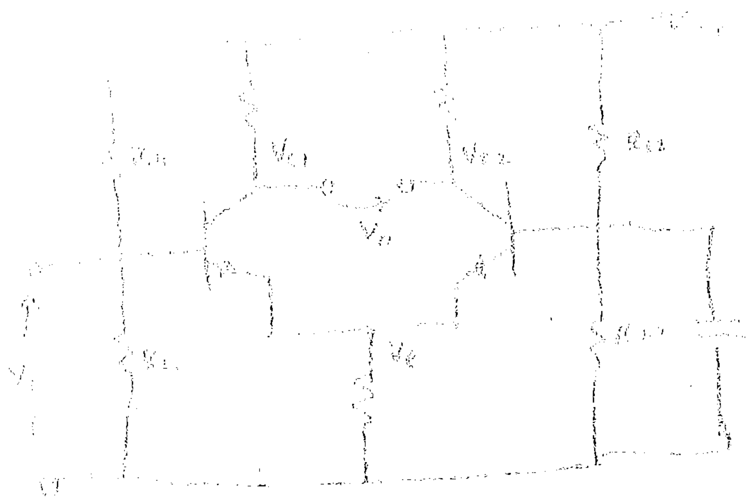
$$A_v(\text{low}) \doteq \frac{-h_{fe} R_L}{h_{ie} + (1 + h_{fe} R_E)}$$

MID FREQ. APPROX. GAIN $Z_E \doteq 0$

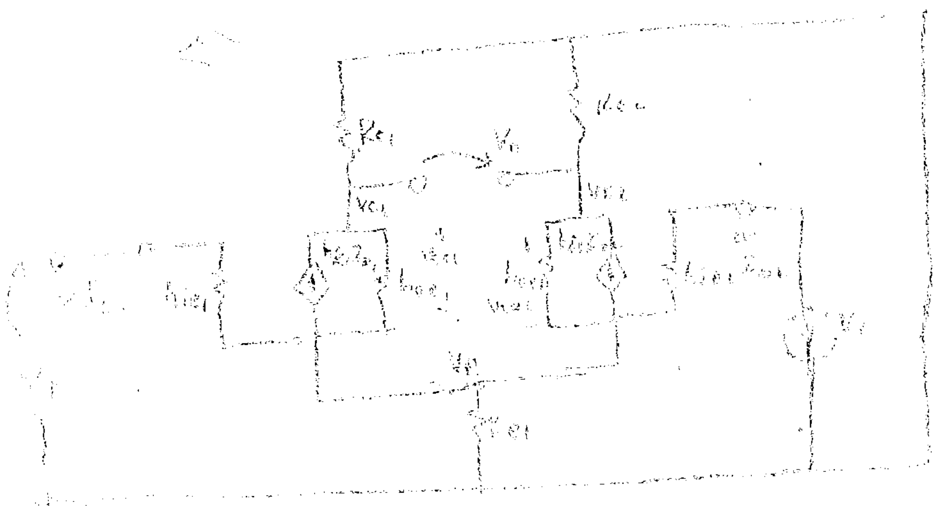
$$A_v(\text{mid}) = \frac{-h_{fe} R_L}{h_{ie}}$$

FREQUENCY RESPONSE





Equivalent circuit — hre = 0



$V_o = V_{c2} - V_{c1}$

$V_{c1} = -I_{c1} R_{c1}$

$V_{c2} = -I_{c2} R_{c2}$

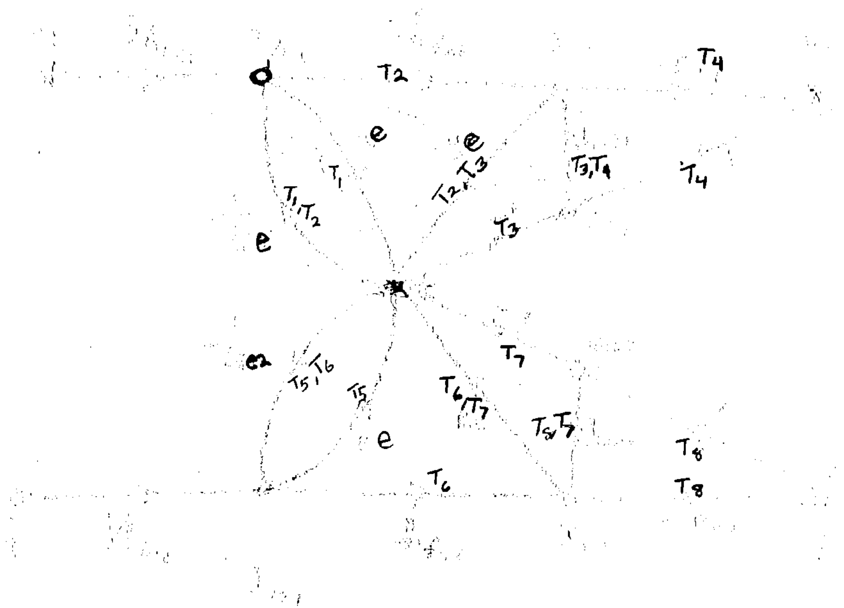
$I_{c1} = h_{fe1} I_{b1} + h_{oe1} V_{ce1}$

$I_{c2} = h_{fe2} I_{b2} + h_{oe2} V_{ce2}$

$I_{b1} = \frac{V_1 - V_E}{h_{ie1}}$ $\quad I_{b2} = \frac{V_2 - V_E}{h_{ie2}}$

$V_E = R_E (I_{b1} + I_{b2} + I_{c1} + I_{c2})$

$G(V_1 \cdot V_{01})$ $G(V_2$



T_1 T_2 e T_3 T_4

T_5 T_6

$V_0 / V_1 = K$ $V_0 = A V_1 - B V_2$

$A = M' - K$

$V_0 / V_2 = M$ $B = M \cdot K'$

V_0 / V_2

$V_0 / V_1 = M'$

$$V_{C1} = T_1 V_1 + T_2 V_2$$

BOB MARKS
(ORIGINAL)

MACE

OPERATING SYSTEM

VERSION 4.1

JOB ORIGIN - EXPORT/IMPORT

```
X          X  RRRRRRRRRRR   RRRRRRRRRRR             JJ  MM        MM    99999999       000000
XX        XX  RRRRRRRRRRRR  RRRRRRRRRRRR            JJ  MMM      MMM   9999999999     00000000
XX        XX  RR        RR  RR        RR            JJ  MMMM    MMMM  99        99   00      00
 XX      XX   RR        RR  RR        RR            JJ  MM MM  MM MM  99        99  00        00
  XX    XX    RR        RR  RR        RR            JJ  MM  MMMM  MM  99        99  00        00
   XX  XX     RR        RR  RR        RR            JJ  MM   MM   MM  99        99  00        00
    XXXX      RR        RR  RR        RR            JJ  MM        MM  99        99  00        00
     XX       RRRRRRRRRRRR  RRRRRRRRRRRR            JJ  MM        MM   99999999999  00        00
     XX       RRRRRRRRRRR   RRRRRRRRRRR             JJ  MM        MM    9999999999  00        00
    XXXX      RR  RR        RR  RR                  JJ  MM        MM            99  00        00
   XX  XX     RR   RR       RR   RR                 JJ  MM        MM           99   00        00
  XX    XX    RR    RR      RR    RR                JJ  MM        MM          99    00        00
 XX      XX   RR     RR     RR     RR               JJ  MM        MM         99     00        00
XX        XX  RR      RR    RR      RR    JJ        JJ  MM        MM        99       00      00
XX        XX  RR       RR   RR       RR   JJJJJJJJJJJJ  MM        MM       99         00000000
X          X  RR        RR  RR        RR   JJJJJJJJJJ   MM        MM      99           000000

====================================================================================================
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```

Tally

```
               PROGRAM TRAMP(INPUT,OUTPUT,TAPE2=INPUT,TAPE5=OUTPUT)
 000002        DIMENSION SAM(2,7)
 000002        WRITE (5,30)
 000006        READ(2,10)VO,B1,B2,VCEMIN,XIC1,XIC2,XK,VCC
             C SAM (MIN)    B1,VCC1,VO1,R11,R21,RE1,RC1
             C        (MAX)    B2,VCC2,VO2,R12,R22,RE2,RC2
 000032        READ(2,11)((SAM(I,J),I=1,2),J=1,3)
             C        WILL READ ALL NON-RESISTIVE VALUES INTO SAM
 000045        CALL DESIGN(VCC,B1,B2,VCEMIN,XIC1,XIC2,VO,XK,R1,R2,RC,RE,SE1,SE2,
              2XN,RB)
             C        DESIGN COMPUTES VALUES OF THE FOUR BIAS RESISTORS IN A COMMON-EMITTER
             C        TRANSISTOR AMPLIFIER
 000065        WRITE(5,90) R1,R2,RC,RE
             C        FILLING IN THE REST OF SAM
             C        STDVAL COMPUTES CLOSEST STANDARD 10 PER CENT RESISTOR
 000101        SAM(1,4)=STDVAL(R1)*0.9
 000104        SAM(1,5)=STDVAL(R2)*0.9
 000107        SAM(1,6)=STDVAL(RE)*0.9
 000112        SAM(1,7)=STDVAL(RC)*0.9
 000115        SAM(2,4)=STDVAL(R1)*1.1
 000120        SAM(2,5)=STDVAL(R2)*1.1
 000123        SAM(2,6)=STDVAL(RE)*1.1
 000126        SAM(2,7)=STDVAL(RC)*1.1
 000131        XICEO=0.0
             C        DO LOOPS COMBINE SAM INTO 128 SETS OF INPUT PARAMETERS FOR ANALYZ
 000133        DO 12 I1=1,2
 000134          B=SAM(I1,1)
 000136        DO 12 I2=1,2
 000137        VCC=SAM(I2,2)
 000141        DO 12 I3=1,2
 000142         VO=SAM(I3,3)
 000144        DO 12 I4=1,2
 000145         R1=SAM(I4,4)
 000147        DO 12 I5=1,2
 000150         R2=SAM(I5,5)
 000152        DO 12 I6=1,2
 000153         RE=SAM(I6,6)
 000155        DO 12 I7=1,2
 000156         RC=SAM(I7,7)
             C        ANALYZ CALCULATES QUIESCENT OPERATING POINT FOR COMMON EMITTER
             C        TRANSISTOR AMPLIFIER
 000160        CALL ANALYZ(VCC,B,R1,R2,RC,RE,VO,XICEO,XIC,VCE,RB,XN,SE,VBB)
 000175        WRITE(5,99)I1,I2,I3,I4,I5,I6,I7,XIC,VCE,XN,SE
 000227     12 CONTINUE
 000245     10 FORMAT(8F7.3)
 000245     11 FORMAT(6F10.4)
 000245     30 FORMAT(' ROBERT J. MARKS II--EE363=1',/,/)
 000245     90 FORMAT(2X,'R1=',F10.4,2X,'R2=',F10.4,2X,'RC=',F10.4,2X,'RE=',F10.4
              2,/)
 000245     99 FORMAT('  B',I1,X,'VCC',I1,X,'VO',I1,X,'R1',I1,X,'R2',I1,X,'RE',I
              M1,X,'RC',I1     ,4X,'IC=',F10.7,4X,'VCE=',F10.7,4X,'N=',F10.7,
              Y4X,'SE=',F10.7)
 000245        STOP
 000247        END

 PROGRAM LENGTH INCLUDING I/O BUFFERS
 002477
```

```
AAA = XIC1
BBB = XIC2
XIC1 = 2.9
XIC2 = 3.1

XIC1 = AAA
XIC2 = BBB

NOUT = 0
ICMX = 0
ICMN = 0
NVCE = 0

    IF(XIC - XIC1) 400,300,301
301 IF(XIC - XIC2) 300,300,302
300 IF(VCE - VCEMIN) 303,12,12
400 ICMN = ICMN + 1
    GO TO 401
302 ICMX = ICMX + 1
    GO TO 401
303 NVCE = NVCE + 1
401 NOUT = NOUT + 1

    WRITE(5,100) NOUT, ICMX, ICMN, NVCE
100 Format (//// 'AMPLIFIER
    OUT OF TOLERANCE IN', I3,
    ' CASES'///' CAUSED BY'//
```

UNUSED COMPILER SPACE
026100

'ΔICΔΔMAXΔ', I3, 'ΔTIMES'/
'ΔICΔΔMINΔ', I3, 'ΔTIMES'/
'ΔVCEΔMINΔ', I3, 'ΔTIMES'/'1')

LOAD MAP.   09/23/71. 11.32.00.   PAGE   1

FL REQUIRED TO LOAD   16700
FL REQUIRED TO RUN   11100
INITIAL TRANSFER TO TRAMP   -   103

BLOCK ASSIGNMENTS.

BLOCK	ADDRESS	LENGTH	FILE
TRAMP	102	2477	LGO
STDVAL	2601	173	LGO
ANALYZ	2774	103	LGO
DESIGN	3077	112	LGO
ALNLOG	3211	67	SYSLIB
INPUTC	3300	102	SYSLIB
KODER	3402	1247	SYSLIB
KRAKER	4651	1174	SYSLIB
/SCOPE2/	6045	0	
SYSTEM	6045	1076	SYSLIB
SIO$	7143	1425	SYSLIB
OUTPTC	10570	72	SYSLIB
RBAIEX	10662	41	SYSLIB
SQRT	10723	43	SYSLIB
GETBA	10766	17	SYSLIB

ROBERT J. MARKS II--EE363=1

28/128

R1= 142.0987 R2= 40.8834 RC= 4.6061 RE= 1.1515

B1	VCC1	VO1	R11	R21	RE1	RC1	IC= 2.4655277	VCE=10.8547923	N= 7.3138219	SE= .3511744
B1	VCC1	VO1	R11	R21	RE1	RC2	IC= 2.4655277	VCE= 8.5371963	N= 7.3138219	SE= .3511744
B1	VCC1	VO1	R11	R21	RE2	RC1	IC= 2.1494189	VCE=12.0139806	N= 7.3138219	SE= .3086638
B1	VCC1	VO1	R11	R21	RE2	RC2	IC= 2.1494189	VCE= 9.9935269	N= 7.3138219	SE= .3086638
B1	VCC1	VO1	R11	R22	RE1	RC1	IC= 2.7918577	VCE= 9.1149317	N= 8.5622206	SE= .3865851
B1	VCC1	VO1	R11	R22	RE1	RC2	IC= 2.7918577	VCE= 6.4905855	N= 8.5622206	SE= .3865851
B1	VCC1	VO1	R11	R22	RE2	RC1	IC= 2.4510605	VCE=10.3319065	N= 8.5622206	SE= .3417888
B1	VCC1	VO1	R11	R22	RE2	RC2	IC= 2.4510605	VCE= 8.0279096	N= 8.5622206	SE= .3417888
B1	VCC1	VO1	R12	R21	RE1	RC1	IC= 2.4655277	VCE=10.8547923	N= 7.3138219	SE= .3511744
B1	VCC1	VO1	R12	R21	RE1	RC2	IC= 2.4655277	VCE= 8.5371963	N= 7.3138219	SE= .3511744
B1	VCC1	VO1	R12	R21	RE2	RC1	IC= 2.1494189	VCE=12.0139806	N= 7.3138219	SE= .3086638
B1	VCC1	VO1	R12	R21	RE2	RC2	IC= 2.1494189	VCE= 9.9935269	N= 7.3138219	SE= .3086638
B1	VCC1	VO1	R12	R22	RE1	RC1	IC= 2.7918577	VCE= 9.1149317	N= 8.5622206	SE= .3865851
B1	VCC1	VO1	R12	R22	RE1	RC2	IC= 2.7918577	VCE= 6.4905855	N= 8.5622206	SE= .3865851
B1	VCC1	VO1	R12	R22	RE2	RC1	IC= 2.4510605	VCE=10.3319065	N= 8.5622206	SE= .3417888
B1	VCC1	VO1	R12	R22	RE2	RC2	IC= 2.4510605	VCE= 8.0279096	N= 8.5622206	SE= .3417888
B1	VCC1	VO2	R11	R21	RE1	RC1	IC= 2.4354895	VCE=11.0149441	N= 6.7914060	SE= .3511744
B1	VCC1	VO2	R11	R21	RE1	RC2	IC= 2.4354895	VCE= 8.7255840	N= 6.7914060	SE= .3511744
B1	VCC1	VO2	R11	R21	RE2	RC1	IC= 2.1232319	VCE=12.1600097	N= 6.7914060	SE= .3086638
B1	VCC1	VO2	R11	R21	RE2	RC2	IC= 2.1232319	VCE=10.1641717	N= 6.7914060	SE= .3086638
B1	VCC1	VO2	R11	R22	RE1	RC1	IC= 2.7634588	VCE= 9.2663430	N= 7.9506334	SE= .3865851
B1	VCC1	VO2	R11	R22	RE1	RC2	IC= 2.7634588	VCE= 6.6686917	N= 7.9506334	SE= .3865851
B1	VCC1	VO2	R11	R22	RE2	RC1	IC= 2.4261282	VCE=10.4709386	N= 7.9506334	SE= .3417888
B1	VCC1	VO2	R11	R22	RE2	RC2	IC= 2.4261282	VCE= 8.1903781	N= 7.9506334	SE= .3417888
B1	VCC1	VO2	R12	R21	RE1	RC1	IC= 2.4354895	VCE=11.0149441	N= 6.7914060	SE= .3511744
B1	VCC1	VO2	R12	R21	RE1	RC2	IC= 2.4354895	VCE= 8.7255840	N= 6.7914060	SE= .3511744
B1	VCC1	VO2	R12	R21	RE2	RC1	IC= 2.1232319	VCE=12.1600097	N= 6.7914060	SE= .3086638
B1	VCC1	VO2	R12	R21	RE2	RC2	IC= 2.1232319	VCE=10.1641717	N= 6.7914060	SE= .3086638
B1	VCC1	VO2	R12	R22	RE1	RC1	IC= 2.7634588	VCE= 9.2663430	N= 7.9506334	SE= .3865851
B1	VCC1	VO2	R12	R22	RE1	RC2	IC= 2.7634588	VCE= 6.6686917	N= 7.9506334	SE= .3865851
B1	VCC1	VO2	R12	R22	RE2	RC1	IC= 2.4261282	VCE=10.4709386	N= 7.9506334	SE= .3417888
B1	VCC1	VO2	R12	R22	RE2	RC2	IC= 2.4261282	VCE= 8.1903781	N= 7.9506334	SE= .3417888
B1	VCC2	VO1	R11	R21	RE1	RC1	IC= 2.5845288	VCE=11.2203265	N= 7.6185645	SE= .3511744
B1	VCC2	VO1	R11	R21	RE1	RC2	IC= 2.5845288	VCE= 8.7908694	N= 7.6185645	SE= .3511744
B1	VCC2	VO1	R11	R21	RE2	RC1	IC= 2.2531626	VCE=12.4354641	N= 7.6185645	SE= .3086638
B1	VCC2	VO1	R11	R21	RE2	RC2	IC= 2.2531626	VCE=10.3174912	N= 7.6185645	SE= .3086638
B1	VCC2	VO1	R11	R22	RE1	RC1	IC= 2.9235678	VCE= 9.4127061	N= 8.9189798	SE= .3865851
B1	VCC2	VO1	R11	R22	RE1	RC2	IC= 2.9235678	VCE= 6.6645524	N= 8.9189798	SE= .3865851
B1	VCC2	VO1	R11	R22	RE2	RC1	IC= 2.5666929	VCE=10.6870935	N= 8.9189798	SE= .3417888
B1	VCC2	VO1	R11	R22	RE2	RC2	IC= 2.5666929	VCE= 8.2744021	N= 8.9189798	SE= .3417888
B1	VCC2	VO1	R12	R21	RE1	RC1	IC= 2.5845288	VCE=11.2203265	N= 7.6185645	SE= .3511744
B1	VCC2	VO1	R12	R21	RE1	RC2	IC= 2.5845288	VCE= 8.7908694	N= 7.6185645	SE= .3511744
B1	VCC2	VO1	R12	R21	RE2	RC1	IC= 2.2531626	VCE=12.4354641	N= 7.6185645	SE= .3086638
B1	VCC2	VO1	R12	R21	RE2	RC2	IC= 2.2531626	VCE=10.3174912	N= 7.6185645	SE= .3086638
B1	VCC2	VO1	R12	R22	RE1	RC1	IC= 2.9235678	VCE= 9.4127061	N= 8.9189798	SE= .3865851
B1	VCC2	VO1	R12	R22	RE1	RC2	IC= 2.9235678	VCE= 6.6645524	N= 8.9189798	SE= .3865851
B1	VCC2	VO1	R12	R22	RE2	RC1	IC= 2.5666929	VCE=10.6870935	N= 8.9189798	SE= .3417888
B1	VCC2	VO1	R12	R22	RE2	RC2	IC= 2.5666929	VCE= 8.2744021	N= 8.9189798	SE= .3417888
B1	VCC2	VO2	R11	R21	RE1	RC1	IC= 2.5544905	VCE=11.3804783	N= 7.0743813	SE= .3511744
B1	VCC2	VO2	R11	R21	RE1	RC2	IC= 2.5544905	VCE= 8.9792571	N= 7.0743813	SE= .3511744
B1	VCC2	VO2	R11	R21	RE2	RC1	IC= 2.2269756	VCE=12.5814932	N= 7.0743813	SE= .3086638
B1	VCC2	VO2	R11	R21	RE2	RC2	IC= 2.2269756	VCE=10.4881361	N= 7.0743813	SE= .3086638
B1	VCC2	VO2	R11	R22	RE1	RC1	IC= 2.8951689	VCE= 9.5641174	N= 8.2819098	SE= .3865851
B1	VCC2	VO2	R11	R22	RE1	RC2	IC= 2.8951689	VCE= 6.8426586	N= 8.2819098	SE= .3865851
B1	VCC2	VO2	R11	R22	RE2	RC1	IC= 2.5417607	VCE=10.8261256	N= 8.2819098	SE= .3417888
B1	VCC2	VO2	R11	R22	RE2	RC2	IC= 2.5417607	VCE= 8.4368706	N= 8.2819098	SE= .3417888

B1	VCC2	VO2	R12	R21	RE1	RC1	IC= 2.5544905	VCE=11.3804783	N= 7.0743813	SE= .3511744
B1	VCC2	VO2	R12	R21	RE1	RC2	IC= 2.5544905	VCE= 8.9792571	N= 7.0743813	SE= .3511744
B1	VCC2	VO2	R12	R21	RE2	RC1	IC= 2.2269756	VCE=12.5814932	N= 7.0743813	SE= .3086638
B1	VCC2	VO2	R12	R21	RE2	RC2	IC= 2.2269756	VCE=10.4881361	N= 7.0743813	SE= .3086638
B1	VCC2	VO2	R12	R22	RE1	RC1	IC= 2.8951689	VCE= 9.5641174	N= 8.2819098	SE= .3865851
B1	VCC2	VO2	R12	R22	RE1	RC2	IC= 2.8951689	VCE= 6.8426586	N= 8.2819098	SE= .3865851
B1	VCC2	VO2	R12	R22	RE2	RC1	IC= 2.5417607	VCE=10.8261256	N= 8.2819098	SE= .3417888
B1	VCC2	VO2	R12	R22	RE2	RC2	IC= 2.5417607	VCE= 8.4368706	N= 8.2819098	SE= .3417888
B2	VCC1	VO1	R11	R21	RE1	RC1	IC= 3.3470860	VCE= 6.2088993	N= 7.3138219	SE= .1191845
B2	VCC1	VO1	R11	R21	RE1	RC2	IC= 3.3470860	VCE= 3.0626385	N= 7.3138219	SE= .1191845
B2	VCC1	VO1	R11	R21	RE2	RC1	IC= 2.7968937	VCE= 8.4587803	N= 7.3138219	SE= .1004108
B2	VCC1	VO1	R11	R21	RE2	RC2	IC= 2.7968937	VCE= 5.8297002	N= 7.3138219	SE= .1004108
B2	VCC1	VO1	R11	R22	RE1	RC1	IC= 3.9318551	VCE= 3.1006176	N= 8.5622206	SE= .1361098
B2	VCC1	VO1	R11	R22	RE1	RC2	IC= 3.9318551	VCE= -.5953262	N= 8.5622206	SE= .1361098
B2	VCC1	VO1	R11	R22	RE2	RC1	IC= 3.2959495	VCE= 5.6857272	N= 8.5622206	SE= .1149012
B2	VCC1	VO1	R11	R22	RE2	RC2	IC= 3.2959495	VCE= 2.5875347	N= 8.5622206	SE= .1149012
B2	VCC1	VO1	R12	R21	RE1	RC1	IC= 3.3470860	VCE= 6.2088993	N= 7.3138219	SE= .1191845
B2	VCC1	VO1	R12	R21	RE1	RC2	IC= 3.3470860	VCE= 3.0626385	N= 7.3138219	SE= .1191845
B2	VCC1	VO1	R12	R21	RE2	RC1	IC= 2.7968937	VCE= 8.4587803	N= 7.3138219	SE= .1004108
B2	VCC1	VO1	R12	R21	RE2	RC2	IC= 2.7968937	VCE= 5.8297002	N= 7.3138219	SE= .1004108
B2	VCC1	VO1	R12	R22	RE1	RC1	IC= 3.9318551	VCE= 3.1006176	N= 8.5622206	SE= .1361098
B2	VCC1	VO1	R12	R22	RE1	RC2	IC= 3.9318551	VCE= -.5953262	N= 8.5622206	SE= .1361098
B2	VCC1	VO1	R12	R22	RE2	RC1	IC= 3.2959495	VCE= 5.6857272	N= 8.5622206	SE= .1149012
B2	VCC1	VO1	R12	R22	RE2	RC2	IC= 3.2959495	VCE= 2.5875347	N= 8.5622206	SE= .1149012
B2	VCC1	VO2	R11	R21	RE1	RC1	IC= 3.3063075	VCE= 6.4256533	N= 6.7914060	SE= .1191845
B2	VCC1	VO2	R11	R21	RE1	RC2	IC= 3.3063075	VCE= 3.3177243	N= 6.7914060	SE= .1191845
B2	VCC1	VO2	R11	R21	RE2	RC1	IC= 2.7628184	VCE= 8.6481234	N= 6.7914060	SE= .1004108
B2	VCC1	VO2	R11	R21	RE2	RC2	IC= 2.7628184	VCE= 6.0510741	N= 6.7914060	SE= .1004108
B2	VCC1	VO2	R11	R22	RE1	RC1	IC= 3.8918602	VCE= 3.3132066	N= 7.9506334	SE= .1361098
B2	VCC1	VO2	R11	R22	RE1	RC2	IC= 3.8918602	VCE= -.3451420	N= 7.9506334	SE= .1361098
B2	VCC1	VO2	R11	R22	RE2	RC1	IC= 3.2624230	VCE= 5.8720204	N= 7.9506334	SE= .1149012
B2	VCC1	VO2	R11	R22	RE2	RC2	IC= 3.2624230	VCE= 2.8053428	N= 7.9506334	SE= .1149012
B2	VCC1	VO2	R12	R21	RE1	RC1	IC= 3.3063075	VCE= 6.4256533	N= 6.7914060	SE= .1191845
B2	VCC1	VO2	R12	R21	RE1	RC2	IC= 3.3063075	VCE= 3.3177243	N= 6.7914060	SE= .1191845
B2	VCC1	VO2	R12	R21	RE2	RC1	IC= 2.7628184	VCE= 8.6481234	N= 6.7914060	SE= .1004108
B2	VCC1	VO2	R12	R21	RE2	RC2	IC= 2.7628184	VCE= 6.0510741	N= 6.7914060	SE= .1004108
B2	VCC1	VO2	R12	R22	RE1	RC1	IC= 3.8918602	VCE= 3.3132066	N= 7.9506334	SE= .1361098
B2	VCC1	VO2	R12	R22	RE1	RC2	IC= 3.8918602	VCE= -.3451420	N= 7.9506334	SE= .1361098
B2	VCC1	VO2	R12	R22	RE2	RC1	IC= 3.2624230	VCE= 5.8720204	N= 7.9506334	SE= .1149012
B2	VCC1	VO2	R12	R22	RE2	RC2	IC= 3.2624230	VCE= 2.8053428	N= 7.9506334	SE= .1149012
B2	VCC2	VO1	R11	R21	RE1	RC1	IC= 3.5086362	VCE= 6.3501950	N= 7.6185645	SE= .1191845
B2	VCC2	VO1	R11	R21	RE1	RC2	IC= 3.5086362	VCE= 3.0520770	N= 7.6185645	SE= .1191845
B2	VCC2	VO1	R11	R21	RE2	RC1	IC= 2.9318884	VCE= 8.7086686	N= 7.6185645	SE= .1004108
B2	VCC2	VO1	R11	R21	RE2	RC2	IC= 2.9318884	VCE= 5.9526935	N= 7.6185645	SE= .1004108
B2	VCC2	VO1	R11	R22	RE1	RC1	IC= 4.1173463	VCE= 3.1146576	N= 8.9189798	SE= .1361098
B2	VCC2	VO1	R11	R22	RE1	RC2	IC= 4.1173463	VCE= -.7556479	N= 8.9189798	SE= .1361098
B2	VCC2	VO1	R11	R22	RE2	RC1	IC= 3.4514409	VCE= 5.8217237	N= 8.9189798	SE= .1149012
B2	VCC2	VO1	R11	R22	RE2	RC2	IC= 3.4514409	VCE= 2.5773692	N= 8.9189798	SE= .1149012
B2	VCC2	VO1	R12	R21	RE1	RC1	IC= 3.5086362	VCE= 6.3501950	N= 7.6185645	SE= .1191845
B2	VCC2	VO1	R12	R21	RE1	RC2	IC= 3.5086362	VCE= 3.0520770	N= 7.6185645	SE= .1191845
B2	VCC2	VO1	R12	R21	RE2	RC1	IC= 2.9318884	VCE= 8.7086686	N= 7.6185645	SE= .1004108
B2	VCC2	VO1	R12	R21	RE2	RC2	IC= 2.9318884	VCE= 5.9526935	N= 7.6185645	SE= .1004108
B2	VCC2	VO1	R12	R22	RE1	RC1	IC= 4.1173463	VCE= 3.1146576	N= 8.9189798	SE= .1361098
B2	VCC2	VO1	R12	R22	RE1	RC2	IC= 4.1173463	VCE= -.7556479	N= 8.9189798	SE= .1361098
B2	VCC2	VO1	R12	R22	RE2	RC1	IC= 3.4514409	VCE= 5.8217237	N= 8.9189798	SE= .1149012
B2	VCC2	VO1	R12	R22	RE2	RC2	IC= 3.4514409	VCE= 2.5773692	N= 8.9189798	SE= .1149012
B2	VCC2	VO2	R11	R21	RE1	RC1	IC= 3.4678577	VCE= 6.5669490	N= 7.0743813	SE= .1191845
B2	VCC2	VO2	R11	R21	RE1	RC2	IC= 3.4678577	VCE= 3.3071628	N= 7.0743813	SE= .1191845
B2	VCC2	VO2	R11	R21	RE2	RC1	IC= 2.8978131	VCE= 8.8980117	N= 7.0743813	SE= .1004108
B2	VCC2	VO2	R11	R21	RE2	RC2	IC= 2.8978131	VCE= 6.1740674	N= 7.0743813	SE= .1004108
B2	VCC2	VO2	R11	R22	RE1	RC1	IC= 4.0773514	VCE= 3.3272466	N= 8.2819098	SE= .1361098
B2	VCC2	VO2	R11	R22	RE1	RC2	IC= 4.0773514	VCE= -.5054637	N= 8.2819098	SE= .1361098

```
B2 VCC2 VO2 R11 R22 RE2 RC1    IC= 3.4179144   VCE= 6.0080169   N= 8.2819098   SE=  .1149012
B2 VCC2 VO2 R11 R22 RE2 RC2    IC= 3.4179144   VCE= 2.7951773   N= 8.2819098   SE=  .1149012
B2 VCC2 VO2 R12 R21 RE1 RC1    IC= 3.4678577   VCE= 6.5669490   N= 7.0743813   SE=  .1191845
B2 VCC2 VO2 R12 R21 RE1 RC2    IC= 3.4678577   VCE= 3.3071628   N= 7.0743813   SE=  .1191845
B2 VCC2 VO2 R12 R21 RE2 RC1   →IC= 2.8978131   VCE= 8.8980117   N= 7.0743813   SE=  .1004108
B2 VCC2 VO2 R12 R21 RE2 RC2   →IC= 2.8978131   VCE= 6.1740674   N= 7.0743813   SE=  .1004108
B2 VCC2 VO2 R12 R22 RE1 RC1    IC= 4.0773514   VCE= 3.3272466   N= 8.2819098   SE=  .1361098
B2 VCC2 VO2 R12 R22 RE1 RC2    IC= 4.0773514   VCE= -.5054637   N= 8.2819098   SE=  .1361098
B2 VCC2 VO2 R12 R22 RE2 RC1    IC= 3.4179144   VCE= 6.0080169   N= 8.2819098   SE=  .1149012
B2 VCC2 VO2 R12 R22 RE2 RC2    IC= 3.4179144   VCE= 2.7951773   N= 8.2819098   SE=  .1149012

        XRRJM90.   09/23/71.PURDUE MACE 71/09/12.

11.31.54.XRRJM,     41031,STUDENT,P10,T10,CM70000.
11.31.54.COMMENT. $RJM 8069 ROBERT J. MARKS II PU
11.31.54.RDUE
11.31.54.MAP(PART)
11.31.54.FUN(S)
11.31.55. CTIME 000.469 SEC. FUN MOD LEVEL 60F
11.31.55.PFILES(GET,SADIST)
11.31.57. DONE
11.31.57.REWIND(SADIST)
11.31.57.FUN(,,,SADIST)
11.31.59. CTIME 000.539 SEC. FUN MOD LEVEL 60F
11.31.59.LGO
11.31.59.LGO.
11.32.00.CX      1.834 SEC., NL   11100 WORDS
11.32.02.STOP
11.32.02.CP     2.742 SEC., IO        449 UNITS.
11.32.02.LINES     224
11.32.02.CM     2.761 MWD-SEC.,  FL   11100 WORDS
```

$V_o = 7$
$\beta_1 = 25$
$\beta_2 = 500$
VCEMIN = 6
XIC1 = 2.7
XIC2 = 3.3
XK = .5
VCC = 25.

BOB MARKS
(REVISION)

MACE

OPERATING SYSTEM

VERSION 4.1

JOB ORIGIN - EXPORT/IMPORT

```
X          X  RRRRRRRRRRR   RRRRRRRRRRR             JJ  MM         MM  333333333333    88888888
XX        XX  RRRRRRRRRRRR  RRRRRRRRRRRR            JJ  MMM       MMM  333333333333   8888888888
XX        XX  RR        RR  RR        RR            JJ  MMMM     MMMM            33  88        88
 XX      XX   RR        RR  RR        RR            JJ  MM MM   MM MM           33   88        88
  XX    XX    RR        RR  RR        RR            JJ  MM  MMMM  MM          33     88        88
   XX  XX     RR        RR  RR        RR            JJ  MM   MM   MM        33       88        88
    XXXX      RR        RR  RR        RR            JJ  MM        MM       33         88      88
     XX       RRRRRRRRRRRR  RRRRRRRRRRRR            JJ  MM        MM      33           88888888
     XX       RRRRRRRRRRR   RRRRRRRRRRR             JJ  MM        MM      333          88888888
    XXXX      RR  RR        RR  RR                  JJ  MM        MM        33        88      88
   XX  XX     RR   RR       RR   RR                 JJ  MM        MM         33      88        88
  XX    XX    RR    RR      RR    RR                JJ  MM        MM          33     88        88
 XX      XX   RR     RR     RR     RR               JJ  MM        MM           33    88        88
XX        XX  RR      RR    RR      RR    JJ        JJ  MM        MM  33       33    88        88
XX        XX  RR       RR   RR       RR   JJJJJJJJJJJJ  MM        MM   3333333333   8888888888
X          X  RR        RR  RR        RR    JJJJJJJJJ   MM        MM    33333333     88888888
```

```
=====================================================================================================
=====================================================================================================
=====================================================================================================
=====================================================================================================
=====================================================================================================
=====================================================================================================
```

ALL PERMANENT FILES LOST AS OF 01.00 A. M. OCTOBER 1, 1971.
FILES WERE RESTORED FOR TAPE BACK UP AT 09.00 OCTOBER 1, 1971.
PFILES WERE SAVED AS OF 01.00 OCTOBER 1, 1971.

Not much improvement

final design values are not standard values

(8)

```
                   PROGRAM TRAMP(INPUT,OUTPUT,TAPE2=INPUT,TAPE5=OUTPUT)
 000002            DIMENSION SAM(2,7)
 000002            WRITE (5,30)
 000006            READ(2,10)VO,B1,B2,VCEMIN,XIC1,XIC2,XK,VCC
             C SAM (MIN)    B1,VCC1,VO1,R11,R21,RE1,RC1
             C      (MAX)    B2,VCC2,VO2,R12,R22,RE2,RC2
 000032            READ(2,11)((SAM(I,J),I=1,2),J=1,3)
             C     WILL READ ALL NON-RESISTIVE VALUES INTO SAM
 000045            AAA=XIC1
 000046            BBB=XIC2
 000050            XIC1=2.9
 000051            XIC2=3.1
 000052            CALL DESIGN(VCC,B1,B2,VCEMIN,XIC1,XIC2,VO,XK,R1,R2,RC,RE,SE1,SE2,
                  2XN,RB)
             C     DESIGN COMPUTES VALUES OF THE FOUR BIAS RESISTORS IN A COMMON-EMITTER
             C     TRANSISTOR AMPLIFIER
 000072            XIC1=AAA
 000073            XIC2=BBB
 000075            WRITE(5,90) R1,R2,RC,RE
             C     FILLING IN THE REST OF SAM
             C     STDVAL COMPUTES CLOSEST STANDARD 10 PER CENT RESISTOR
 000111            SAM(1,4)=STDVAL(R1)*0.9
 000114            SAM(1,5)=STDVAL(R2)*0.9
 000117            SAM(1,6)=STDVAL(RE)*0.9
 000122            SAM(1,7)=STDVAL(RC)*0.9
 000125            SAM(2,4)=STDVAL(R1)*1.1
 000130            SAM(2,5)=STDVAL(R2)*1.1
 000133            SAM(2,6)=STDVAL(RE)*1.1
 000136            SAM(2,7)=STDVAL(RC)*1.1
 000142            XICEO=0.0
 000142            NOUT=0
 000143            ICMN=0
 000144            ICMN=0
 000144            NVCE=0
             C     DO LOOPS COMBINE SAM INTO 128 SETS OF INPUT PARAMETERS FOR ANALYZ
 000145            DO 12 I1=1,2
 000147              B=SAM(I1,1)
 000151            DO 12 I2=1,2
 000152            VCC=SAM(I2,2)
 000154            DO 12 I3=1,2
 000155             VO=SAM(I3,3)
 000157            DO 12 I4=1,2
 000160             RI=SAM(I4,4)
 000162            DO 12 I5=1,2
 000163             R2=SAM(I5,5)
 000165            DO 12 I6=1,2
 000166             RE=SAM(I6,6)
 000170            DO 12 I7=1,2
 000171             RC=SAM(I7,7)
             C     ANALYZ CALCULATES QUIESCENT OPERATING POINT FOR COMMON EMITTER
             C     TRANSISTOR AMPLIFIER
 000173            CALL ANALYZ(VCC,B,RI,R2,RC,RE,VO,XICEO,XIC,VCE,RB,XN,SE,VBB)
 000210            IF(XIC-XIC1)400,300,301
 000213        301 IF(XIC-XIC2)300,300,302
 000216        300 IF (VCE-VCEMIN)303,12,12
 000221        400 ICMN=ICMN+1
 000223            GO TO 401
 000223        302 ICMX=ICMX+1
```

```
000225      303 NVCE=NVCE+1
000227      401 NOUT=NOUT+1
000231          WRITE(5,99)I1,I2,I3,I4,I5,I6,I7,XIC,VCE,XN,SE
000262       12 CONTINUE
000300          WRITE(5,100)NOUT,ICMX,ICMN,NVCE
000314       10 FORMAT(8F7.3)
000314       11 FORMAT(6F10.4)
000314       30 FORMAT(' ROBERT J. MARKS II--EE363=1',/,/)
000314       90 FORMAT(2X,'R1=',F10.4,2X,'R2=',F10.4,2X,'RC=',F10.4,2X,'RE=',F10.4
              2,/)
000314       99 FORMAT('  B',I1,X,'VCC',I1,X,'VO',I1,X,'R1',I1,X,'R2',I1,X,'RE',I
              M1,X,'RC',I1    ,4X,'IC=',F10.7,4X,'VCE=',F10.7,4X,'N=',F10.7,
              Y4X,'SE=',F10.7)
000314      100 FORMAT(////,' AMPLIFIER OUT OF TOLERANCE IN ',I3,'CASES',
              2///,'CAUSED BY',//,'ICMAX ',I3,' TIMES',/,'ICMIN',I3,'  TIMES',
              4/,' VCEMIN',I3,' TIMES')
000314          STOP
000316          END

PROGRAM LENGTH INCLUDING I/O BUFFERS
002577

UNUSED COMPILER SPACE
025600



ROBERT J. MARKS II--EE363=1


  R1=   18.7769  R2=    3.4613  RC=     5.1075  RE=     1.0215

  B1 VCC1 VO1 R11 R21 RE2 RC1    IC= 2.2396080    VCE=12.0136180    N= 5.0426223    SE=  .0624635
  B1 VCC1 VO1 R11 R21 RE2 RC2    IC= 2.2396080    VCE= 9.9083865    N= 5.0426223    SE=  .0624635
  B1 VCC1 VO1 R11 R22 RE1 RC1    IC= 3.3080873    VCE= 6.9699667    N= 5.9816667    SE=  .0805430
  B1 VCC1 VO1 R11 R22 RE1 RC2    IC= 3.3080873    VCE= 3.8603646    N= 5.9816667    SE=  .0805430
  B1 VCC1 VO1 R12 R21 RE2 RC1    IC= 2.2396080    VCE=12.0136180    N= 5.0426223    SE=  .0624635
  B1 VCC1 VO1 R12 R21 RE2 RC2    IC= 2.2396080    VCE= 9.9083865    N= 5.0426223    SE=  .0624635
  B1 VCC1 VO1 R12 R22 RE1 RC1    IC= 3.3080873    VCE= 6.9699667    N= 5.9816667    SE=  .0805430
  B1 VCC1 VO1 R12 R22 RE1 RC2    IC= 3.3080873    VCE= 3.8603646    N= 5.9816667    SE=  .0805430
  B1 VCC1 VO2 R11 R21 RE1 RC1    IC= 2.6593802    VCE=10.3095107    N= 4.6824350    SE=  .0714831
  B1 VCC1 VO2 R11 R21 RE1 RC2    IC= 2.6593802    VCE= 7.8096933    N= 4.6824350    SE=  .0714831
  B1 VCC1 VO2 R11 R21 RE2 RC1    IC= 2.1969927    VCE=12.2416951    N= 4.6824350    SE=  .0624635
  B1 VCC1 VO2 R11 R21 RE2 RC2    IC= 2.1969927    VCE=10.1765220    N= 4.6824350    SE=  .0624635
  B1 VCC1 VO2 R11 R22 RE1 RC2    IC= 3.2570063    VCE= 4.1713455    N= 5.5544048    SE=  .0805430
  B1 VCC1 VO2 R11 R22 RE2 RC1    IC= 2.6952819    VCE= 9.5748512    N= 5.5544048    SE=  .0700337
  B1 VCC1 VO2 R11 R22 RE2 RC2    IC= 2.6952819    VCE= 7.0412862    N= 5.5544048    SE=  .0700337
  B1 VCC1 VO2 R12 R21 RE1 RC1    IC= 2.6593802    VCE=10.3095107    N= 4.6824350    SE=  .0714831
  B1 VCC1 VO2 R12 R21 RE1 RC2    IC= 2.6593802    VCE= 7.8096933    N= 4.6824350    SE=  .0714831
  B1 VCC1 VO2 R12 R21 RE2 RC1    IC= 2.1969927    VCE=12.2416951    N= 4.6824350    SE=  .0624635
  B1 VCC1 VO2 R12 R21 RE2 RC2    IC= 2.1969927    VCE=10.1765220    N= 4.6824350    SE=  .0624635
  B1 VCC1 VO2 R12 R22 RE1 RC2    IC= 3.2570063    VCE= 4.1713455    N= 5.5544048    SE=  .0805430
  B1 VCC1 VO2 R12 R22 RE2 RC1    IC= 2.6952819    VCE= 9.5748512    N= 5.5544048    SE=  .0700337
  B1 VCC1 VO2 R12 R22 RE2 RC2    IC= 2.6952819    VCE= 7.0412862    N= 5.5544048    SE=  .0700337
  B1 VCC2 VO1 R11 R21 RE2 RC1    IC= 2.3560083    VCE=12.3906437    N= 5.2527315    SE=  .0624635
  B1 VCC2 VO1 R11 R21 RE2 RC2    IC= 2.3560083    VCE=10.1759959    N= 5.2527315    SE=  .0624635
  B1 VCC2 VO1 R11 R22 RE1 RC1    IC= 3.4735931    VCE= 7.1179427    N= 6.2309028    SE=  .0805430
  B1 VCC2 VO1 R11 R22 RE1 RC2    IC= 3.4735931    VCE= 3.8527652    N= 6.2309028    SE=  .0805430
  B1 VCC2 VO1 R12 R21 RE2 RC1    IC= 2.3560083    VCE=12.3906437    N= 5.2527315    SE=  .0624635
```

```
B1 VCC2 V01 R12 R21 RE2 RC2   IC= 2.3560083   VCE=10.1759959   N= 5.2527315   SE=  .0624635
B1 VCC2 V01 R12 R22 RE1 RC1   IC= 3.4735931   VCE= 7.1179427   N= 6.2309028   SE=  .0805430
B1 VCC2 V01 R12 R22 RE1 RC2   IC= 3.4735931   VCE= 3.8527652   N= 6.2309028   SE=  .0805430
B1 VCC2 V02 R11 R21 RE2 RC1   IC= 2.3133930   VCE=12.6187208   N= 4.8775364   SE=  .0624635
B1 VCC2 V02 R11 R21 RE2 RC2   IC= 2.3133930   VCE=10.4441314   N= 4.8775364   SE=  .0624635
B1 VCC2 V02 R11 R22 RE1 RC1   IC= 3.4225121   VCE= 7.3809075   N= 5.7858383   SE=  .0805430
B1 VCC2 V02 R11 R22 RE1 RC2   IC= 3.4225121   VCE= 4.1637460   N= 5.7858383   SE=  .0805430
B1 VCC2 V02 R12 R21 RE2 RC1   IC= 2.3133930   VCE=12.6187208   N= 4.8775364   SE=  .0624635
B1 VCC2 V02 R12 R21 RE2 RC2   IC= 2.3133930   VCE=10.4441314   N= 4.8775364   SE=  .0624635
B1 VCC2 V02 R12 R22 RE1 RC1   IC= 3.4225121   VCE= 7.3809075   N= 5.7858383   SE=  .0805430
B1 VCC2 V02 R12 R22 RE1 RC2   IC= 3.4225121   VCE= 4.1637460   N= 5.7858383   SE=  .0805430
B2 VCC1 V01 R11 R21 RE2 RC1   IC= 2.3730120   VCE=11.3466254   N= 5.0426223   SE=  .0066184
B2 VCC1 V01 R11 R21 RE2 RC2   IC= 2.3730120   VCE= 9.1159941   N= 5.0426223   SE=  .0066184
B2 VCC1 V01 R11 R22 RE1 RC1   IC= 3.5666273   VCE= 5.6967820   N= 5.9816667   SE=  .0086838
B2 VCC1 V01 R11 R22 RE1 RC2   IC= 3.5666273   VCE= 2.3441523   N= 5.9816667   SE=  .0086838
B2 VCC1 V01 R11 R22 RE2 RC2   IC= 2.9217094   VCE= 5.6744543   N= 5.9816667   SE=  .0074745
B2 VCC1 V01 R12 R21 RE2 RC1   IC= 2.3730120   VCE=11.3466254   N= 5.0426223   SE=  .0066184
B2 VCC1 V01 R12 R21 RE2 RC2   IC= 2.3730120   VCE= 9.1159941   N= 5.0426223   SE=  .0066184
B2 VCC1 V01 R12 R22 RE1 RC1   IC= 3.5666273   VCE= 5.6967820   N= 5.9816667   SE=  .0086838
B2 VCC1 V01 R12 R22 RE1 RC2   IC= 3.5666273   VCE= 2.3441523   N= 5.9816667   SE=  .0086838
B2 VCC1 V01 R12 R22 RE2 RC2   IC= 2.9217094   VCE= 5.6744543   N= 5.9816667   SE=  .0074745
B2 VCC1 V02 R11 R21 RE2 RC1   IC= 2.3278583   VCE=11.5873940   N= 4.6824350   SE=  .0066184
B2 VCC1 V02 R11 R21 RE2 RC2   IC= 2.3278583   VCE= 9.3992071   N= 4.6824350   SE=  .0066184
B2 VCC1 V02 R11 R22 RE1 RC1   IC= 3.5115542   VCE= 5.9794062   N= 5.5544048   SE=  .0086838
B2 VCC1 V02 R11 R22 RE1 RC2   IC= 3.5115542   VCE= 2.6785453   N= 5.5544048   SE=  .0086838
B2 VCC1 V02 R11 R22 RE2 RC2   IC= 2.8765946   VCE= 5.9574234   N= 5.5544048   SE=  .0074745
B2 VCC1 V02 R12 R21 RE2 RC1   IC= 2.3278583   VCE=11.5873940   N= 4.6824350   SE=  .0066184
B2 VCC1 V02 R12 R21 RE2 RC2   IC= 2.3278583   VCE= 9.3992071   N= 4.6824350   SE=  .0066184
B2 VCC1 V02 R12 R22 RE1 RC1   IC= 3.5115542   VCE= 5.9794062   N= 5.5544048   SE=  .0086838
B2 VCC1 V02 R12 R22 RE1 RC2   IC= 3.5115542   VCE= 2.6785453   N= 5.5544048   SE=  .0086838
B2 VCC1 V02 R12 R22 RE2 RC2   IC= 2.8765946   VCE= 5.9574234   N= 5.5544048   SE=  .0074745
B2 VCC2 V01 R11 R21 RE2 RC1   IC= 2.4963458   VCE=11.6889851   N= 5.2527315   SE=  .0066184
B2 VCC2 V01 R11 R21 RE2 RC2   IC= 2.4963458   VCE= 9.3424201   N= 5.2527315   SE=  .0066184
B2 VCC2 V01 R11 R22 RE1 RC1   IC= 3.7450681   VCE= 5.7810598   N= 6.2309028   SE=  .0086838
B2 VCC2 V01 R11 R22 RE1 RC2   IC= 3.7450681   VCE= 2.2606958   N= 6.2309028   SE=  .0086838
B2 VCC2 V01 R11 R22 RE2 RC2   IC= 3.0678845   VCE= 5.7576151   N= 6.2309028   SE=  .0074745
B2 VCC2 V01 R12 R21 RE2 RC1   IC= 2.4963458   VCE=11.6889851   N= 5.2527315   SE=  .0066184
B2 VCC2 V01 R12 R21 RE2 RC2   IC= 2.4963458   VCE= 9.3424201   N= 5.2527315   SE=  .0066184
B2 VCC2 V01 R12 R22 RE1 RC1   IC= 3.7450681   VCE= 5.7810598   N= 6.2309028   SE=  .0086838
B2 VCC2 V01 R12 R22 RE1 RC2   IC= 3.7450681   VCE= 2.2606958   N= 6.2309028   SE=  .0086838
B2 VCC2 V01 R12 R22 RE2 RC2   IC= 3.0678845   VCE= 5.7576151   N= 6.2309028   SE=  .0074745
B2 VCC2 V02 R11 R21 RE2 RC1   IC= 2.4511921   VCE=11.9297537   N= 4.8775364   SE=  .0066184
B2 VCC2 V02 R11 R21 RE2 RC2   IC= 2.4511921   VCE= 9.6256331   N= 4.8775364   SE=  .0066184
B2 VCC2 V02 R11 R22 RE1 RC1   IC= 3.6899949   VCE= 6.0636840   N= 5.7858383   SE=  .0086838
B2 VCC2 V02 R11 R22 RE1 RC2   IC= 3.6899949   VCE= 2.5950888   N= 5.7858383   SE=  .0086838
B2 VCC2 V02 R12 R21 RE2 RC1   IC= 2.4511921   VCE=11.9297537   N= 4.8775364   SE=  .0066184
B2 VCC2 V02 R12 R21 RE2 RC2   IC= 2.4511921   VCE= 9.6256331   N= 4.8775364   SE=  .0066184
B2 VCC2 V02 R12 R22 RE1 RC1   IC= 3.6899949   VCE= 6.0636840   N= 5.7858383   SE=  .0086838
B2 VCC2 V02 R12 R22 RE1 RC2   IC= 3.6899949   VCE= 2.5950888   N= 5.7858383   SE=  .0086838


AMPLIFIER OUT OF TOLERANCE IN  76CASES


AUSED BY

ICMAX  28 TIMES
ICMIN 40  TIMES
VCEMIN 36 TIMES
```

XRRJM38. 10/01/71.PURDUE MACE 71/09/12.

```
14.25.27.XRRJM,    41031,STUDENT,P10,T10,CM70000.
14.25.27.COMMENT. $RJM 8069 ROBERT J. MARKS II PU
14.25.27.RDUE
14.25.27.FUN(S)
14.26.10. CTIME 000.643 SEC. FUN MOD LEVEL 60F
14.26.10.PFILES(GET,SADIST)
14.26.38. DONE
14.26.39.REWIND(SADIST)
14.26.39.FUN(,,,SADIST)
14.26.48. CTIME 000.551 SEC. FUN MOD LEVEL 60F
14.26.48.LGO
14.26.49.LGO.
14.26.50.CX      1.947 SEC., NL  11200 WORDS
14.26.51.STOP
14.26.51.CP    2.524 SEC., IO        437 UNITS.
14.26.51.LINES     177
14.26.51.CM    5.002 MWD-SEC.,  FL  11200 WORDS
```

13113

12
11
10
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3

```
  88888888    00000000    66666666    99999999
 8888888888  0000000000  6666666666  9999999999
 88      88  00      00  66      66  99      99
 88      88  00      00  66          99      99
 88      88  00      00  66          99      99
  88888888   00      00  666666666   9999999999
  88888888   00      00  6666666666   999999999
 88      88  00      00  66      66           99
 88      88  00      00  66      66          99
 88      88  00      00  66      66  99      99
 8888888888  0000000000  6666666666  9999999999
  88888888    00000000    66666666    99999999
```

```
*******************************************
*               JOB HISTORY               *
*          AT ENTRY TO SYSTEM,            *
*        PRIORITY-24 TIME-1533            *
*        AT RUN TIME ON   10/6/71,        *
*        PRIORITY-27 TIME-1555            *
*  00029 JOBS RUN THIS ID SINCE           *
*   RPI MONITOR V2 M08 DISK ASSIGNMENT    *
*     LOGICAL DRIVE NO - 00   01   02     *
*    PHYSICAL DRIVE NO - 00   01          *
*     CARTRIDGE ID ---- 0001 0002         *
*     CIB ON LOG 1  SYSTEM WS ON LOG 0    *
*******************************************
```

```
// JOB T        08069      ROBERT J. MARKS II
// FOR
*LIST SOURCE PROGRAM
      SUBROUTINE Y(RE,RC1,RC2,HFE1,HFE2,HOE1,HOE2,HIE1,HIE2,S51,S52,
     1S61,S62)
      DIMENSION S(7,2)
C  S  RC1  HFE1  HOE1  HIE1  (GAIN FROM V1 TO VC1)  GAIN FROM V1 TO VC2)
C     RC2  HFE2  HOE2  HIE2  (GAIN FROM V2 TO VC2)  (GAIN FROM V2 TO VC1)
      DEL=1.+RE/HIE1+HFE1*RE/HIE1+HOE1 *RE+RC1*HOE1+RE/HIE2+HFE2*RE/HIE2
     2+HOE2*RE+RC2*HOE2+(HOE1*RC2)*(RE/HIE1+RE/HIE2+HFE2*RE/HIE2+
     2HOE2*RE+HOE2*RC2)+(HOE2    *RC2)*(RE/HIE2+RC2/HIE1+HFE1*RE/HIE1+
     3HOE1*RE)-HOE2*RC2*HOE1*RC1*(RE/HIE1+RE/HIE2)
      S(1,1)=RC1
      S(1,2)=RC2
      S(2,1)=HFE1
      S(2,2)=HFE2
      S(3,1)=HOE1
      S(3,2)=HOE2
      S(4,1)=HIE1
      S(4,2)=HIE2
      DO 70 I=1,2
      IF (I-1)14,15,14
   15 J=2
      GO TO 17
   14 J=1
C  GAINS AND DELS FROM VI TO VCI
   17 G11=(-1)*S(2,I)*S(1,I)/S(4,I)
      D11=1.+(1.+S(2,J))*RE/S(4,J)+S(3,J)*(RE+S(1,J))+S(3,J)*S(1,J)
     2*RE/S(4,J)
      G12=S(3,I)*S(1,I)*RE/S(4,I)
      D12=1.+S(3,J)*S(1,J)
C  GAINS AND DELS FROM VJ TO VCI.
      G21=RE*S(1,I)*S(2,I)/(S(4,I)*S(4,J))
      D21=1.+S(4,J)*S(1,J)
      G22=S(1,I)*S(3,I)*RE/S(4,J)
      D22=1.+S(3,J)*S(1,J)
      G23=S(1,I)*S(2,I)*RE*S(2,J)/(S(4,I)*S(4,J))
      D23=1.
      G24=(-1.)*S(1,I)*S(3,I)*RE*S(2,J)/S(4,J)
      D24=1.
C  S(5,I)= GAIN FROM VI TO VCI
      S(5,I)=(G11*D11+G12*D12)/DEL
C  S(6,I)= GAIN FROM VJ TO VCI
      S(6,I)=(G21*D21+G22*D22+G23*D23)/DEL
   70 CONTINUE
      S51=S(5,1)
      S52=S(5,2)
      S61=S(6,1)
```

All screwed up, fix and resubmit.

```
      S62=S(6,2)
      RETURN
      END

CORE REQUIREMENTS FOR Y
 COMMON       0  VARIABLES     114  PROGRAM     674

RELATIVE ENTRY POINT ADDRESS IS 0078 (HEX)

END OF COMPILATION
// DUP

*STORE       WS  UA  Y
CART ID 0001   DB ADDR  2340   DB CNT   0034
// FOR
*IOCS(1403 PRINTER,CARD)
*LIST SOURCE PROGRAM
      DIMENSION X(2,4)
C  X  RC1  HFE1  HOE1  HIE1
C     RC2  HFE2  HOE2  HIE2
      WRITE(5,5)
      READ(2,10) RE,X(1,1),X(1,2)
      DO 15 N=1,3
      READ(2,20)X(1,2),X(2,2),X(1,3),X(2,3),X(1,4),X(2,4)
      CALL Y(RE,X(1,1),X(2,1),X(1,2),X(2,2),X(1,3),X(2,3),X(1,4),X(2,4),
     7S51,S52,S61,S62)
      WRITE(5,25)N,S51,S52,S61,S62
   15 CONTINUE
    5 FORMAT(' ROBERT J. MARKS II-EE363',/,' COMPUTER ASSIGNMENT =2',///
     2)
   10 FORMAT(3F10.4)
   20 FORMAT(6F10.4)
   25 FORMAT(' CASE',I2,/,4X,'GAIN FROM V1 TO VC1=',F10.4,/,4X,
     1'GAIN FROM V2 TO VC2=',F10.4,/,4X,'GAIN FROM V2 TO VC1=',F10.4,
     3/,4X,'GAIN FROM V1 TO VC2=',F10.4)
      STOP
      END

FEATURES SUPPORTED
 IOCS

CORE REQUIREMENTS FOR
 COMMON       0  VARIABLES      42  PROGRAM     278

END OF COMPILATION
// XEQ

ROBERT J. MARKS II-EE363
COMPUTER ASSIGNMENT =2



CASE 1
    GAIN FROM V1 TO VC1=  -32.8333
    GAIN FROM V2 TO VC2=   -0.0000
    GAIN FROM V2 TO VC1=   32.2725
    GAIN FROM V1 TO VC2=    0.0000
CASE 2
    GAIN FROM V1 TO VC1=  -79.9471
```

```
      GAIN FROM V2 TO VC2=    -0.0000
      GAIN FROM V2 TO VC1=    79.4691
      GAIN FROM V1 TO VC2=     0.0000
   F007 MORE THAN ONE DECIMAL POINT ENCOUNTERED

    EXECUTION TIME 0003
```

```
   88888888     00000000     66666666     99999999          ****************************************
  8888888888   0000000000   6666666666   9999999999         *              JOB HISTORY             *
  88      88   00      00   66      66   99      99         *         AT ENTRY TO SYSTEM,          *
  88      88   00      00   66           99      99         *       PRIORITY-24 TIME-1600          *
  88      88   00      00   66           99      99         *      AT RUN TIME ON  10/13/71,       *
   88888888    00      00   666666666    9999999999         *       PRIORITY-24 TIME-1600          *
   88888888    00      00   6666666666    999999999         * 00014 JOBS RUN THIS ID SINCE 09/12/71 *
  88      88   00      00   66      66           99         *  RPI MONITOR V2 M08 DISK ASSIGNMENT  *
  88      88   00      00   66      66           99         *    LOGICAL DRIVE NO - 00   01   02   *
  88      88   00      00   66      66   99      99         *     PHYSICAL DRIVE NO - 00   01      *
  8888888888   0000000000   6666666666   9999999999         *      CARTRIDGE ID ---- 0001 0002     *
   88888888     00000000     66666666     99999999          *     CIB ON LOG 1  SYSTEM WS ON LOG 0  *
                                                            ****************************************
// JOB T       8069      ROBERT J. MARKS II
// NOTE  PLEASE DO NOT FOLD OUTPUT- ROBERT J. MARKS II -8069
// FOR
*IOCS(1403 PRINTER,CARD)
*LIST SOURCE PROGRAM
      WRITE(5,15)
      DO 90 J=1,3
      READ(2,55)HI1,HI2,RC1,RC2
      READ(2,56)HF1,HF2,HO1,HO2,RE
C  GAIN OF LOOPS TWO AT A TIME

      T1=-RE/HI1
      T2=-HF1*RE/HI1
      T3=-HO1*RE
      T4=-RC1*HO1
      T5=-RE/HI2
      T6=-HF2*RE/HI2
      T7=-HO2*RE
      T8=-RC2*HO2
C  PRODUCT OF UNTOUCHING LOOPS TWO AT A TIME
      T14=T1*T4
      T18=T1*T8
      T28=T2*T8
      T38=T3*T8
      T45=T4*T5
      T46=T4*T6
      T47=T4*T7
      T48=T4*T8
      T58=T5*T8
C  PRODUCT OF UNTOUCHING LOOPS THREE AT A TIME
      T148=T1*T4*T8
      T458=T4*T5*T8
      DEL=1.-(T1+T2+T3+T4+T5+T6+T7+T8)+(T14+T18+T28+T38+T45+T46+T47+T48
     1+T58)-(T148+T458)
C  EVALUATION FROM V1 TO VC1
      G1=-HF1*RC1/HI1
      DEL1=1.-(T5+T6+T7+T8)+T58
      G2=RE*HO1*RC1/HI1
      DEL2=1.-T8
      G1C1=(G1*DEL1+G2*DEL2)/DEL
C  EVALUATION FROM V2 TO VC1
      G1=RE*RC1*HF1/(HI1*HI2)
      DEL1=1.-T8
      G2=RE*HO1*RC1/HI2
      DEL2=1.-T8
      G3=HF2*RE*HF1*RC1/(HI2*HI1)
      G4=HF2*RE*HO1*RC1/HI2
      G2C1=(G1*DEL1+G2*DEL2+G3+G4)/DEL
```

Case II values
RJM

```
C   EVALUATION FROM V2 TO VC2
       G1=-HF2*RC2/HI2
       DEL1=1.-(T1+T2+T3+T4)+T14
       G2=RE*HO2*RC2/HI1
       DEL2=1.-T4
       G2C2=((G1*DEL1+G2*DEL2)/DEL)
C   EVALUATION FROM V1 TO VC2
       G1=RE*RC2*HF2/(HI1*HI2)
       DEL1=1.-T4
       G2=RE*HO2*RC2/HI1
       DEL2=1.-T4
       G3=HF1*RE*HF2*RC2/(HI1*HI2)
       G4=HF1*RE*HO2*RC2/HI1
       G1C2=(G1*DEL1+G2*DEL2+G3+G4)/DEL
       A=G1C2-G1C1
       B=G2C1-G2C2
       WRITE(5,50)J,RE,HI1,HI2,HF1,HF2,HO1,HO2,RC1,RC2,G1C1,G1C2,G2C2,
      1G2C1,A,B
    90 CONTINUE
    15 FORMAT('1',//,' ROBERT J. MARKS II',/,' EE363, PROB 3',/,
      1' DIFFERENTIAL AMPLIFIER',///)
    50 FORMAT(3X,'CASE',I2,/,4X,'RE=',E9.2 ,4X,/,'HIE1=',E9.2,5X,'HIE2=',
      1E9.2 ,/,4X,'HFE1=',E9.2 ,5X,'HFE2=',E9.2 ,/,4X,'HOE1=',E9.2 ,
      25X,'HOE2=',E9.2 ,/,4X,'RC1 =',E9.2 ,5X,'R 2 =',E9.2 ,//,
      32X,'GAIN FROM V1 TO VC1=',E15.8,/,2X,'GAIN FROM V1 TO VC2=',E15.8,
      4/,2X,'GAIN FROM V2 TO VC2=',E15.8,/,2X,'GAIN FROM V2 TO VC1=',E15.
      58,//,4X,'V(OUT)=',E15.8,'*V1-',E15.8,'*V2')
    55 FORMAT(4F10.4)
    56 FORMAT(5F10.4)
       STOP
       END

FEATURES SUPPORTED
 IOCS

CORE REQUIREMENTS FOR
 COMMON      0  VARIABLES     88  PROGRAM     778

END OF COMPILATION
// LOAD
```

```
ROBERT J. MARKS II
EE363, PROB 3
DIFFERENTIAL AMPLIFIER


  CASE 1
    RE= 0.33E 04
IE1= 0.25E 04      HIE2= 0.25E 04
     HFE1= 0.88E 02      HFE2= 0.88E 02
     HOE1= 0.10E-04      HOE2= 0.10E-04
     RC1  = 0.12E 05     R 2 = 0.12E 05

  GAIN FROM V1 TO VC1=-0.18946395E 03
  GAIN FROM V1 TO VC2= 0.18767898E 03
  GAIN FROM V2 TO VC2=-0.18946395E 03
  GAIN FROM V2 TO VC1= 0.18767898E 03

     V(OUT)= 0.37714294E 03*V1- 0.37714294E 03*V2
  CASE 2
    RE= 0.33E 04
IE1= 0.25E 04      HIE2= 0.25E 04
     HFE1= 0.88E 02      HFE2= 0.12E 03
     HOE1= 0.10E-04      HOE2= 0.10E-04
     RC1  = 0.12E 05     R 2 = 0.12E 05

  GAIN FROM V1 TO VC1=-0.21790841E 03
  GAIN FROM V1 TO VC2= 0.21712146E 03
  GAIN FROM V2 TO VC2=-0.21920327E 03
  GAIN FROM V2 TO VC1= 0.21641021E 03

     V(OUT)= 0.43502984E 03*V1- 0.43561346E 03*V2
  CASE 3
    RE= 0.33E 04
IE1= 0.25E 04      HIE2= 0.20E 04
     HFE1= 0.88E 02      HFE2= 0.10E 03
     HOE1= 0.10E-04      HOE2= 0.20E-04
     RC1  = 0.12E 05     R 2 = 0.12E 05

  GAIN FROM V1 TO VC1=-0.21261215E 03
  GAIN FROM V1 TO VC2= 0.21111602E 03
  GAIN FROM V2 TO VC2=-0.21309893E 03
  GAIN FROM V2 TO VC1= 0.21102334E 03

     V(OUT)= 0.42372815E 03*V1- 0.42412225E 03*V2
S 32 STOP 0000

  EXECUTION TIME 0008
```

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Ind.
October 21, 1971

EE 363 - Electronic Circuits
Experiment No. _____
Emitter Follower Amplifier

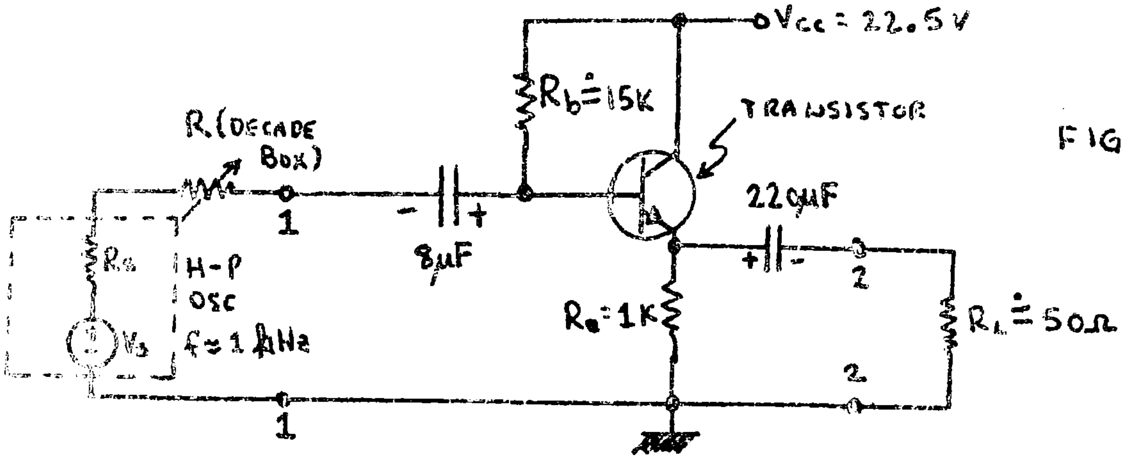


FIGURE 1

1. Before connecting the circuit of Figure 1, connect the 50-Ohm resistor directly across the output terminals of the H.P. Oscillator after setting the open circuit voltage of the oscillator to 0.5 Volt, peak. Compare the measured voltage across the 50-Ohm resistor with the predicted value assuming that the internal resistance of the oscillator is 600 Ohms.

2. Connect the circuit shown in Figure 1. Change the value of R_b, if necessary, to obtain approximately 20 V. d-c, at the emitter of the transistor. With the open circuit voltage of the oscillator set to 0.5-Volt, peak, what is the peak voltage across the 50-Ohm resistor? Be sure to monitor output voltage on CRO at all times.

3. Increase the signal from the oscillator until the sine-wave voltage across the 50-Ohm resistor becomes distorted. Sketch this waveform. At what peak voltage does the distortion become obvious? What causes this distortion, cutoff or saturation?

4. Estimate the input impedance of the 1-1 terminals of the emitter-follower circuit by increasing R until the voltage across R_L is reduced to 1/2 of its original value. (Remember that the 600-Ohm internal resistance of the oscillator is in the circuit also.) Record the input impedance thus measured.

5. Estimate the output impedance at the 2-2 terminals of the circuit by removing R_L, noting the open-circuit voltage and then replacing R_L at a value (use a decade resistance) such that the voltage across R_L is 1/2 of the open-circuit voltage.

(The output signal from the oscillator must be reduced to prevent distortion.

6. Use the transistor curve tracer to obtain h_{fe} of the transistor at your quiescent operating point.

7. Assuming $h_{re} = 0$, estimate the value of h_{ie} using $z_{out} \doteq \frac{h_{fe}}{h_{re}}$.

Remember to include effect of R_b and 600 Ohm output impedance of the oscillator.

8. (a) What value of d-c emitter current would be required if the peak undistorted voltage across R_L must be 2V?

(b) DESIGN:

Determine the values of R_e, R_b, and V_{cc} which would be required to meet the specifications of part (a).

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Ind.
October 19, 1971

EE 360 Electronic Circuits
Homework

Hand in by 4:00 PM (SHARP) Monday, 10/25/71 at least one computer run of computer problem 13. Program must have been compiled and execution begun for credit. Bode plot should extend at least one decade beyond low and high 3dB frequencies.

Electrical Engineering Dept.
Rose-Hulman Institute
Terre Haute, Indiana
September 28, 1971

EE363 - Electronics Circuits
Homework

I. Computer problem no. 4

Hand in Friday, October 1, 1971, 4:00 PM your final results on the problem. List clearly the values of the four resistors. Also list how many of the 128 cases of the worst case analysis meet the specifications of the required amplifier.

Turn in computer output with your name on the front.

II. Differential amplifier

Calculate the gain of the differential amplifier we have been analyzing in class. We are interested in the following cases:

A. Both transistors identical.

$h_{ie} = 2500$ Ohms
$h_{fe} = 80$
$h_{oe} = 1/100$ kOhms

B. One transistor as above (Q1).
The other with $h_{fe2} = 125$

C. Q1 as in part A, Q2 with $h_{ie2} = 5000$ ohms
$h_{oe} = 1/50$ kOhms, $h_{fe2} = 100$

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana
May 20, 1972

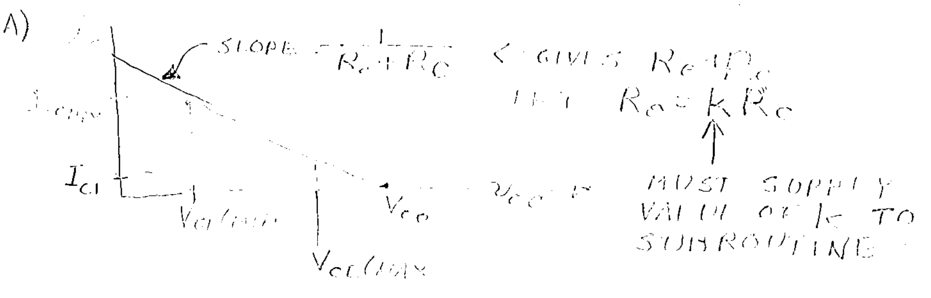
EE365 - Electronic Ckts. I
Assignment
Due when school resumes in the Fall.

Do either or both of the following:

(A) Write a Fortran subroutine subprogram to design a common emitter transistor amplifier of the "Standard Configuration". Input to the subroutine should be V_{CC}, $beta_1$, $beta_2$, V_o, I_{CE}, k, I_{C2}, $V_{CE(min)}$, I_{CEO}; the subroutine should return R_1, R_2, R_c, and R_e. It should compute S_{e1} and S_{e2} and n as well. $V_{BB} = nV_o \Rightarrow n = V_{BB}/V_o$

(B) Write a Fortran subroutine subprogram to analyze the standard configuration common emitter transistor amplifier. The input to the subroutine should be V_{CC}, beta, R_1, R_2, R_e, R_c, I_{CEO}, and V_o. The subroutine should compute and return the quiescent operating point information and Se.

A)



AMPLIFIER FREQUENCY RESPONSE
MAGNITUDE/ANGLE

FREQ(HZ)	ZIN		ZOUT		AV		AI		AP
10.00	7215.8	/ -29.6	11772	/ -1.6	46.862	/ -90.6	12.524	/-120.2	675.00
12.59	6784.7	/ -31.4	11740	/ -1.9	58.914	/ -94.3	14.804	/-125.7	1022.3
15.85	6267.3	/ -33.7	11693	/ -2.3	73.683	/ -98.2	17.104	/-131.8	1514.0
19.95	5678.5	/ -35.8	11625	/ -2.7	91.571	/-102.4	19.259	/-138.2	2173.9
25.12	5055.4	/ -37.4	11529	/ -3.2	112.83	/-107.1	21.127	/-144.5	2998.9
31.62	4446.3	/ -37.9	11402	/ -3.7	137.42	/-112.5	22.629	/-150.4	3943.2
39.81	3894.6	/ -37.3	11244	/ -4.0	164.73	/-118.4	23.760	/-155.7	4920.9
50.12	3428.1	/ -35.4	11065	/ -4.2	193.50	/-124.8	24.568	/-160.2	5833.7
63.10	3057.1	/ -32.5	10881	/ -4.2	221.87	/-131.6	25.122	/-164.1	6606.8
79.43	2777.2	/ -28.8	10711	/ -4.0	247.82	/-138.4	25.491	/-167.3	7209.8
100.00	2575.3	/ -24.8	10568	/ -3.6	269.79	/-145.0	25.733	/-169.8	7650.3
125.9	2435.0	/ -20.9	10458	/ -3.1	287.07	/-151.0	25.889	/-171.9	7957.1
158.5	2340.2	/ -17.3	10377	/ -2.7	299.84	/-156.3	25.989	/-173.6	8163.6
199.5	2277.6	/ -14.2	10321	/ -2.2	308.84	/-160.8	26.052	/-175.0	8299.6
251.2	2236.9	/ -11.6	10283	/ -1.8	314.95	/-164.5	26.093	/-176.1	8387.7
316.2	2210.7	/ -9.4	10259	/ -1.5	318.99	/-167.6	26.118	/-177.0	8444.2
398.1	2193.9	/ -7.6	10243	/ -1.3	321.63	/-170.1	26.134	/-177.7	8480.3
501.2	2183.2	/ -6.2	10232	/ -1.1	323.32	/-172.1	26.144	/-178.4	8503.3
631.0	2176.4	/ -5.2	10226	/ -.9	324.41	/-173.7	26.150	/-178.9	8517.8
794.3	2172.1	/ -4.3	10222	/ -.9	325.10	/-175.0	26.154	/-179.4	8527.0
1000.0	2169.3	/ -3.8	10219	/ -.8	325.54	/-176.0	26.155	/-179.8	8532.8
1259	2167.5	/ -3.4	10217	/ -.8	325.81	/-176.9	26.155	/ 179.8	8536.4
1585	2166.2	/ -3.1	10216	/ -.8	325.99	/-177.5	26.154	/ 179.3	8538.7
1995	2165.2	/ -3.1	10215	/ -.9	326.10	/-178.0	26.150	/ 178.9	8540.1
2512	2164.2	/ -3.2	10214	/ -1.1	326.17	/-178.5	26.144	/ 178.3	8540.9
3162	2163.1	/ -3.5	10213	/ -1.2	326.21	/-178.8	26.134	/ 177.7	8541.4
3981	2161.6	/ -4.0	10212	/ -1.5	326.24	/-179.1	26.118	/ 176.9	8541.5
5012	2159.3	/ -4.7	10210	/ -1.8	326.26	/-179.3	26.093	/ 176.0	8541.4
6310	2155.9	/ -5.6	10207	/ -2.2	326.27	/-179.5	26.052	/ 174.9	8541.0
7943	2150.6	/ -6.8	10203	/ -2.8	326.28	/-179.6	25.989	/ 173.5	8540.3
10000	2142.3	/ -8.4	10196	/ -3.5	326.28	/-179.8	25.889	/ 171.8	8539.0
1.2589E+04	2129.4	/ -10.4	10185	/ -4.4	326.28	/-179.9	25.733	/ 169.7	8536.9
1.5849E+04	2109.4	/ -12.9	10168	/ -5.5	326.28	/ 180.0	25.491	/ 167.1	8533.5
1.9953E+04	2078.8	/ -16.0	10140	/ -6.9	326.28	/ 179.9	25.121	/ 163.8	8528.1
2.5119E+04	2033.0	/ -19.8	10098	/ -8.6	326.28	/ 179.7	24.567	/ 159.9	8519.6
3.1623E+04	1966.2	/ -24.3	10031	/ -10.8	326.27	/ 179.6	23.760	/ 155.3	8506.1
3.9811E+04	1872.6	/ -29.5	9928.3	/ -13.5	326.27	/ 179.4	22.628	/ 149.9	8484.7
5.0119E+04	1748.3	/ -35.4	9771.6	/ -16.8	326.25	/ 179.2	21.125	/ 143.9	8451.2
6.3096E+04	1593.7	/ -41.6	9537.8	/ -20.8	326.23	/ 179.0	19.256	/ 137.4	8398.5
7.9433E+04	1415.4	/ -47.9	9199.3	/ -25.5	326.20	/ 178.7	17.100	/ 130.8	8316.4
1.0000E+05	1225.2	/ -53.9	8729.6	/ -31.0	326.14	/ 178.3	14.800	/ 124.4	8189.5
1.2589E+05	1036.6	/ -59.3	8113.3	/ -37.0	326.06	/ 177.9	12.519	/ 118.6	7996.0
1.5849E+05	860.92	/ -63.9	7357.9	/ -43.4	325.93	/ 177.3	10.393	/ 113.4	7707.5
1.9953E+05	705.13	/ -67.7	6500.1	/ -49.8	325.72	/ 176.6	8.5065	/ 109.0	7290.6
2.5119E+05	571.95	/ -70.5	5598.6	/ -56.0	325.39	/ 175.7	6.8927	/ 105.3	6715.0
3.1623E+05	460.99	/ -72.4	4716.4	/ -61.5	324.86	/ 174.6	5.5466	/ 102.2	5968.1
3.9811E+05	370.19	/ -73.5	3903.4	/ -66.3	324.04	/ 173.3	4.4428	/ 99.7	5073.7
5.0119E+05	296.82	/ -73.8	3188.1	/ -70.2	322.74	/ 171.5	3.5480	/ 97.7	4099.9
6.3096E+05	238.06	/ -73.2	2579.8	/ -73.4	320.72	/ 169.4	2.8279	/ 96.1	3143.7
7.9433E+05	191.37	/ -71.9	2074.5	/ -75.8	317.60	/ 166.7	2.2511	/ 94.8	2295.2
1.0000E+06	154.54	/ -69.6	1661.5	/ -77.5	312.83	/ 163.4	1.7906	/ 93.8	1607.6
1.2589E+06	125.73	/ -66.5	1327.5	/ -78.5	305.69	/ 159.4	1.4235	/ 93.0	1090.0
1.5849E+06	103.44	/ -62.4	1059.4	/ -79.0	295.31	/ 154.7	1.1314	/ 92.3	721.74
1.9953E+06	86.432	/ -57.5	845.16	/ -78.9	280.83	/ 149.3	.89899	/ 91.7	470.04
2.5119E+06	73.693	/ -51.9	674.71	/ -78.3	261.69	/ 143.1	.71425	/ 91.3	302.72
3.1623E+06	64.363	/ -45.7	539.54	/ -77.0	238.03	/ 136.6	.56742	/ 90.9	193.53

AMPLIFIER FREQUENCY RESPONSE

DATA

```
RESISTIVE VALUES (IN OHMS)
 R1  = 3.30000000E+04
 R2  = 1.00000000E+04
 RO  = 7.90000000E+04
 RS  = 8.80000000E+02
 RC  = 1.20000000E+04
 RE  = 5.60000000E+03
 RL  = 2.70000000E+04
 RX  = 2.20000000E+01
 RPI= 3.20000000E+03
 RU  = 1.52000000E+07

CAPACITIVE PARAMETERS (IN FARADS)
 C1  = 1.20000000E-05
 CO  = 1.00000000E-05
 CE  = 1.00000000E-04
 CPI= 1.09000000E-11
 CU  = 3.20000000E-12

DATA FOR      8 DECADES, WITH INITIAL FREQUENCY  1.00000000E+01 HERTZ

TRANSISTOR BETA= 1.40000000E+02
```

LOAD MAP.   11/10/71. 10.02.13.   PAGE   1

FL REQUIRED TO LOAD   20100
FL REQUIRED TO RUN   12200
INITIAL TRANSFER TO TRAMP   -   103

BLOCK ASSIGNMENTS.

BLOCK	ADDRESS	LENGTH	FILE
TRAMP	102	3015	LGO
HYORYH	3117	61	LGO
ZTOZT	3200	40	LGO
ZTTOZ	3240	37	LGO
AMPROP	3277	366	LGO
POLAR	3665	40	LGO
YZORZY	3725	77	LGO
ALNLOG	4024	67	SYSLIB
ATAN	4113	74	SYSLIB
ATAN2	4207	113	SYSLIB
CABS	4322	36	SYSLIB
EXP	4360	57	SYSLIB
INPUTC	4437	102	SYSLIB
KODER	4541	1247	SYSLIB
KRAKER	6010	1174	SYSLIB
/SCOPE2/	7204	0	
SYSTEM	7204	1076	SYSLIB
SIO$	10302	1425	SYSLIB
OUTPTC	11727	72	SYSLIB
GETBA	12021	17	SYSLIB
RBAREX	12040	57	SYSLIB

```
                   C  ADDING IN RB AND RD
      000272             Y1=Y1+1./RB
      000301             Y4=Y4+1./RC
                   C  BACK TO Z PARAMETERS
      000307             CALL YZORZY(Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4)
                   C  ADDING IN C1
      000317             Z1=Z1+1./(S*C1)
                   C  BACK TO Y MATRIX
      000334             CALL YZORZY(Z1,Z2,Z3,Z4,Y1,Y2,Y3,Y4)
                   C  COMPUTING GAINS AND THINGS
      000344             CALL AMPROP(Y1,Y2,Y3,Y4,YL,YS,ZIN,ZOUT,AV,AI,AP,APA,API,APT)
                   C  DIVIDING COMPLEX OUTPUT INTO MAGNITUDE AND PHASE
      000362             CALL POLAR(ZIN,ZINM,ZINA)
      000365             CALL POLAR(ZOUT,ZOUTM,ZOUTA)
      000370             CALL POLAR(AV,AVM,AVA)
      000373             CALL POLAR(AI,AIM,AIA)
      000376             WRITE(5,51)F,ZINM,ZINA,ZOUTM,ZOUTA,AVM,AVA,AIM,AIA,AP
      000426             F=F*(10.**(1./10.))
      000435          92 CONTINUE
      000437          50 FORMAT(F15.8)
      000437          51 FORMAT(1X,G10.4,4(4X,G12.5,'/',F6.1),G15.5)
      000437          52 FORMAT('7',31X,'AMPLIFIER FREQUENCY RESPONSE',////,' DATA',
                        1///,' RESISTIVE VALUES (IN OHMS)',/,'  R1 =',E15.8,/,'  R2 =',E15.
                        28,/,'  RO =',E15.8,/,'  RS =',E15.8,/,'  RC =',E15.8,/,'  RE =',
                        3E15.8,/,'  RL =',E15.8,/,'  RX =',E15.8,/,'  RPI=',E15.8,/,
                        4'  RU =',E15.8,//,' CAPACITIVE PARAMETERS (IN FARADS)',/,
                        5'  C1 =',E15.8,/,'  CO =',E15.8,/,'  CE =',E15.8,/,'  CPI=',E15.8,
                        6/,'  CU =',E15.8,//,' DATA FOR ',I5,' DECADES, WITH INITIAL FREQUE
                        7NCY ',E15.8,' HERTZ',//,' TRANSISTOR BETA=',E15.8,/,'7',31X,
                        8'AMPLIFIER FREQUENCY RESPONSE',/,53X,'MAGNITUDE/ANGLE',
                        9///,' FREQ(HZ) ',14X,'ZIN',20X,'ZOUT',19X,'AV',21X,'AI',17X,'AP'/)
                   C  DATA (READ IN FLOATING POINT IN COLUMNS 1-15)
                   C  R1,R2,RO,RS,RC,RE,RL,RX,RPI,RU,C1,CO,CE,CPI,CU,B,F,D
      000437             STOP
      000441             END

      PROGRAM LENGTH INCLUDING I/O BUFFERS
      003015

      UNUSED COMPILER SPACE
      015000
```

```
                     PROGRAM TRAMP(INPUT,OUTPUT,TAPE2=INPUT,TAPE5=OUTPUT)
000002               DIMENSION R(10),C(5)
000002               COMPLEX Y(4),Z(4),T(4),YS,YL,S,YE,YU,YPI,ZIN,ZOUT,AV,AI
                    +,Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4,T1,T2,T3,T4
000002               EQUIVALENCE (R(1),R1),(R(2),R2),(R(3),RO),(R(4),RS),(R(5),RC),
                    1(R(6),RE),(R(7),RL),(R(8),RX),(R(9),RPI),(R(10),RU)
000002               EQUIVALENCE(C(1),C1),(C(2),CO),(C(3),CE),(C(4),CPI),(C(5),CU)
000002               EQUIVALENCE(Y(1),Y1),(Y(2),Y2),(Y(3),Y3),(Y(4),Y4)
000002               EQUIVALENCE(Z(1),Z1),(Z(2),Z2),(Z(3),Z3),(Z(4),Z4)
000002               EQUIVALENCE(T(1),T1),(T(2),T2),(T(3),T3),(T(4),T4)
               C   READ IN ALL RESISTIVE VALUES IN KOHMS
               C   R(I)=R1,R2,RO,RS,RC,RE,RL,RX,RPI,RU
000002               DO 90 M=1,10
000004               READ(2,50) R(M)
000011               R(M)=R(M)*(10.**3.)
000017           90 CONTINUE
               C   READ IN ALL CAPACITIVE VALUES IN NANOFARADS
               C   C(I)=C1,CO,CE,CPI,CU
000020               DO 91 M=1,5
000022               READ (2,50)C(M)
000027               C(M)=C(M)*(10.**(-9.))
000035           91 CONTINUE
               C   B=TRANSISTOR BETA
000036               READ(2,50) B
               C   F=INITIAL FREQUENCY
000044               READ(2,50) F
               C   D=NUMBER OF DECADES (READ IN FLOATING POINT)
000052               READ(2,50)D
000060               ND=D
000062               WRITE(5,52)(R(M),M=1,10),(C(I),I=1,5),ND,F,B
000077               TPI=8.*ATAN(1.)
000103               ND=((10.*D)+1.)
000106               RB=R1*R2/(R1+R2)
000111               YS=CMPLX(1./RS,0.0)
000115               YL=CMPLX(1./RL,0.0)
               C   COMPUTING GAINS AT DIFFERENT FREQUENCIES
000120               DO 92 N=1,ND
000122               S=CMPLX(0.0,TPI*F)
000125               YU=1./RU+S*CU
000135               YPI=1./RPI+S*CPI
000144               YE=1./RE+CE*S
               C   FIRST Y MATRIX OF HYBRID PI MODEL W/O RX
000155               Y1=YU+YPI
000162               Y2=-YU
000164               Y3=B/RPI-YU
000173               Y4=YU+1./RO
               C   TRANSFORMING TO Z MATRIX
000201               CALL YZORZY(Y1,Y2,Y3,Y4,Z1,Z2,Z3,Z4)
               C   TRANSFORMING TO Z-T MATRIX
000211               CALL ZTOZT(Z1,Z2,Z3,Z4,T1,T2,T3,T4)
               C   ADDING IN ZE,RO,AND CO
000221               T1=T1+RX
000225               T2=T2+1./(S*CO)
000242               T3=T3+1./YE
               C   TO Z MATRIX
000253               CALL ZTTOZ(T1,T2,T3,T4,Z1,Z2,Z3,Z4)
               C   TO Y MATRIX
000262               CALL YZORZY(Z1,Z2,Z3,Z4,Y1,Y2,Y3,Y4)
```

MACE

OPERATING SYSTEM

VERSION 4.1

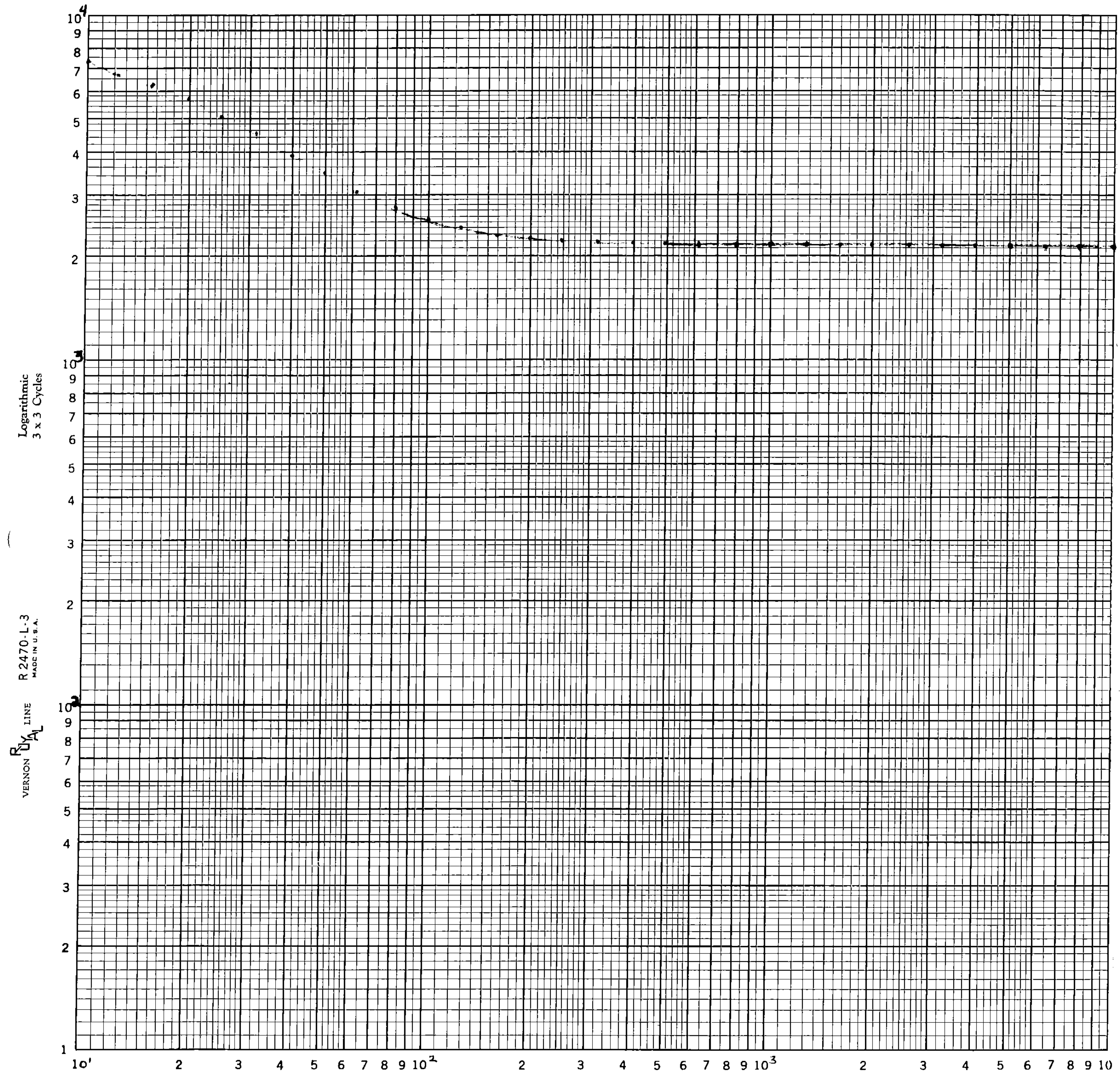
JOB ORIGIN - EXPORT/IMPORT

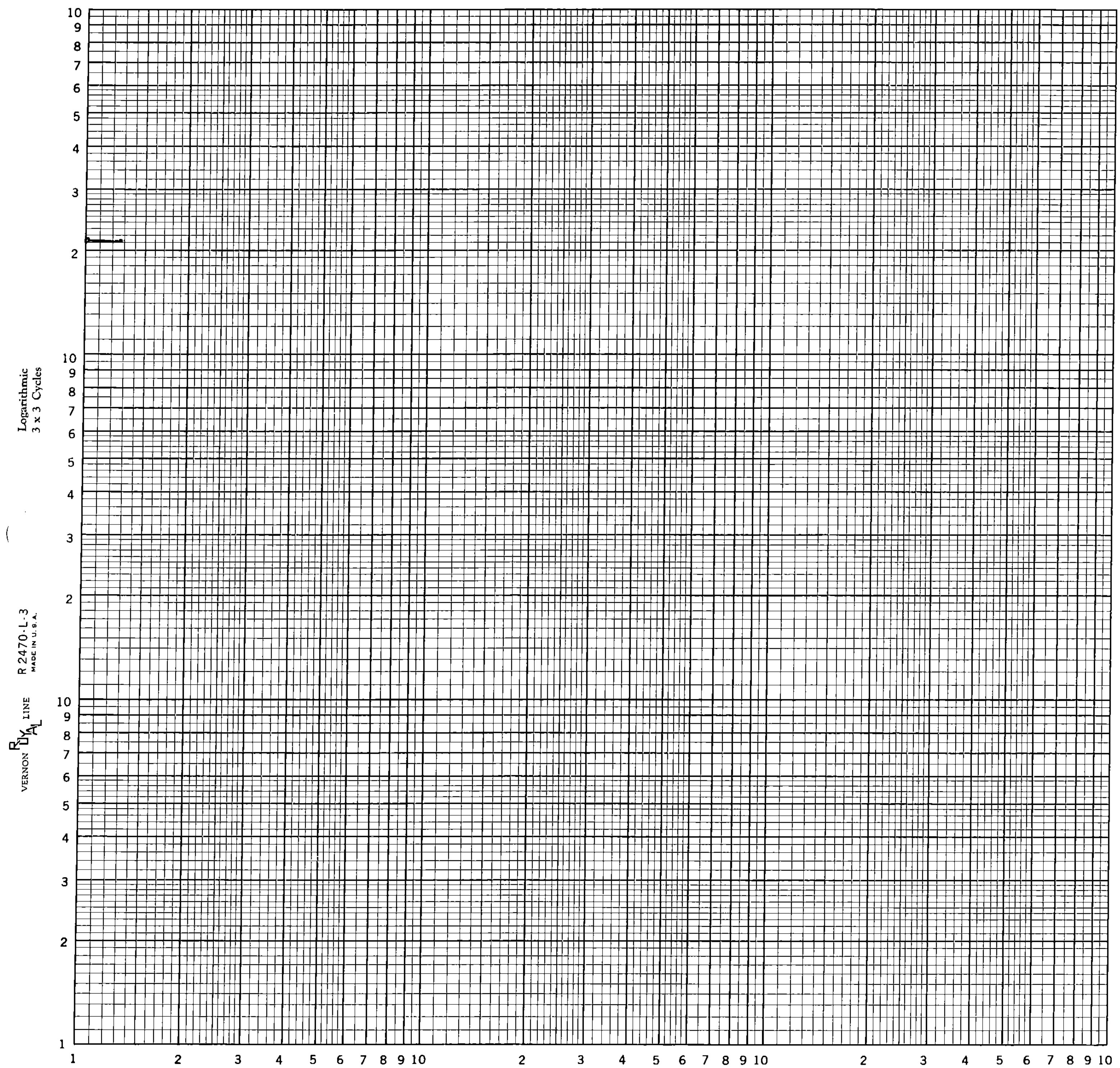
```
X          X  RRRRRRRRRRR   RRRRRRRRRRR              JJ  MM          MM   99999999           44
XX        XX  RRRRRRRRRRRR  RRRRRRRRRRRR             JJ  MMM        MMM  9999999999         444
XX        XX  RR        RR  RR        RR             JJ  MMMM      MMMM 99        99       4444
 XX      XX   RR        RR  RR        RR             JJ  MM MM    MM MM 99        99      44 44
  XX    XX    RR        RR  RR        RR             JJ  MM  MMMM  MM 99        99     44  44
   XX  XX     RR        RR  RR        RR             JJ  MM   MM     MM 99        99    44   44
    XXXX      RR        RR  RR        RR             JJ  MM          MM 99        99   44    44
     XX       RRRRRRRRRRRR  RRRRRRRRRRRR             JJ  MM          MM  99999999999  44     44
     XX       RRRRRRRRRRR   RRRRRRRRRRR              JJ  MM          MM   9999999999 44444444444
    XXXX      RR  RR        RR  RR                   JJ  MM          MM           99 44444444444
   XX  XX     RR   RR       RR   RR                  JJ  MM          MM          99         44
  XX    XX    RR    RR      RR    RR                 JJ  MM          MM         99          44
 XX      XX   RR     RR     RR     RR                JJ  MM          MM        99           44
XX        XX  RR      RR    RR      RR     JJ        JJ  MM          MM       99            44
XX        XX  RR       RR   RR       RR    JJJJJJJJJJJJ  MM          MM      99             44
X          X  RR        RR  RR        RR    JJJJJJJJJJ   MM          MM     99              44

==================================================================================================
==================================================================================================
==================================================================================================
==================================================================================================
==================================================================================================
==================================================================================================
```

3.9811E+06	57.702 / -39.5	432.76 / -75.1	210.92 / 130.0	.45076 / 90.5	123.14
5.0119E+06	53.070 / -33.4	348.80 / -72.5	182.17 / 123.6	.35806 / 90.2	78.111
6.3096E+06	49.925 / -27.8	283.23 / -69.2	153.82 / 117.7	.28443 / 89.9	49.451
7.9433E+06	47.834 / -22.9	232.49 / -65.0	127.53 / 112.5	.22593 / 89.6	31.268
1.0000E+07	46.465 / -18.7	193.74 / -60.1	104.28 / 107.9	.17946 / 89.3	19.755
1.2589E+07	45.579 / -15.2	164.65 / -54.5	84.437 / 104.1	.14254 / 88.9	12.474
1.5849E+07	45.009 / -12.5	143.28 / -48.5	67.914 / 100.9	.11321 / 88.4	7.8743
1.9953E+07	44.642 / -10.3	127.97 / -42.4	54.381 / 98.2	8.99140E-02/ 87.9	4.9693
2.5119E+07	44.403 / -8.6	117.27 / -36.5	43.418 / 95.9	7.14037E-02/ 87.3	3.1354
3.1623E+07	44.244 / -7.4	109.96 / -31.3	34.599 / 93.9	5.66958E-02/ 86.5	1.9779
3.9811E+07	44.129 / -6.5	105.06 / -26.8	27.537 / 92.1	4.50072E-02/ 85.6	1.2474
5.0119E+07	44.036 / -6.0	101.78 / -23.3	21.899 / 90.3	3.57154E-02/ 84.4	.78638
6.3096E+07	43.943 / -5.8	99.572 / -20.7	17.404 / 88.6	2.83258E-02/ 82.9	.49549
7.9433E+07	43.831 / -5.8	98.006 / -19.1	13.826 / 86.9	2.24450E-02/ 81.0	.31195
1.0000E+08	43.678 / -6.2	96.777 / -18.3	10.979 / 84.9	1.77603E-02/ 78.7	.19614
1.2589E+08	43.453 / -6.9	95.636 / -18.5	8.7132 / 82.7	1.40227E-02/ 75.8	.12308
1.5849E+08	43.114 / -7.9	94.360 / -19.6	6.9104 / 80.2	1.10347E-02/ 72.2	7.69917E-02
1.9953E+08	42.605 / -9.3	92.715 / -21.6	5.4751 / 77.1	8.63959E-03/ 67.8	4.79292E-02
2.5119E+08	41.854 / -10.9	90.441 / -24.6	4.3313 / 73.3	6.71411E-03/ 62.4	2.96187E-02
3.1623E+08	40.776 / -12.9	87.250 / -28.5	3.4186 / 68.8	5.16297E-03/ 55.9	1.81047E-02
3.9811E+08	39.303 / -14.9	82.871 / -33.3	2.6891 / 63.2	3.91448E-03/ 48.3	1.08948E-02
5.0119E+08	37.409 / -16.9	77.133 / -38.9	2.1050 / 56.5	2.91645E-03/ 39.6	6.41779E-03
6.3096E+08	35.156 / -18.6	70.079 / -45.0	1.6367 / 48.5	2.13110E-03/ 29.9	3.68021E-03
7.9433E+08	32.710 / -19.6	62.028 / -51.2	1.2617 / 39.0	1.52856E-03/ 19.4	2.04721E-03
1.0000E+09	30.294 / -19.7	53.522 / -57.3	.96334 / 28.2	1.08086E-03/ 8.5	1.10600E-03

XRRJM94. 11/10/71.PURDUE MACE 71/11/01.

```
10.01.30.XRRJM,    41031,STUDENT,P10,T10,CM60000.
10.01.30.COMMENT. $RJM 8069 ROBERT J. MARKS II PU
10.01.30.RDUE
10.01.30.MAP(PART)
10.01.31.FUN(S)
10.01.36. CTIME 000.759 SEC. FUN MOD LEVEL 60F
10.01.36.PFILES(GET,SADIST,N=FACULTY,A=41029,X=LG
10.01.36.O)
10.02.10. DONE
10.02.10.LGO.
10.02.13.CX      1.903 SEC., NL  12200 WORDS
10.02.16.STOP
10.02.16.CP    2.983 SEC., IO       298 UNITS.
10.02.16.LINES    250
10.02.16.CM    5.238 MWD-SEC.,  FL  12200 WORDS
```


Logarithmic 3 x 3 Cycles
R 2470-L-3
MADE IN U.S.A.
VERNON LINE


Logarithmic
3 x 3 Cycles
R 2470-L-3
MADE IN U.S.A.
VERNON LINE

USE THE SUBROTINES IN THE SADIST SYSTEM TO PERFORM A FREQUENCY RESPONSE ANALYSIS ON THE AMPLIFIER SHOWN

$A_v = V_2 / V_1$

PLOT ON LOG-LOG GRAPH PAPER THE MAGNETUDES OF A_v, A_i, A_p, Z_{IN}, AND Z_{OUT} FOR THE AMPLIFIER. PLOT A SMOOTH CURVE WITH AT LEAST 10 POINTS PER DECADE.

$r_x = 22\ \Omega$

$r_\pi = 3200$

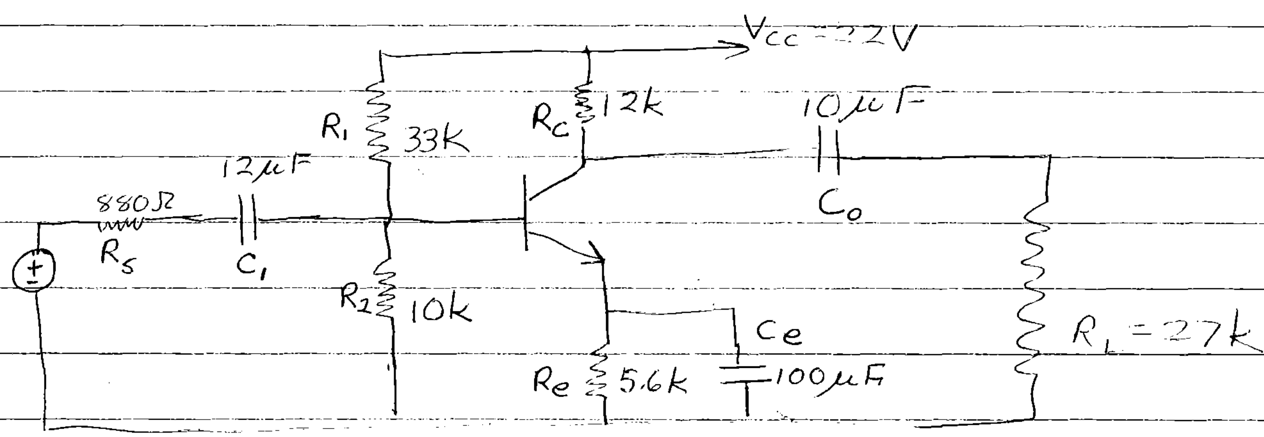
$r_o = 79\ k\Omega$

$r_\mu = 15.2\ M\Omega$

$\beta = 140$

$C_\mu = 3.2\ pF$

$C_\pi = 10.9\ pF$



EE 363

DECK SETUP TO USE

SADIST SYSTEM SUBROUTINES

15 1925   25 R.D. QUICK

#PDQ

4103I, STUDENT, T10, CM60000, L - - - . ← END WITH PERIOD

(T10 ← TIME IN SEC.; CM60000 ← CENTRAL MEMORY ALLOCATION; L ← # OF LINES OF OUTPUT)

MAP(PART)

FUN(S) → FORTRAN COMPILER S

PFILES(GET, SADIST)

REWIND (SADIST)

FUN(G,,, SADIST)

7/8/9

PRØGRAM ------(INPUT, OUTPUT, TAPE2=INPUT, TAPE5=OUTPUT)

FORTRAN DECK WITH HEADER CARD

CALL DESIGN (< ,–, –, –, ...) ← INPUT AND OUTPUT PARAMETERS

DESIGN

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

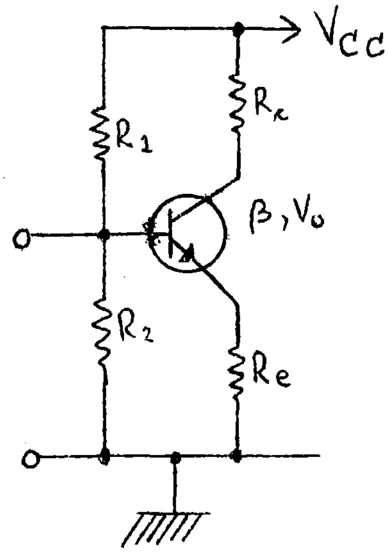
```
SUBRØUTINE DESIGN(VCC,BETA1,BETA2,VCEMIN,IC1,IC2,VØ,K,
        R1,R2,RC,RE,SE1,SE2,N,RB)
```

Inputs: VCC,BETA1,BETA2,VCEMIN,IC1,IC2,VO,K [redacted]

VCC	Collector supply voltage.
BETA1	Minimum value of beta.
BETA2	Maximum value of beta.
VCEMIN	Minimum quiescent collector-to-emitter voltage.
IC1	Minimum quiescent collector current.
IC2	Maximum quiescent collector current.
VØ	Transistor base-to-emitter voltage.
K	Ratio of RE to RC
R1,R2, RC,RE	Computed values of bias resistors
SE1,SE2	Stability factors corresponding to BETA1 and BET2 respectively.
N	Ratio of V_{BB} to VØ.
RB	Parallel equivalent of R1 in parallel with R2.

NOTE: All variables are REAL as opposed to INTGER.

This subprogram calculates the values of the four bias resistors in the standard configuration common emitter transistor amplifier.



JHD
9.16.71

ANALYZ

Elecrtical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

```
SUBRØUTINE ANALYZ(VCC,BETA,R1,R2,RC,RE,VØ,ICØ,IC,VCE,RB
          N,SE,VBB)
```

Inputs: VCC,BETA,R1,R2,RC,RE,VØ,ICØ

VCC	Collector supply voltage.
BETA	Beta of the transistor.
R1,R2, RC,RE	Bias resistors values.
VØ	Transistor base-to-emitter voltage.
ICØ	Collector leakage current.

Computed values: IC,VCE,RB,N,SE,VBB

IC	Quiescent collector current.
VCE	Quiescent collector-to-emitter voltage.
RB	R1 in parallel with R2.
N	Ratio of VBB to VØ.
SE	Stability factor.
VBB	Thevenin's equivalent base supply voltage.

This program calcultads the quiescent operatíng point information for the standard configuration common emitter transistor amplifier as well as other useful quantities.

NOTE: All variables are REAL as opposed to INTEGER.

JHD
9.16.71

STDVAL

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

FUNCTION STDVAL(RIN)

This function computes the closest standard ten percent value of resistor to RIN.

JHD
9.16.71

ZTØZT

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE ZTØZT(Z11,Z12,Z21,Z22,Z1,Z2,Z3,ZM)

Inputs: Z11,Z12,Z21,Z22 (Complex)

Computed values: Z1,Z2,Z3,ZM (Complex)

This subroutine gives the elements in the T form of the z-parameter two-port network.

JHD
10.4.71

PØLAR

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE PØLAR(RECT,PØLMAG,ANGLE)

Inputs:

RECT - A complex FORTRAN variable

Computed values:

PØLMAG - the magnitude of RECT

ANGLE - the angle of RECT

This subroutine converts a complex number from rectangular to polar form.

JHD
10.4.71

YTØABC

Electrical Engineering Dept.
Rose-Hulman Inst itute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE YTØABC(Y11,Y12,Y21,Y22,A,B,C,D)

Inputs: Y11,Y12,Y21,Y22 (complex)

Computed values: A,B,C,D (Complex)

This subroutine computes the ABCD parameters of a two-port given the y parameters.

JHD
10.4.71

CASCADE

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

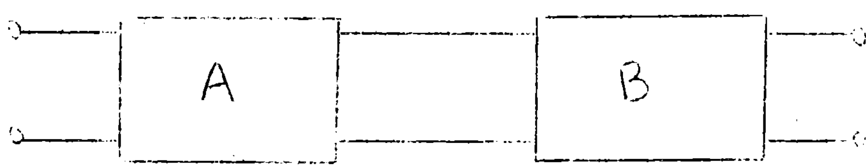
SADIST System subprogram

SUBRØUTINE CASCADE(A1,B1,C1,D1,A2,B2,C2,D2,A3,B3,C3,D3)

Inputs: A1,B1,C1,...C2,D2 (Complex)

Computed values: A3,B3,C3,D3 (Complex)

This subroutine gives the ABCD parameters of the combination of two two-ports in cascade. The two two-ports are characterized by their ABCD matrices.



JHD
10.4.71

ABCTØY

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE ABCTØY(A,B,C,D,Y11,Y12,Y21,Y22)

Inputs: A,B,C,D (All complex)

Computed values: Y11,Y12,Y21,Y22 (Complex)

This subroutine computes the y parameters of a two-port given the ABCD parameters.

JHD
10.4.71

ZTTØZ

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE ZTTØZ(Z1,Z2,Z3,ZM,Z11,Z12,Z21,Z22)

Inputs: Z1,Z2,Z3,ZM (Complex)

Computed values: Z11,Z12,Z21,Z22 (Complex)

This subroutine converts from the T-form of the z parameter network to the standard form.

JHD
10.4.71

YZØRZY

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE YZØRZY(A11,A12,A21,A22,B11,B12,B21,B22)

Inputs: A11,A12,A21,A22 - Y or Z parameters (complex)

Computed values:

B11,B12,B21,B22 - Z or Y parameters (complex)

This subroutine converts from y-parameters to z-parameters or vice-versa.

JHD
10.4.71

AMPRØP

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subroutine

SUBRØUTINE AMPRØP(Y11,Y12,Y21,Y22,YL,YS,ZIN,ZØUT,
AV,AI,AP,APA,API,APT)

Inputs:

Y11,Y12,Y21,Y22, the network y-parameters	)	
	)	Complex
YL,YS - source and load admittances	)	

Computed values:

ZIN,ZØUT, the input and output impedances	)	
	)	Complex
AV,AI, voltage gain and current gain	)	

AP	Power gain	)	
APA	Available power gain	)	
		)	Real
API	Insertion power gain	)	
APT	Transducer power gain	)	

This subroutine computes important properties of an amplifier (two-port) given the y-parameters.

JHD
10.4.71

HYØRYH

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

SADIST System subprogram

SUBRØUTINE HYØRYH(A11,A12,A21,A22,B11,B12,B21,B22)

Inputs:

A11,A12,A21,A22 - h-parameters or y-parameters (complex)

Computed values:

B11,B12,B21,B22 - y-parameters or h-parameters (complex)

This subroutine converts from h to y-parameters or vice-versa.

JHD
10.4.71

Electrical Engineering Dept.,
Rose-Hulman Institute of Tech.,
Terre Haute, Ind.,
October 7, 1977

$$\rho = \frac{|A+B|}{\frac{1}{2}(|A|+|B|)}$$

common mode rejection ratio

EE 368 — ELECTRONIC CIRCUITS
Experiment No.
Differential Amplifier

1. Build a two-transistor differential amplifier as shown. The approximate quiescent operating point for each transistor is to be $V_{CE} = -5$ V and $I_C = 1.0$ mA. Select values of resistors so that $-2V > V_E > -4V$. After the amplifier is designed and built, measure the quiescent conditions. Measure and record the beta values of your transistors. BETA = 150

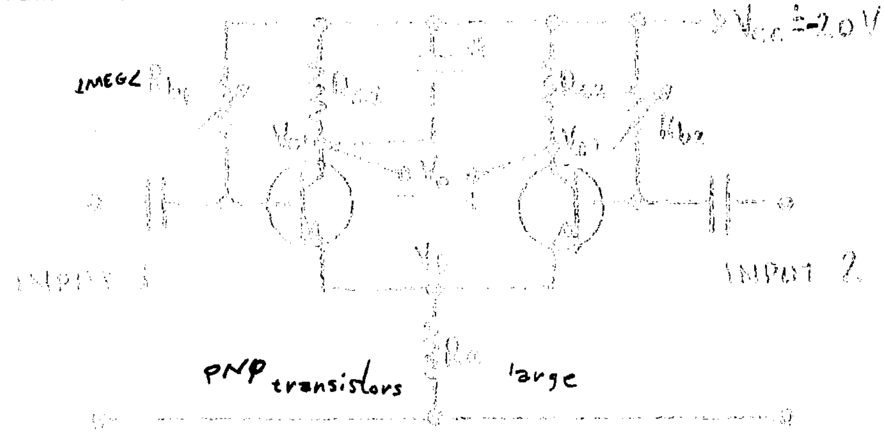


FIG. 1
DIFFERENTIAL AMPLIFIER

* See part 2.

2. Interchange the transistors and again measure the quiescent conditions including V_E. Make sure the transistors are biased in their active regions. Record your measured values.

3. Apply AC signals first to input #1, then to input #2 and measure the 4 values of voltage gain

$$\frac{V_{c1}}{V_1}, \quad \frac{V_{c2}}{V_1}, \quad \frac{V_{c1}}{V_2} \text{ and } \frac{V_{c2}}{V_2}.$$

Combine these gains to predict A and B in the equation $V_o = AV_1 + BV_2$.

4. Calculate V_o for $V_1 = V_2$ = some appropriate value. From parts 3 and 4 calculate the common mode rejection ratio.

5. Apply input signals as in Part 4 and measure V_o. Compare results with predicted value from Part 4.

6. Measure the output impedance to ground of each of the two outputs, V_{o1} and V_{o2}.

7. Ground input #2 and short out (with a capacitor) R_{e1} and you have an emitter coupled two-stage amplifier. Measure the gain of this amplifier.

BOB MARKS

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana
Sept. 21, 1971

EE365 (Both)
Note on first computer
homework assignment.

Not later than 1500 PM EST Friday, September 24, 1971 you are to turn in the first attempt at the problem ~~assigned originally on Aug. 30, 1971~~. This problem will subsequently be called computer problem number one. The problem must compile and execute in order to meet the requirements for credit on this homework problem. Please turn in the computer print-out as well as anything else that you feel is worthy of note; e. g., an explanation of how you are altering your original design so that more of the cases considered in your worst case analysis will meet the design specs of the amplifier regarding quiescent operating point stability.

A test is made to see that Z does not converge to a previously found root. If ZABS(Z-Z(I)).LT.EPS2 then Z is replaced by Z+0.001.

[illegible] inequality is necessary: ZABS(Y(Z-Z(I+1))).GT.AMAX1(EPS,[illegible](Z(I))). If this inequality is not satisfied then Z(I+1) is replaced by 0.5*(Z(I+1)+Z(I)).

Muller's method is used.

[illegible] is [illegible].

Henrici, P., 'Elements of Numerical Analysis', Wiley 1964, pp. 198-200.

Muller, D. E., 'A Method of Solving Algebraic Equations Using an Automatic Computer', Math. Tables and Aids to Computation 10(1956), pp. 208-215.

RANDY MILLER 11-2-77

LIBCØPY(CSCBIN, LGØ, MULLER)

LGØ.

SUBROUTINE MULLER

DECKS USED

MULLER

Purpose

To find the zeros of a complex valued function of a complex variable, F(Z).

Usage

CALL MULLER(KN,N,RTS,MAXIT,EP1,EP2,FN,FNREAL)

Parameter FN requires an external statement.

Description of Parameters

KN - the number of previously computed roots, stored in RTS(1),...,RTS(KN). (known at time of call)

N - the number of roots to be found for this call of MULLER - will be stored in RTS(KN+1),...,RTS(KN+N).

RTS - complex (KN+N)-vector of roots. Initially, RTS(KN+1),...,RTS(KN+N) should contain approximations to the N roots. (If approximations are not known set RTS(KN+I)=0.0, I=1,...,N).

MAXIT - the maximum number of iterations allowed. Usually MAXIT .LE. 100. If the number of iterations exceeds MAXIT, the last iterate is accepted as a root of F(Z)=0.

EP1 - criterion for relative convergence test. Let {Z(I)} be a sequence generated by Muller. (10^{-9})

If CABS((Z(N)-Z(N-1))/Z(N)).LT.EP1 then Z(N) is accepted as a root of F(Z)=0.

EP2 - criterion for absolute convergence test. (10^{-8})

Let FP(Z)=F(Z)/P where P=(Z-Z(1))*(Z-Z(2))*,...,*(Z-Z(K-1)), and Z(1),...,Z(K-1) are the previously found roots.

If ((CABS(F(Z)).LT.EP2).AND.(CABS(FP(Z)).LT.EP2)) then Z is accepted as a root of F(Z)=0.

FN - a user supplied subroutine which evaluates F(Z). Its calling sequence must be of the form CALL FN(Z,FZ) where FZ=F(Z), both Z and FZ are complex. (name in External statement)

FNREAL - logical, if (FNREAL) then iterates will be restricted to real values. FNREAL is passed to Muller as .TRUE. or .FALSE.. This option may be used when F is defined for real values only. In that case use REAL(Z) in the function evaluation subroutine.

RANDY MILLER 11-2-71

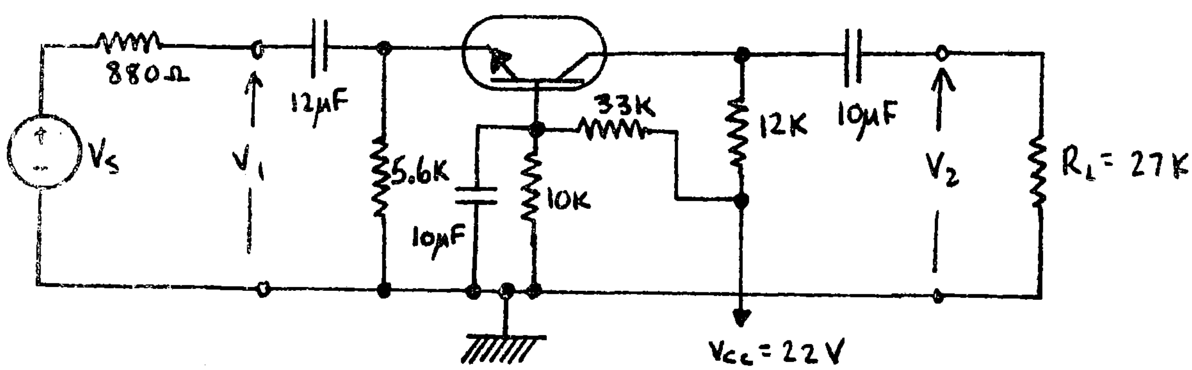
Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana
November 3, 1971

EE363 - Electronics Circuits
Computer problem no. 4
Due at a later date.

Two possibilities=

I. Common base amplifier

Use the same transistor as in computer problem no. 3 and do a frequency response analysis on the common base amplifier shown. Assume the same source and load impedances. Plot the same curves. In addition compare the insertion power gains of the two amplifiers in the midband region.



II. Common emitter, design program

Use the amplifier of problem 3 and alter the program to use Muller's method to determine the correct value of emitter bypass capacitor such that the low frequency half power point is at (a) 20 Hz, (b) 200 Hz. Assume that the input and output capacitors are "large" for this calculation. You will not need to print out or plot frequency response for this problem. Use the power gain as the criterion for frequency response.

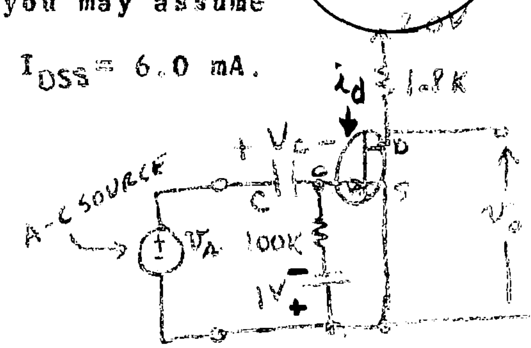
BOB MARKS

Electrical Engineering Dept.
Rose-Hulman Institute of Technology
Terre Haute, Indiana
May 25, 1971

EE 262 - Electronics I
Test No. 2
Closed books - 50 minutes.

44

1. Shown is an FET amplifier. For this FET you may assume $i_D = I_{DSS}(1 - v_{GS}/V_p)^2$ where $V_p = -2.5V$ and $I_{DSS} = 6.0$ mA. Second order effects may be neglected.



C is "LARGE"

3 (a) Find I_D and V_{DS}, the quiescent operating point values.

1 (b) Find v_c.

(c) What instantaneous value of v_s will cause the transistor to be on the threshold of cutoff during one instant of the a-c cycle.

(d) What is the small signal voltage gain of the amplifier, v_o/v_s?

a) $V_p = -2.5$; $I_{DSS} = 6.0$
AT QUIESCENCE

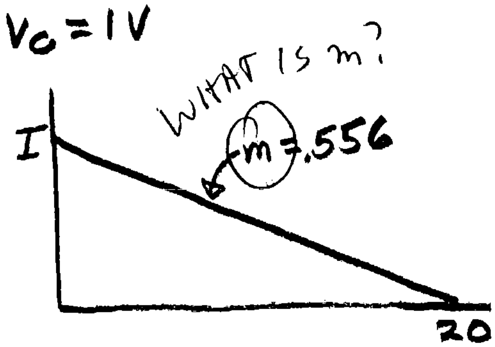
$$i_d = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

$$\Rightarrow I_D = 6\left(1 - \frac{1}{2.5}\right)^2$$
$$= 6(1 - .4)^2 = 3.6 \text{ mA}$$

$$V_{DS} = 20 - 1.8(3.6)$$
$$= 20 - 6.47 = 13.53 V$$

1 b) $V_c = 1V$

c)



$\frac{I_c}{20} = .566 \Rightarrow I_c = 11.3$

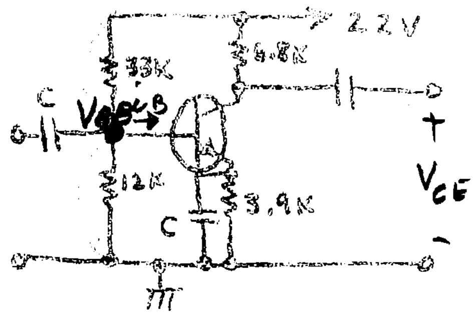
$V_{GS} = \left[\sqrt{I_D/I_{DSS}} - 1\right] V_p$
$= (1 - .358) 2.5$
$= .642(2.5) = 1.6 V$

4

d) $K_v = -\frac{2 R_d I_{DSS}}{V_p} = \frac{+2(1.8)(6)}{2.5} = 8.64$

6

2. Analyze the amplifier shown. Assume $\beta = 100$, $I_{CEO} = 0$, and $V_o = .6V$ for the transistor.



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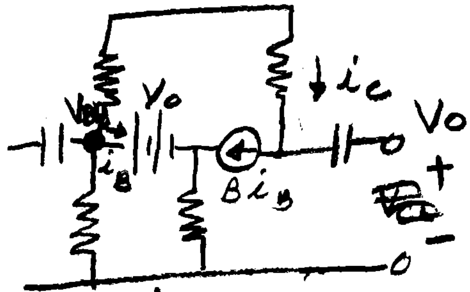
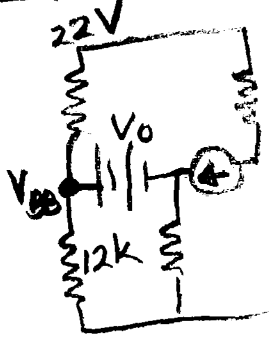




(a) Find I_C.

(b) Find V_{CE}.

(c) n, the ratio of V_{BB}/V_o.

(d) S_e.

0 a) $I_C = \beta I_B$

$I_B = \frac{V_o}{15.9} = \frac{.6}{15.9} = .0377\ mA$ — Where from?

$\Rightarrow I_C = 3.77\ mA$

✓ b) ~~$V_{CE} = 22 - (6.8)(3.77)$~~

~~$= 22$~~

~~$6.8k \| 33k = \frac{224}{39.8} = 3.22k$~~

~~$V_{CE} = 22 - (3.22)(3.77)$~~

~~$= 22 - 12.8 = 9.2V$~~

~~c) V_o +~~ $3.9 \| 12 = \frac{46.8}{15.9} = 2.94k$

$V_{CE} = 22 - (2.94)(3.77)$

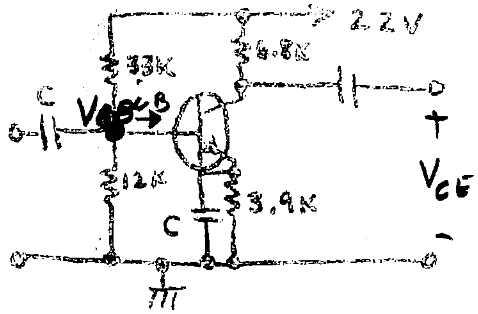
$= 22 - 11 = 11V$

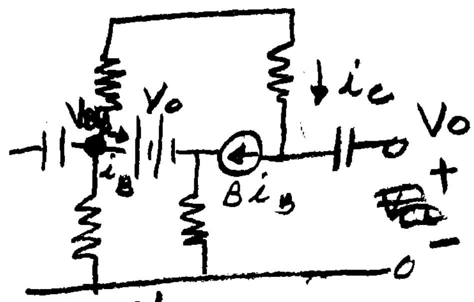
✓ c) ~~$V_o = 39.8\ i_c$~~ $V_{BB} = 22\ \frac{12}{45} = 5.87$

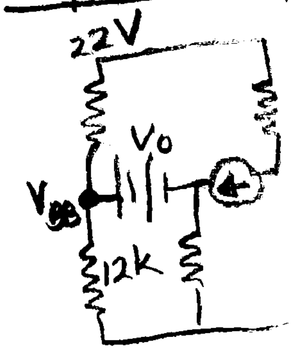
$\frac{V_{BB}}{V_o} = \frac{5.87}{.6} = 9.79$

4

2. Analyse the amplifier shown. Assume $\beta = 100$, $I_{CEO} = 0$, and $V_o = .6V$ for the transistor.







(a) Find I_C.

(b) Find V_{CE}.

(c) n, the ratio of V_{BB}/V_o.

(d) S_e.

0 a) $I_c = \beta I_B$

$I_B = \frac{V_o}{15.9} = \frac{.6}{15.9} = .0377\ mA$ — Where from?

$\Rightarrow I_c = 3.77\ mA$

✓ b) ~~$V_{CE} = 22 - (6.8)(3.77)$~~

~~$= 22$~~

~~$6.8k \| 33k = \frac{224}{69.8} = 3.22k$~~

~~$V_{CE} = 22 - (3.22)(3.77)$~~

~~$= 22 - 12.8 = 9.2V$~~

~~c) V_o +~~ $3.9 \| 12 = \frac{4.68}{15.9} = 2.94k$

$V_{CE} = 22 - (2.94)(3.77)$

$= 22 - 11 = 11V$

✓ c) ~~$V_o = 39.8\ i_c$~~ $V_{BB} = 22\ \frac{12}{45} = 5.87$

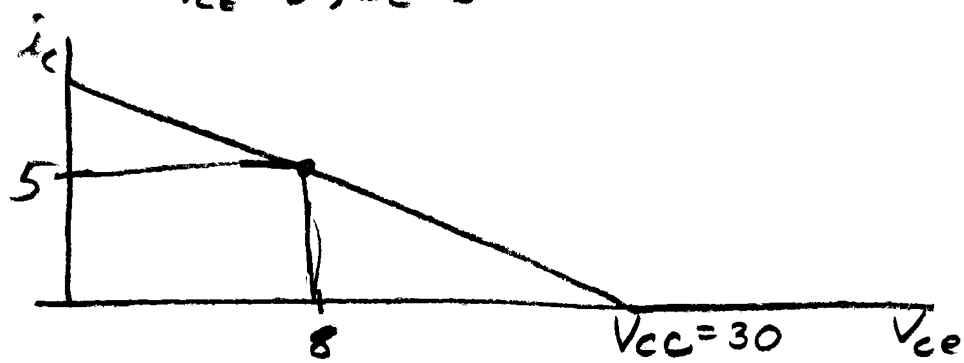
$\frac{V_{BB}}{V_o} = \frac{5.87}{.6} = 9.79$

4

3. A transistor amplifier is being designed with regard to stabilizing its quiescent operating point with respect to variations in β. The beta spread is known to be 70–200, and V_0 is 0.7V. If the d-c supply voltage is 30V, select values of R_1, R_2, R_e, and R_c such that I_c is guaranteed to lie between 4 and 5 mA and V_{CE} is 8V when I_c = 5.0 mA.

$70 < \beta < 200$ $\quad V_0 = .7 \quad V_{cc} = 30V \quad 4 < I_c < 5$

$V_{CE} = 8 \,;\, I_c = 5$

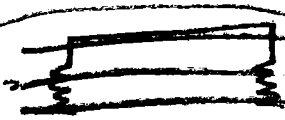


$$\frac{5}{8} = \frac{1}{R_c + R_e} \Rightarrow R_c + R_e = \frac{8}{5}k$$

$$1.25 R_c = \frac{8}{5}$$

$$S_{e_2} = \frac{1}{100} \cdot 4 \quad \frac{(1)(70)}{(4)(130)} = .134 \quad \Rightarrow R_c = 2.13\,k\Omega$$

$$\therefore R_e = .52\,k\Omega$$



$$V_{BB} = \frac{R_1}{R_1+R_2} 30$$

$$R_b = \frac{R_1 R_2}{R_1+R_2} = R_1 V_{BB}$$

$$\to 30 R_b = R_1 V_{BB}$$

$$V_{BB}\left(1 - \frac{R_1}{R_2}\right) = 30$$

$$R_b = \frac{R_1 V_{BB}}{30}$$

$$\frac{V_{BB}}{30} = \frac{R_2}{R_1+R_2} = \frac{(1 - \frac{R_1}{R_2})}{900}$$

$$900 R_2 = R_1$$

$$\frac{R_1}{R_b} = \frac{S_{e_2}(1-\beta_1)}{(1+\beta_1)}$$

$$.134 = S_{e_2} = \frac{R_1 + R_c}{R_1 + (\beta+1) R_c}$$

$$V_{BB} = 30 \frac{R_2}{R_1 + R_2}$$

TWO TIMES IT WAS ANNOUNCED IN CLASS THAT THIS PROBLEM WOULD BE ON THE TEST, BOO!

3

Hey, Hey, Hey!
It's
FREAKY
Bob!

LAB

Electrical Engineering Dept.
Rose-Hulman Inst. of Tech.
Terre Haute, Ind.
Sept. 16, 1971

EE 363 - Electronic Circuits
HOMEWORK ASSIGNMENT

To design, build, and analyze on the computer a single stage common emitter transistor amplifier utilizing a silicon transistor.

The amplifier is to be designed to have a quiescent collector current of 3.0 mA ± 10% when transistors with a beta spread of 50 to 200 are used. Furthermore, collector-to-emitter quiescent voltage should not fall below 6.0 volts under any conditions. The power supply voltage is 25 volts nominally and V_0 for the transistor is 0.7 volts nominally.

Ignoring I_{CBO}, design the transistor amplifier and compute R_1, R_2, R_e, and R_c. After you have arrived at values of these resistors, you should select standard value resistors which are closest and analyze the resulting amplifier.

Perform a worst case analysis based on the following:

(a) $50 < \beta < 200$

(b) $.65 < V_0 < .7$

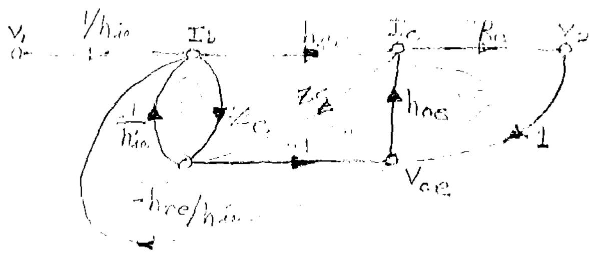
(c) $24\ V < V_{CC} < 25\ V$

(d) Resistors have specific tolerances.

Determine in how many of the possible cases the original design specifications are <u>not</u> met. Redesign the amplifier to improve upon this.

Use subroutines stored in permanent files of the CDC 6500 computer.

4/4



a) $\Delta_a = 1 - \left[\frac{Z_e}{h_{ie}} + \frac{h_{re} Z_e}{h_{ie}} + \frac{h_{fe} R_c h_{re}}{h_{ie}} - Z_e h_{oe} - R_c h_{oe} \right] + \left[\frac{-Z_e R_c V_{ce}}{h_{ie}} \right]$

$= 1 + \frac{Z_e}{h_{ie}} - \frac{h_{re} Z_e}{h_{ie}} - \frac{h_{fe} R_c h_{re}}{h_{ie}} + Z_e h_{oe} + R_c h_{oe} + \frac{Z_e R_c V_{ce}}{h_{ie}}$

$= 1 + \frac{Z_e}{h_{ie}} \left[1 - h_{re} + R_c V_{ce} \right] - \frac{h_{fe} R_c h_{re}}{h_{ie}} + h_{oe}(R_c + Z_e)$

$P_{1a} = \frac{-R_c h_{fe}}{h_{ie}}$

$\Delta_{1a} = 1$

$P_{2a} = \frac{+Z_e h_{oe} R_c}{h_{ie}}$

$\Delta_{2a} = 1$

$\frac{V_2}{V_1} = \frac{Z_e h_{oe} R_c - R_c h_{fe}}{h_{ie} + Z_e[1 + h_{re} + R_c V_{ce}] - h_{fe} R_c h_{re} + h_{oe} h_{ie} (R_c + Z_e)}$

b) $\Delta_b = \Delta_a$

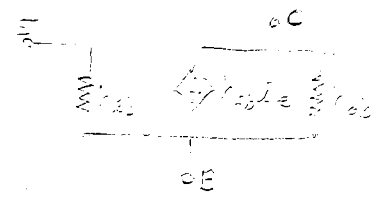
$P_{1b} = 1/h_{ie}$

$\Delta_{1b} = 1 + h_{oe} Z_e + R_c h_{oe} = 1 + h_{oe}(Z_e + R_c)$

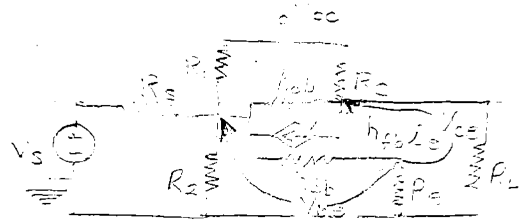
$\frac{I_b}{V_1} = \frac{1 + h_{oe}(Z_e + R_c)}{h_{ie} + Z_e[1 + h_{re} + R_c V_{ce}] - h_{fe} R_c h_{re} + h_{oe} h_{ie} (R_c + Z_e)}$

$\Rightarrow Z_{in} = \frac{V_1}{I_b} = \frac{h_{ie} + Z_e(1 + h_{re} + R_c V_{ce}) - h_{fe} R_c h_{re} + h_{oe} h_{ie} (R_c + Z_e)}{1 + h_{oe}(Z_e + R_c)}$

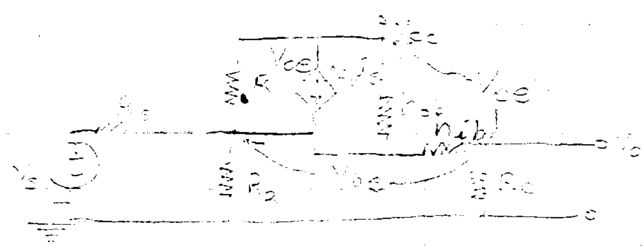
10-22



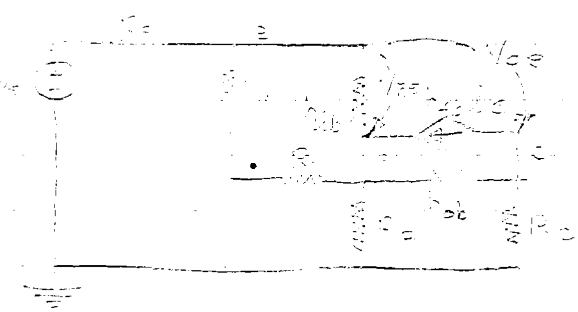
a)



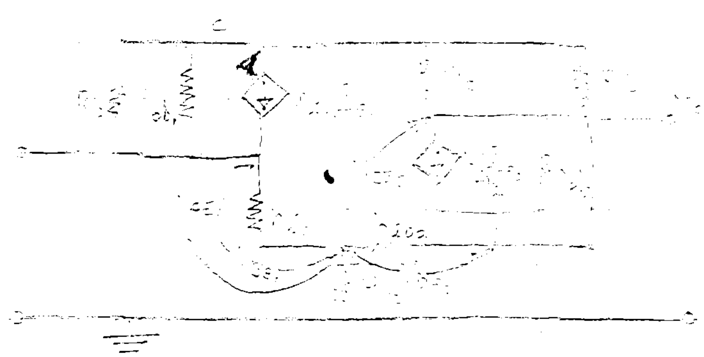
b)



c)



d)



(1/8) TOTAL 7.5/18

(-1) $h_{fe}r_e$

Electrical Engineering Dept.
Rose-Hulman Institute of Tech.
Terre Haute, Indiana

EE-211 and EE-363 Laboratory

Helpful hints for happy lab books.

1. Always keep the notebook in ink.

2. No loose pages will be allowed.

3. Always keep all lab notes in the notebook <u>as you are doing the experiment</u>.

4. Keep accurage records which would enable you to repeat your experiment at a later date and get the same results.

5. Make sure a complete circuit diagram is included for all measurements.

6. Record instrument information and numbers. Same for components used in calculations.

7. All tables should have column headings and appropriate units.

8. Tell what it is that you are doing preferably in diary style. When in doubt write it down.

9. All graphs should be on appropriate graph paper permanently attached to the notebook. Each graph should have a title, labelled axes, and units. The preparer of the graph should put his name on the graph.

10. Always use straight edge or curves to draw the graphs.

11. In general put all writing in the lab notebook. It is much easier to keep track of all your notes this way.

12. The experiment instruction sheets are merely to act as a guide in most cases. Do not "Parrot" these instructions in your notebook.

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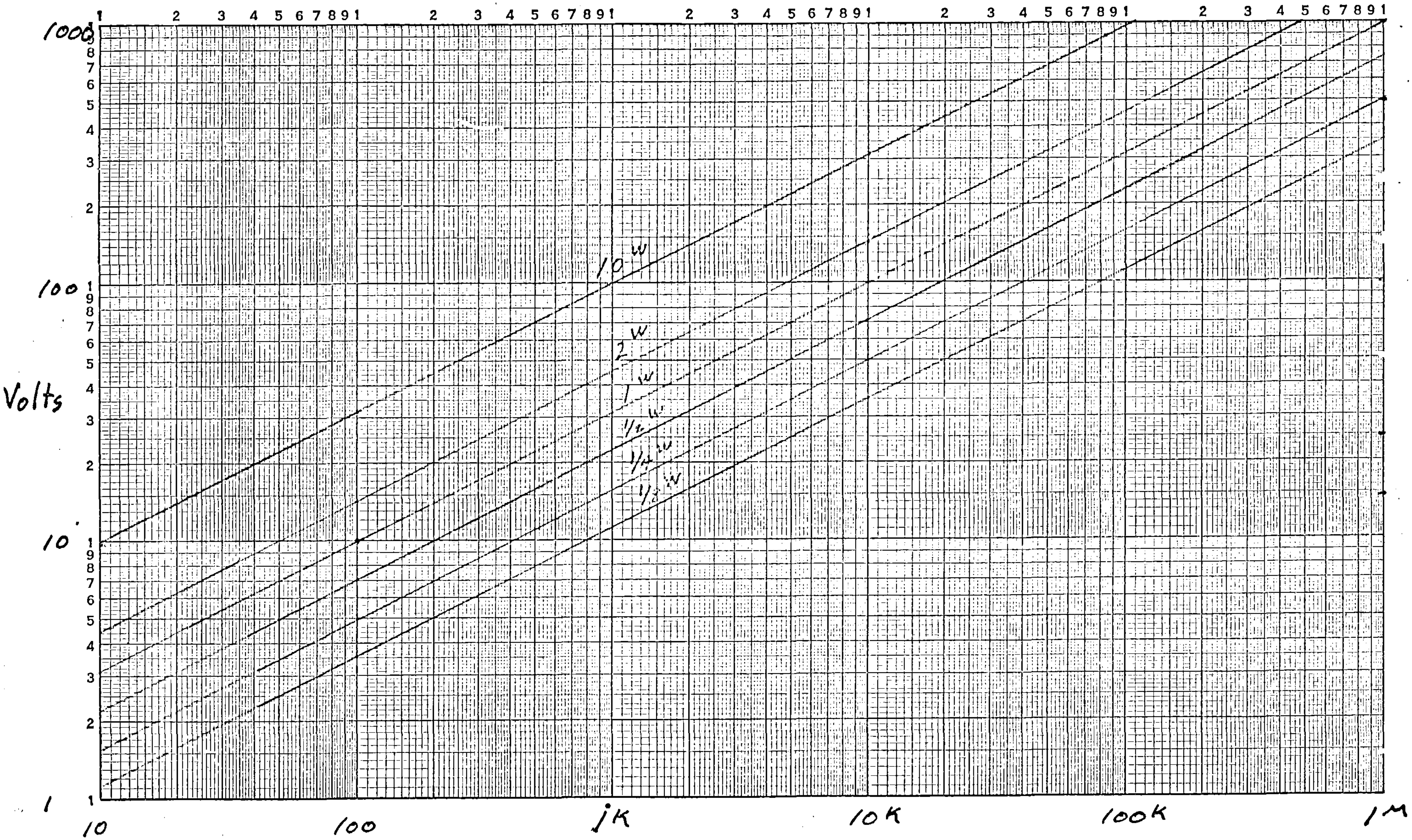
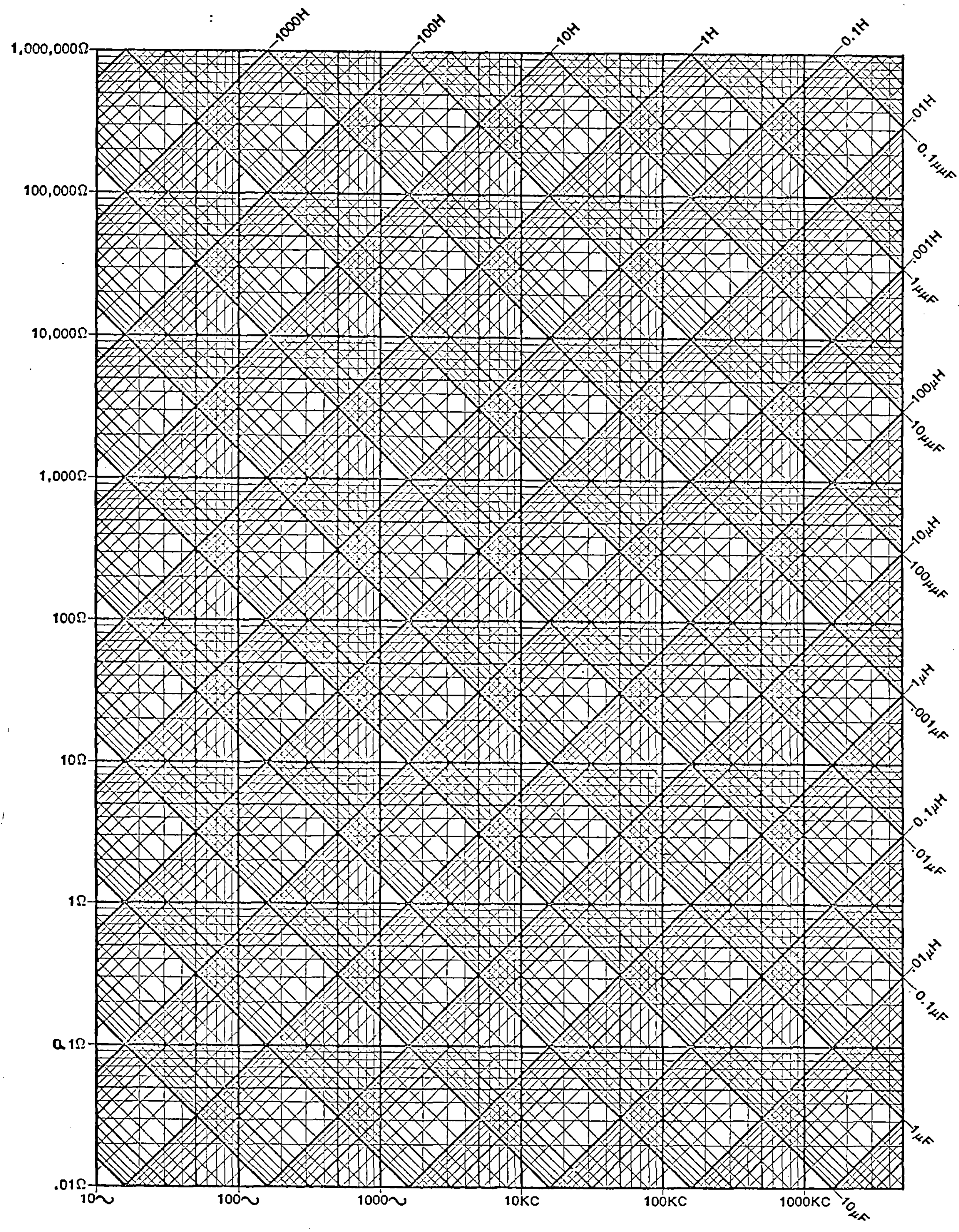




PRINTED IN U.S.A.

ISSUE	APP'LS	CH.	DR.	ENG.

NO. OF SHEETS PER SET | SEE SHEET 1 | SHEET

D180 K & E CO. 2372 F-1707 (11-52)

In the serial adder since the carry resulting from an addition of two bits must be added to the sum of the bits in the next higher place. Hence the time delay for the carry pulse must be the same as the period T for the signals to be added.

In comparing the parallel and the serial adders it becomes immediately obvious that the parallel adder requires much more in the way of full-adders and is so more expensive. However parallel is faster than serial and can produce a "stored" output w/o losing or destroying the input.

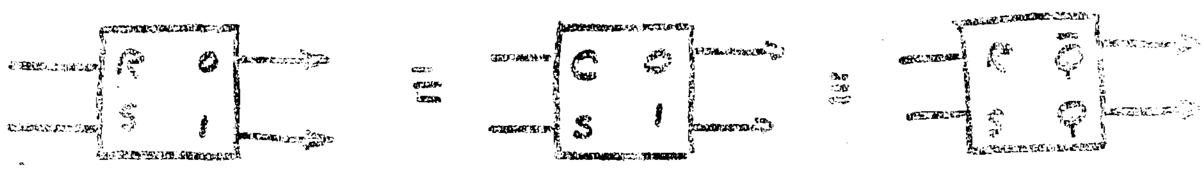
An example of parallel subtractors applied to a problem is the determination of an unknown frequency using SN7483N's, 4 bit adder/subtractors, as shown in the handout (pp 105A)

Registers

Flip-Flop - retains info. indefinitely in the level (state) of 2 outputs each of which has two stable states.

Since it possesses 2 stable states it may be used to store one binary bit of info.. Hence it is also called a "BINARY"

A. R-S FF

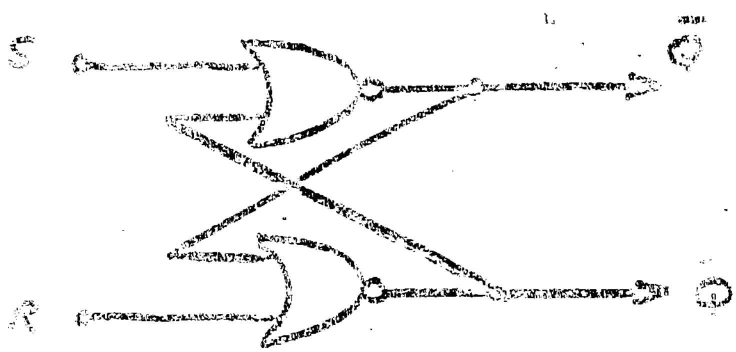


S (set) = 1 , "1" (Q) = 1 , "0" ($\bar{Q}$) = 0

R (reset) = 1 , "0" ($\bar{Q}$) = 1 , "1" (Q) = 0

The condition R · S = 1 is constrained

1. NOR-logic RS FF

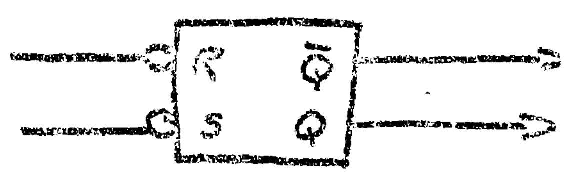


A "1" on R or S unconditionally controls
Asynchronous

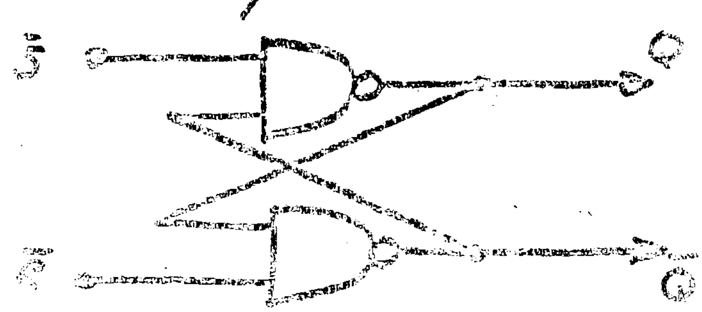
R	S	Q	$\bar{Q}$
1	0	0	1
0	1	1	0
1	1	0	0
0	0	X	X

PREVIOUS STATE

Many FF's require a logical zero to energize the inputs. The recommended symbol for this is



2. NAND-logic RS FF



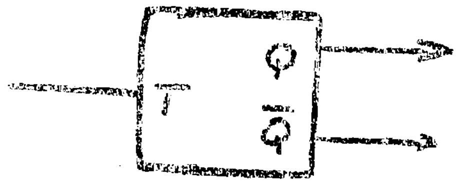
In this ckt, the ... (or reset) levels ... R & S are "1"

If, for the NAND FF, "O" is GND, then grounding either input will activate the FF. In this case $\bar{R} \cdot \bar{S} = 0$ is constrained.

B. Type T FF (TOGGLE)

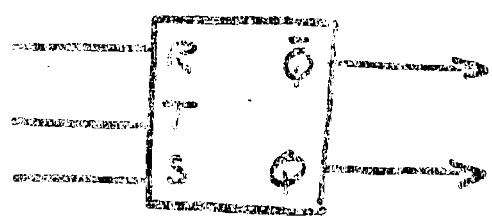
Triggered or complementing FF

A pulse (EDGE) applied to T will change the state

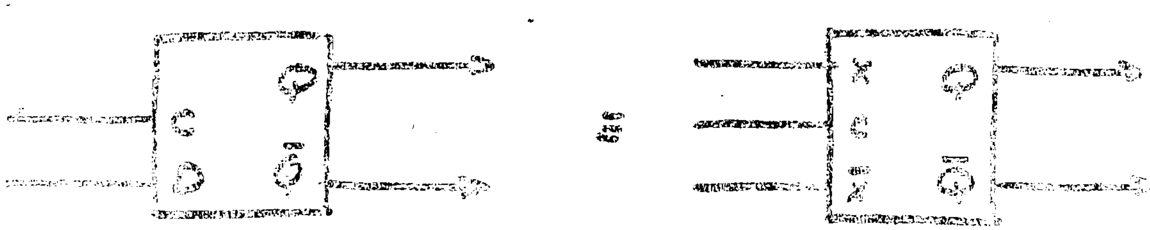


C. RST FF

R S control operates independently of T



D. Type D FF



Type D FF will pass or transfer a bit but with a delay determined by the clock pulse.

[illegible]

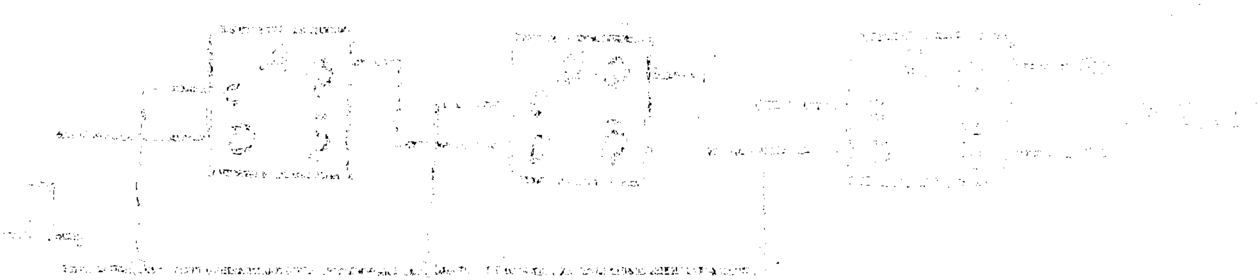
[illegible]	[illegible]	[illegible]
0	0	[illegible]
[illegible]	1	0

[illegible]

[illegible]

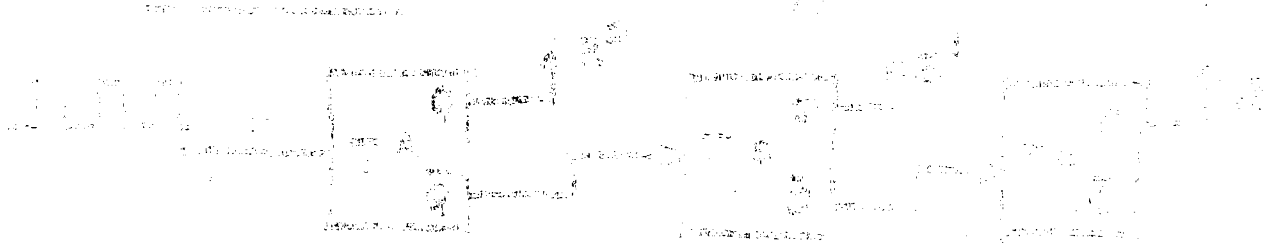
[illegible]

[illegible]



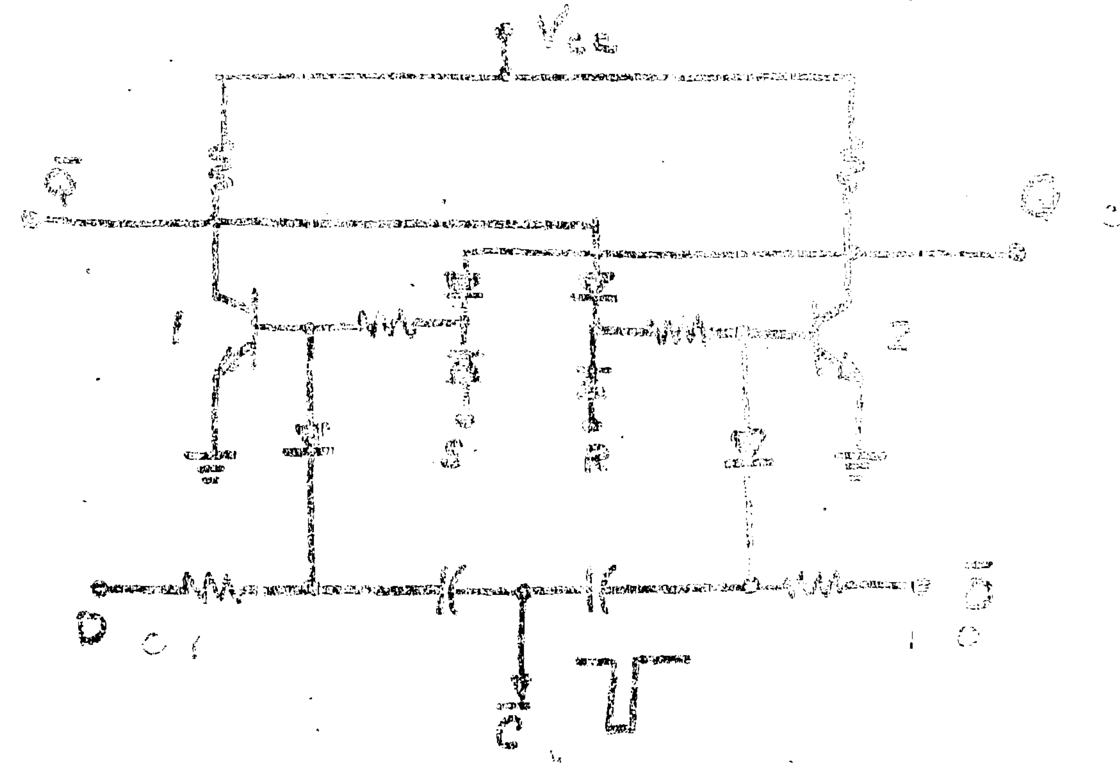
[illegible]

[illegible]



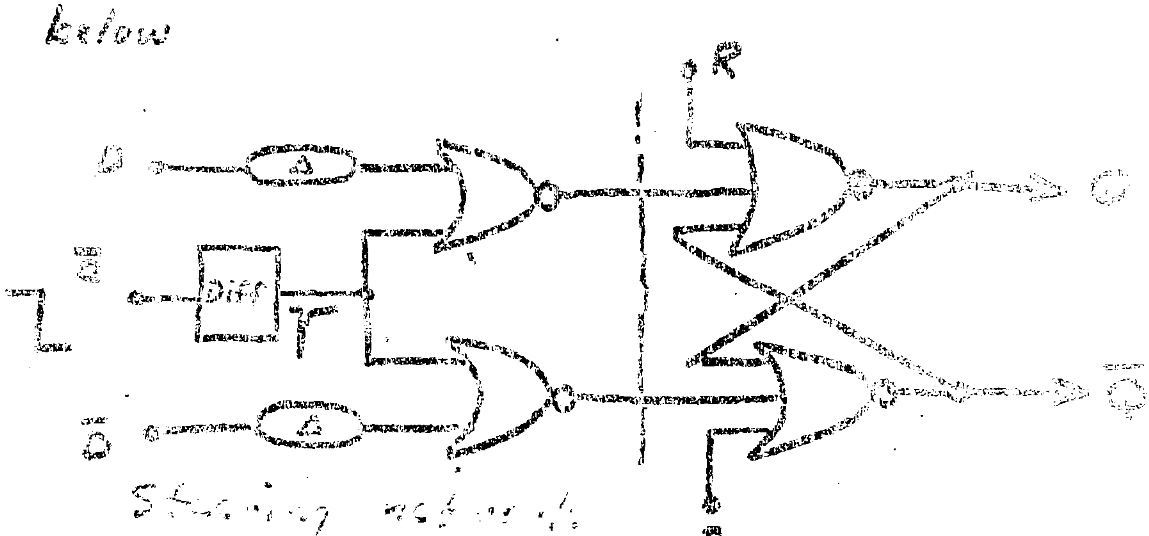
[illegible]

How could we construct a D-type FF?



Discrete-Component D-type

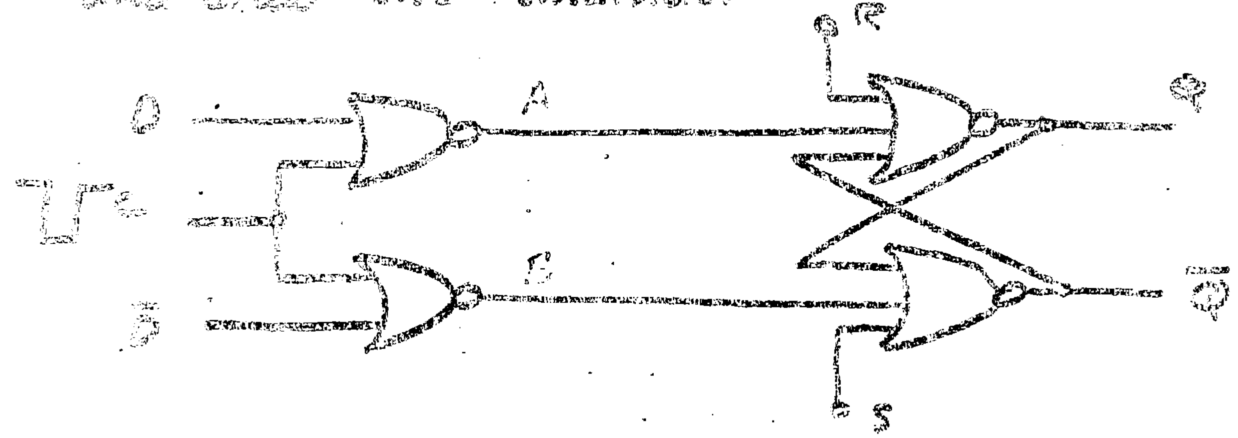
We can redraw in basic logic form as shown below



Steering network

where Δ represent time delays and Diff is a differentiator

Suppose we ignore the diff. of delays and draw the remainder



This results in a Half-Shift FF (what happens w/o differ. of T.D.'s?)

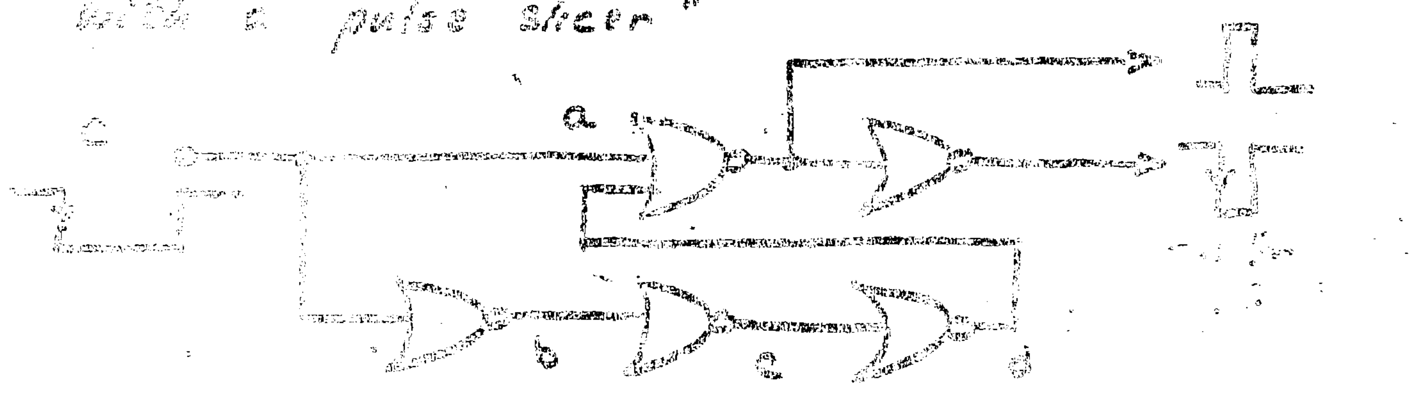
For proper operation for a full-shift we will find that

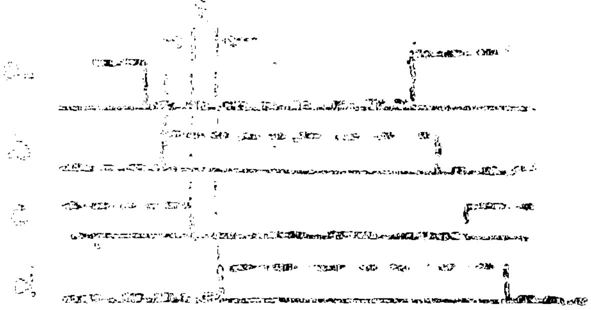
$$\Delta > T_p > 2\delta$$

where

δ = Half-Pair Delay

We can reduce the pulse width of the clock with a "pulse slicer"

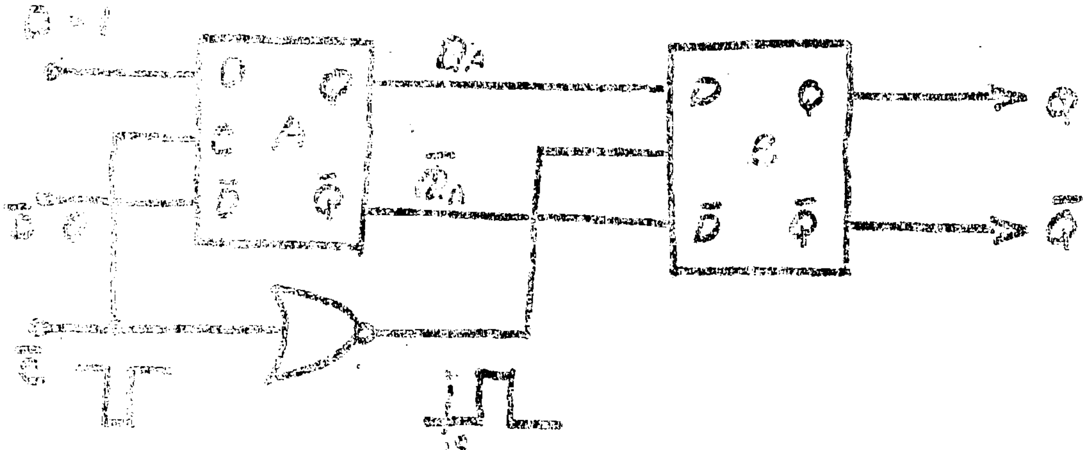




This configuration reduces the clock to only 3δ width

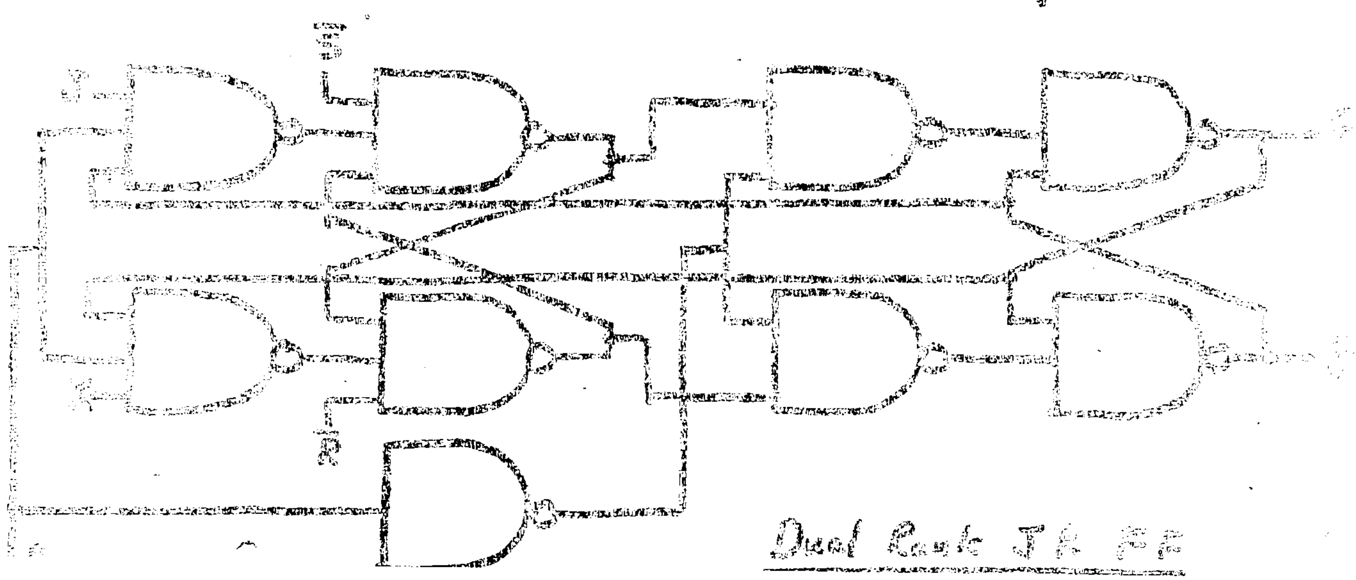
For a 75 clock width, we will need a minimum of 4 gates/per delay. Hence a min. no. of gates to replace the steering ckt directly is 13. Let us try an easier approach.

Suppose we cascade two Half-shift FF's.



This technique still requires 5 additional gates to replace diff. but none for the delay action which is provided for by the undiff. clock pulse width.

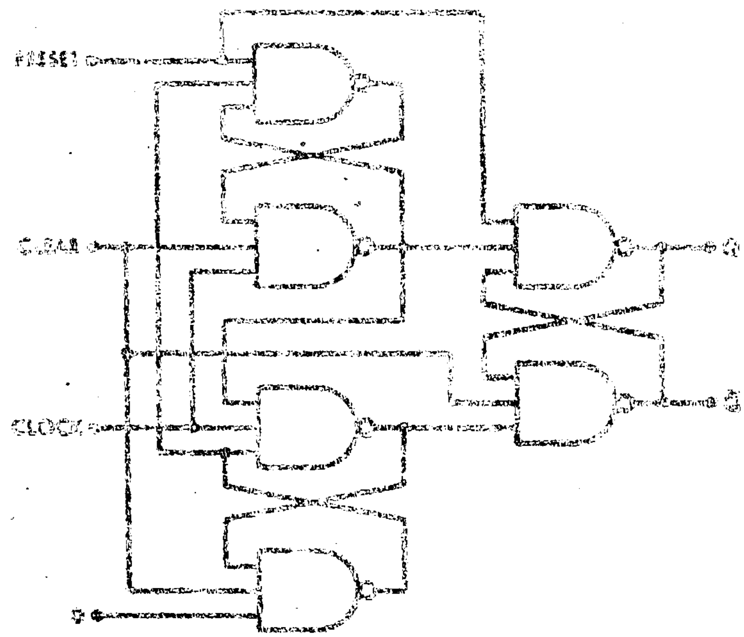
This very common application is called a dual rank or master-slave FF (Note the change in name)



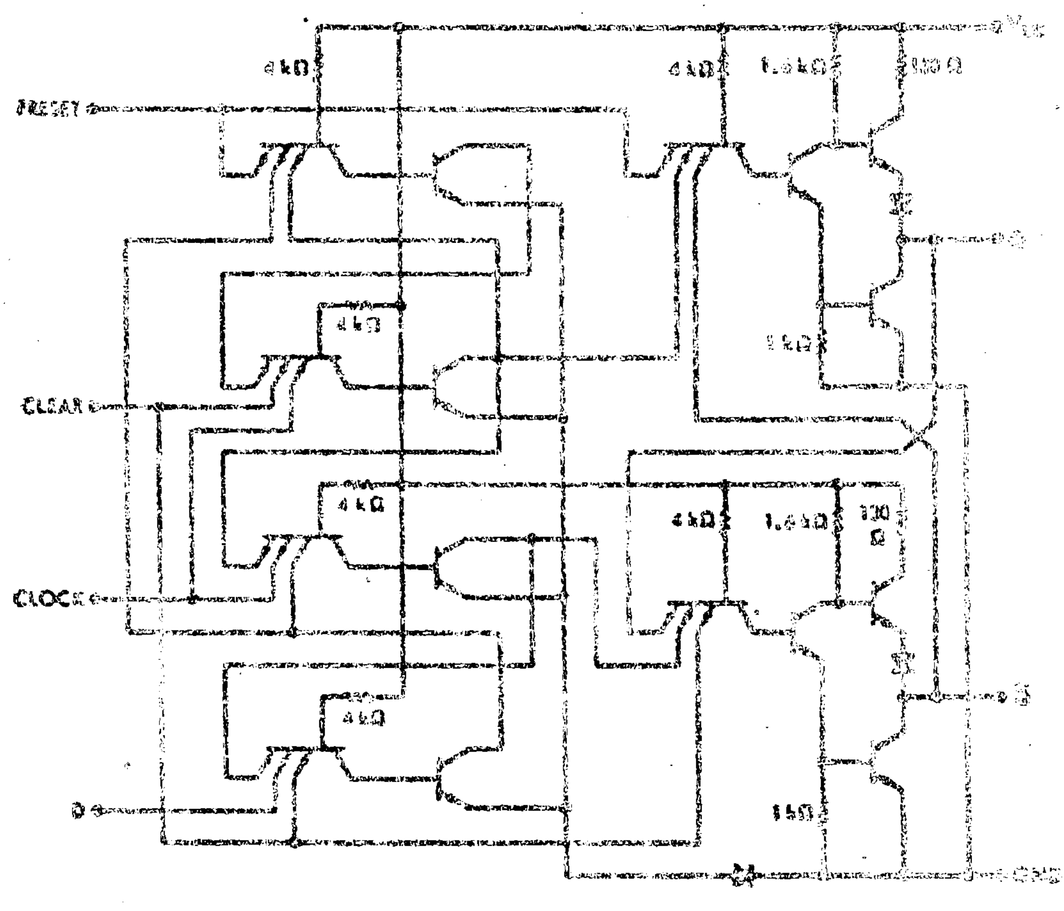
Dual Rank JK FF

D-TYPE EDGE-TRIGGERED FLIP-FLOP

functional block diagram (each flip-flop)

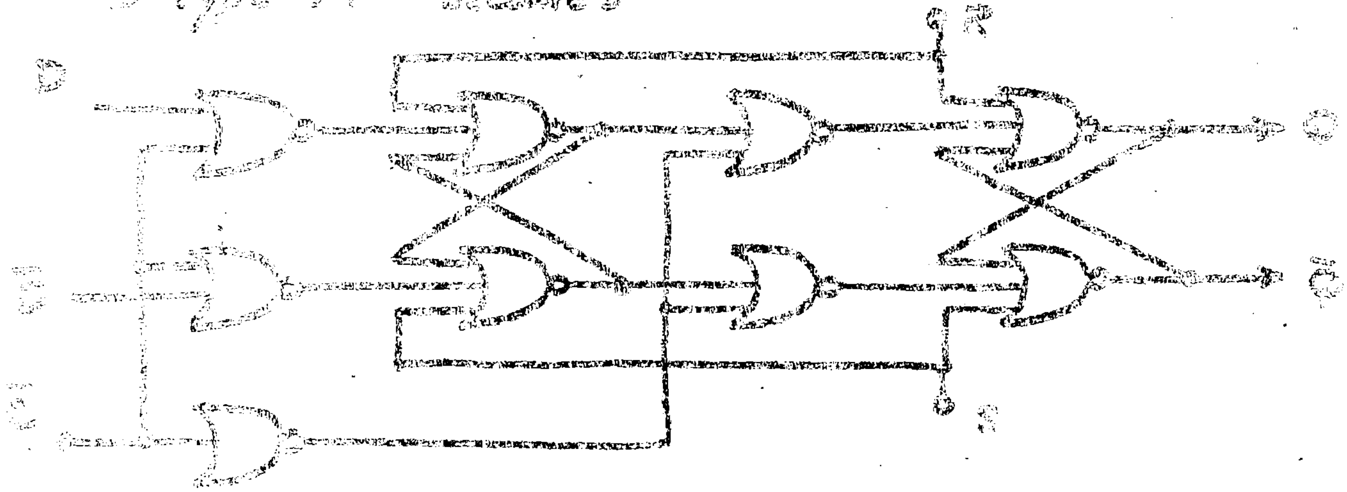


schematic (each flip-flop)



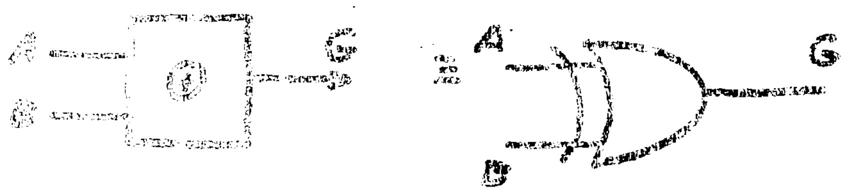
Component values shown are nominal.

may be [illegible] and on page the complete D-type FF becomes



Verification of proper operation is left as a exercise for the student.

Review of Mod 2 Adder (Exclusive OR)

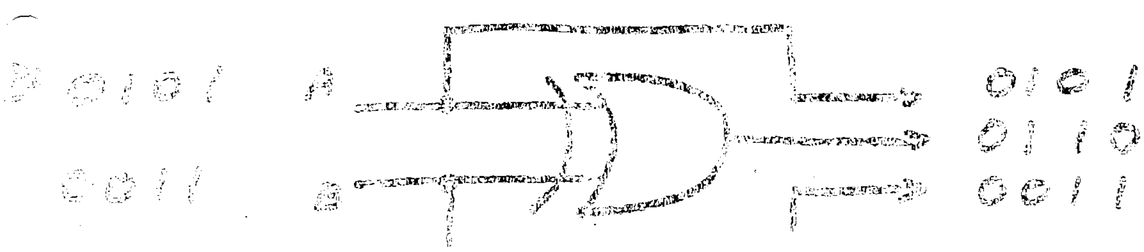


A	B	G
0	0	0
1	0	1
0	1	1
1	1	0

$G = A\bar{B} + \bar{A}B$

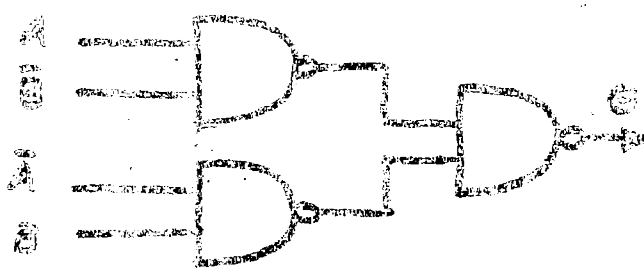
Sometimes called a "binary Comparator" because it compares A & B, indicating a mismatch by an output of "1".

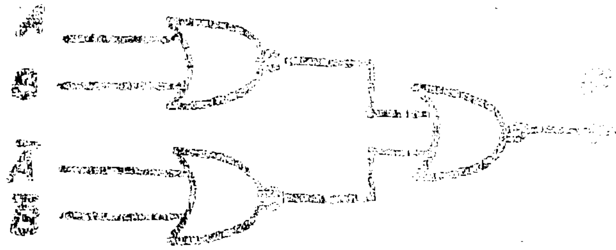
Used as a "parity" checker because it measures the no. of 1's at input in terms of evenness or oddness (OE is an even parity generator)



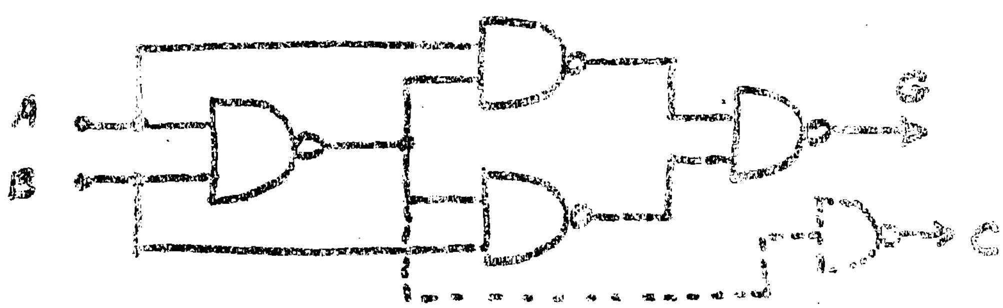
Implementation

A. NAND logic   B. NOR logic

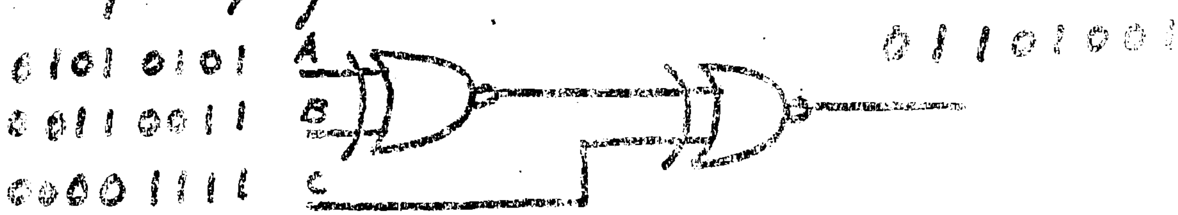




The above are not suited for I.C. applicati because too many inputs are required or too inverters are necessary. By adding another ga as shown below the need for inverted inputs is obviated!



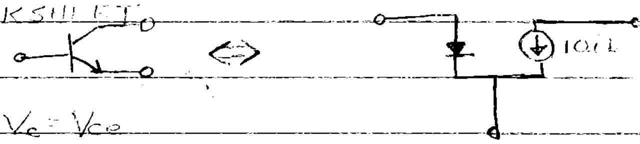
Two OE's could be combined to produce a 3-input parity generator



DIGITAL ELECTRONICS

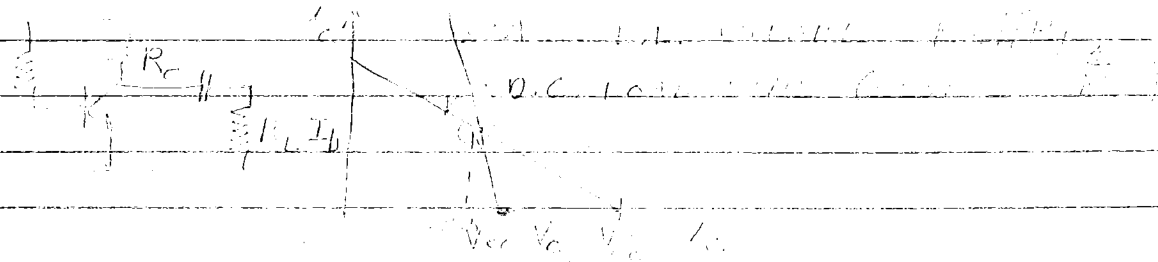
WORKSHEET

7)



$V_c = V_{co}$

8) A-C LOADLINE



10) WILL BE ... GO BELOW ... OF i_c CURVE

11) $\beta = 120$

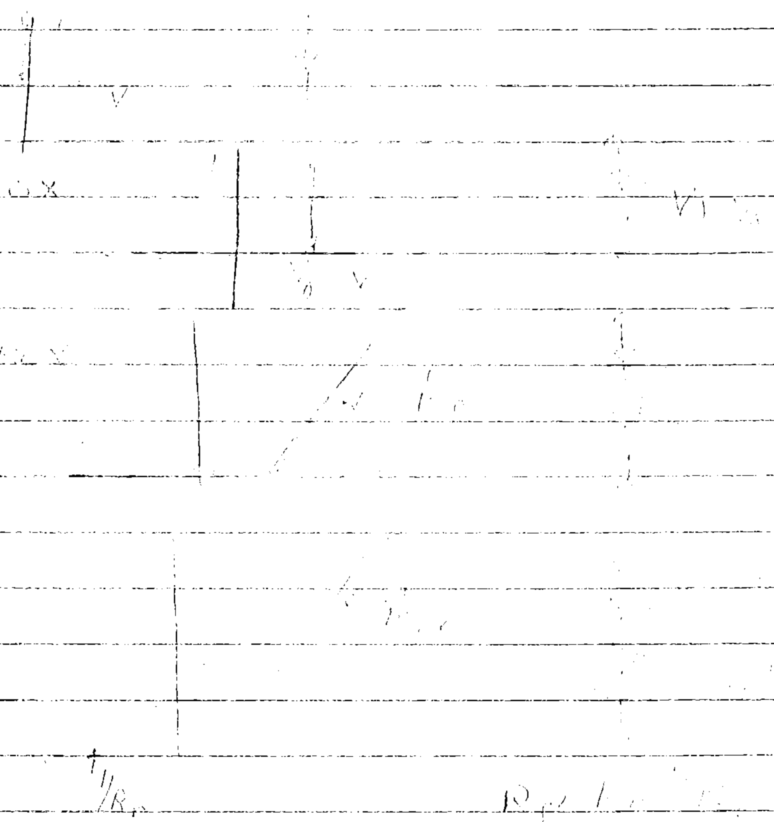
NOTES

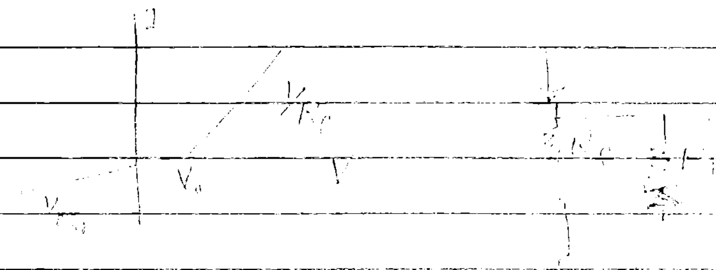
1) IDEAL

2) 1st ORDER APPROX

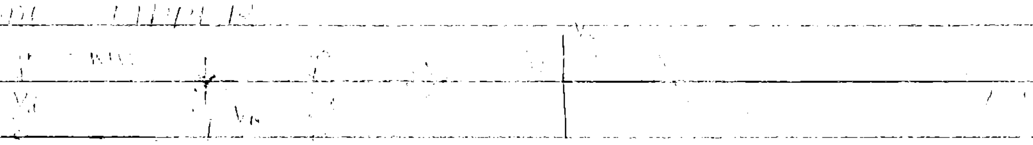
3) 2nd ORDER APPROX

4) 3rd ORDER

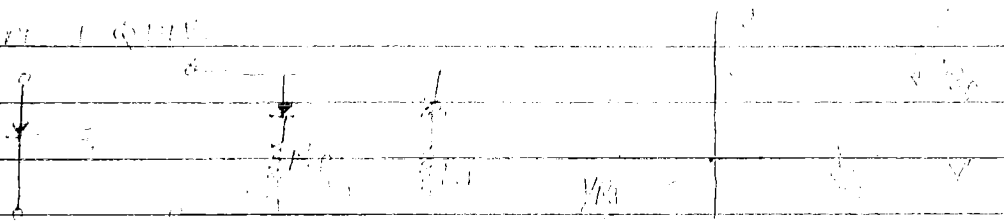




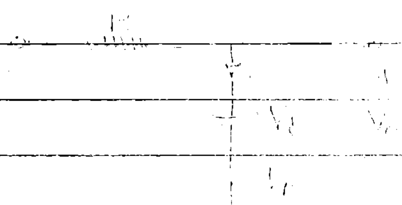
B) DIODE CLIPPER



DIODE EQUIV.



FORWARD CONDUCTION



CLIPPING AT GROUND

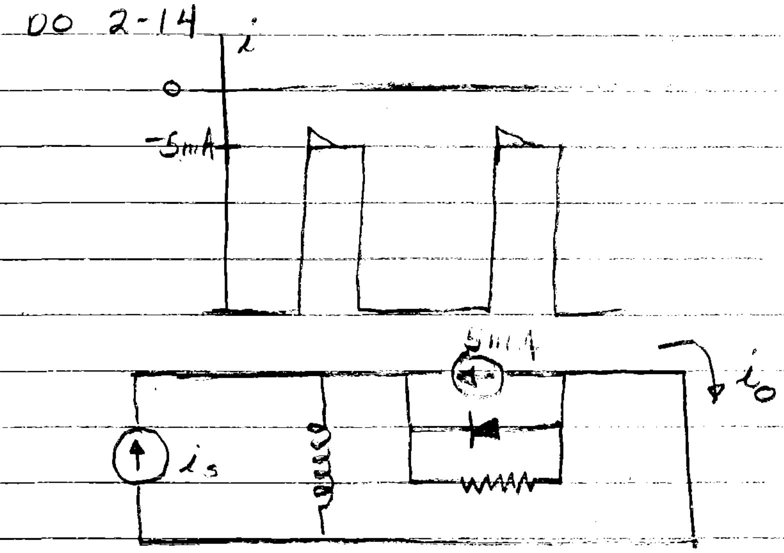
a) [illegible]

[illegible]

[illegible]

9-28-71

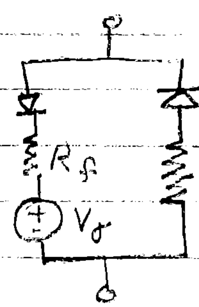
DO 2-14



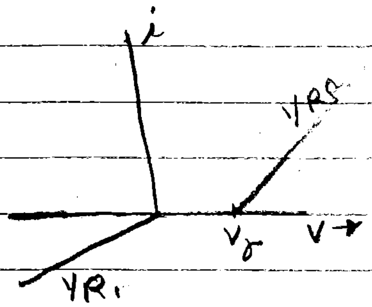
MODELS TO USE

R_f, V_γ

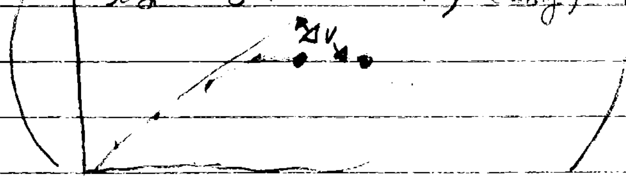
R_r



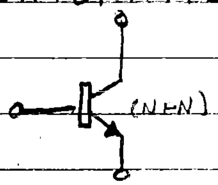
IDEAL DIODE

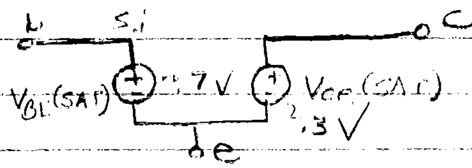


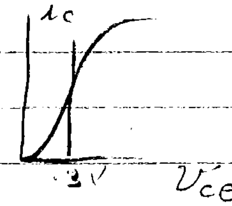
$i_d = I_0 \left(e^{V/V_P} - 1\right)$ (log)



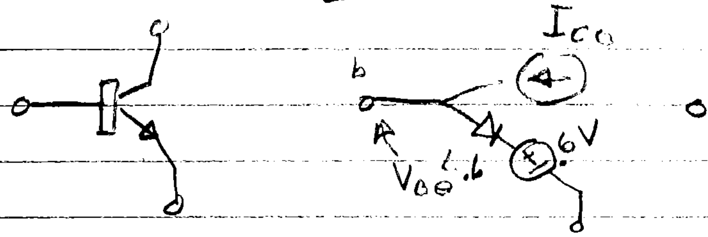
2) BJT MODEL
(SATURATION)



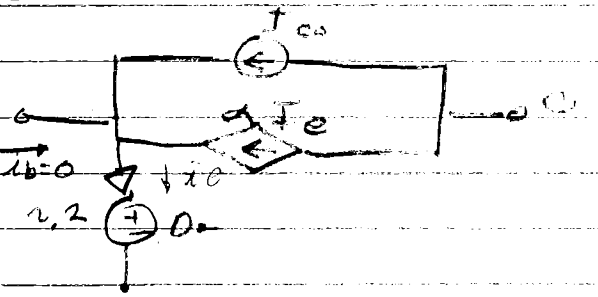




3) CUT-OFF MODEL (BJT



3) ACTIVE

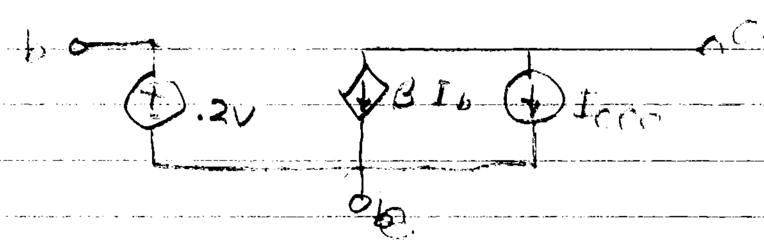


$I_e = \alpha I_e + I_{co}$

$I_{ceo} = \frac{1}{1-\alpha} I_{co}$

Pg 257 of ANGELO

ANGELO'S MODEL



3-8 p. 142

$I_{co} = 0$ (si)

c) $S_e = \frac{\delta I_c}{\delta T}$

9-29-71 (CHARGE STORAGE)

$\frac{dQ}{dt} + \frac{Q}{\tau} = i$ (MINORITY CHARGE CARRIES)

FOR STEADY STATE; $\frac{dQ}{dt} = 0$

REFERENCE FOR STORAGE IN SEMICONDUCTORS

1.) DIODES

STRAUSS pp 85-87

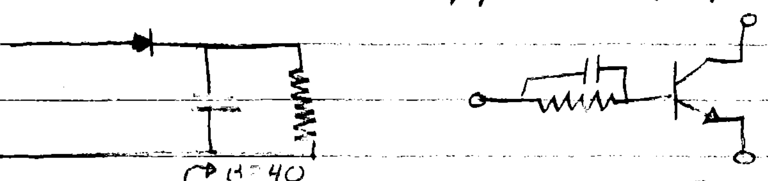
ANGELO pp 199-203

MILLMAN & TAUB pp 747-763

2.) BJT'S

STRAUSS pp 124-131

MILLMAN & TAUB pp 765-771



PROBLEM 3-9(a); 3-21(a); 3-8; $I_{co} = 0$, SILICON TRAN.

FOR 3-8: $I_{co} = 0$; $\frac{\partial I_c}{\partial V_{be}} = S_e$

10-14-71

4-2, 4-8, 4-20

TOPICS IN EE 563

RC TRANSIENTS

RISE TIME 10% 90% $t_r = 2.2RC$

TILT

COMPENSATED ATTENUATOR

CLIPPING CIRCUITS

DIODE MODELS

VOLTAGE CLIPPER

CURRENT CLIPPER

EMITTER COUPLED CLIPPER

CLAMPING CIRCUITS

TRANSISTOR MODELS

BJT CUT-OFF, ACTIVE, SATURATION

CHARGE STORAGE MODEL

LOGIC FAMILIES

RTL

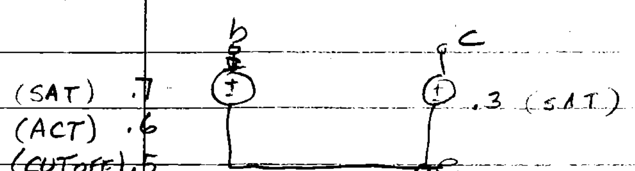
DTL

CML

TTL

MOS

(CONT.)



LOGIC

- BOOLEAN ALGEBRA
- DE MORGAN'S LAWS
- KARNAUGH MAP
- D.C. LOGIC LEVELS
- FAN-OUT
- NOISE IMMUNITY
- SWITCHING TIME
- PROPAGATION DELAY
- OUTPUT DRIVE (BOTH AS SOURCE & SINK)
- NOR, NAND CIRCUITS
- EXCLUSIVE OR
- HALF ADDER,
- FULL ADDER

FLIP FLOPS (MEMORY)

- R-S
- TOGGLE
- TYPE D
- J-K

PROBLEMS

- 2 - 10, 12
- 3 - 8, 9, 21, 25
- 4 - 2, 8, 10, 20
- TYPE D FF
- 5-18-23

MARKS

[illegible]
FALL 1971

COURSE OUTLINE - EE 563

DIGITAL ELECTRONICS I

DATE	SUBJECT	READING ASSIGNMENT	PROBLEM ASSIGNMENT
Sept. 14	Compensated Attenuators	3-26 (3,4,8)	
15	Clipping Circuits	33-61 (4,5)	
16	Clamping Circuits	61-68 (6)	
21	Current Clipping & Clamping	68-86 (7,8,9)	
22	Problem Review	All problems to date	
23	Transistor Models	99-114 (2,3)	
28	Transistor Switching	114-131 (4,7)	
29	I. C. Devices	131-140 (8)	
30	Gates (AND,OR)	149-159 (2)	
Oct. 5	Gates (NAND, NOR)	159-166 (3)	
6	DTL, DCTL, RTL	166-171 (5)	
7	TTL	171 - 183 (7)	
12	ECL, Wired Logic	183 - 193 (8,9)	
13	MID-TERM EXAM DURING LAB	All material to date	
13	Sampling Gate	193-207 (10)	
14	JFET, MOSFET	205-215 (1,2)	
19	NO CLASS MEETING		
20	MOSFET Biasing	215-224 (3,4)	
21	MOSFET Resistor	224-234 (5,6)	
26	Transient Response	234-245 (8)	
27	MOSFET Logic	245-257 (9)	
28	Problem Review	All problems to date	
Nov. 2	Bistable Multivibrator	252-265 (1,2)	

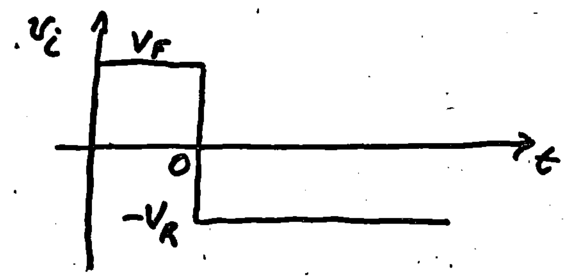
Nov.	3	Triggering of FF	361-369 (3,4)
	4	Monostable Multi	369-380 (5)
	9	FET Mono	380-388 (6)
	10	Astable Multi	388-401 (7,8)
	11	Hour Exam	All material to date
	16	R-S FF, Clocking	547-553 (1,2)
	17	MOSFET R-S	557-563 (3,4)
	18	Review	

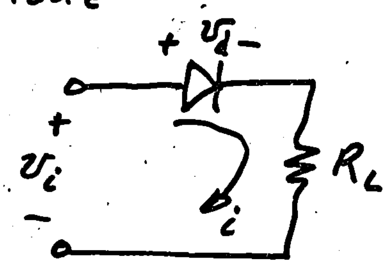
NOTE: 1. Text - Wave Generation & Shaping, Strauss, McGraw-Hill, 1970.

2. Numbers in parenthesis refer to sections of particular interest in the text.

3. Problem assignments to be made weekly.

Reverse Recovery Time for a diode





$$i(0^-) = \frac{V_F - V_\gamma}{R_L + R_F} \approx \frac{V_F}{R_L} \equiv I_F$$

$Q_0 \equiv I_F \tau$ from $\frac{Q_0}{\tau} = I_F$

$$i(0^+) \approx -\frac{V_R}{R_L} \equiv -I_R$$

For $t > 0$ until $Q = 0$

$$\frac{dQ}{dt} + \frac{Q}{\tau} = -I_R$$

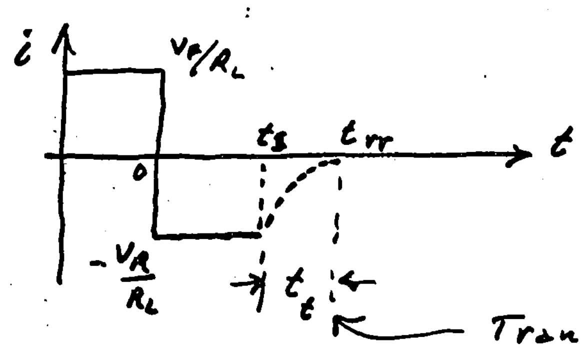
$$\frac{dQ}{Q + \tau I_R} = -\frac{dt}{\tau}$$

$$\int_{Q_0}^{0} \frac{dQ}{Q + \tau I_R} = -\int_0^{t_s} \frac{dt}{\tau}$$ ← when $Q = 0$

$$\ln (Q + \tau I_R) \Big|_{Q_0}^{0} = -\frac{t}{\tau}\Big|_0^{t_s}$$

$$\ln \frac{\tau I_R}{\underbrace{Q_0}_{I_F \tau} + \tau I_R} = -\frac{t_s}{\tau}$$

$$t_s = \tau \ln \frac{I_F + I_R}{I_R}$$ ≡ the "Storage Time"



$$t_{rr} = t_s + t_t$$

↑ Reverse recovery time

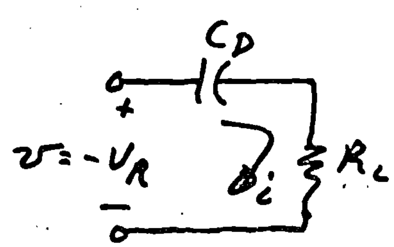
<u>Computation of transition time</u>

$C_D \equiv$ the depletion-region capacitance (when reverse voltage is present)

$$C_D = \frac{\text{constant}}{\sqrt{V_j - V}}, \text{ for abrupt junction}$$

V_j ← junction voltage; V ← diode applied voltage

For a first-order analysis, take C_D = constant



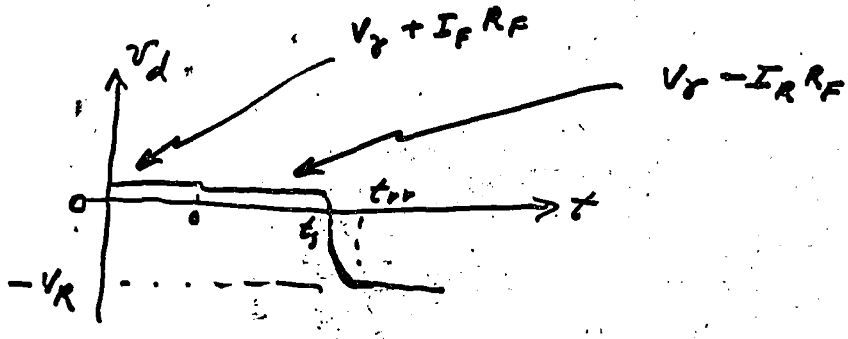
$$v_d(t_s) \approx 0$$

$$i(t_s) = -I_R = -\frac{V_R}{R_L}$$

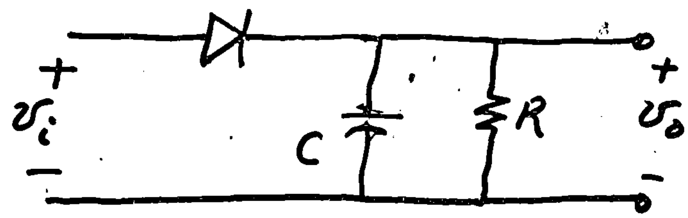
$$i = -I_R\, e^{-\frac{t - t_s}{R_L C_D}}, \quad t_s \le t \le t_{rr}$$

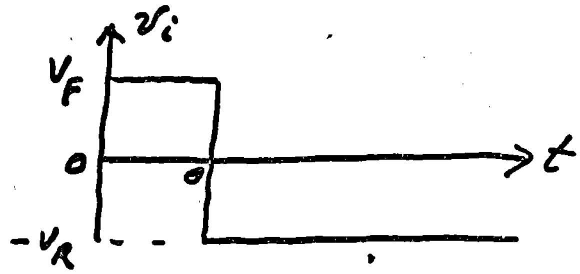
$$i(t_{rr}) \approx 0 \quad \text{when} \quad t_t = t_{rr} - t_s \approx \underline{\underline{3 R_L C_D}}$$

3 "time constants"



Charge Compensation Capacitor





$$Q_o = \tau I_F \approx \tau \frac{V_F}{R}$$

when all charge is removed from the diode at $t=0$

$$\Delta v_o = -\frac{Q_o}{C} = -\frac{\tau V_F}{RC}$$

The max Δv_o is $V_F + V_R$. For this Δv_o to remove Q_o from the diode,

$$C(V_F + V_R) = Q_o = \frac{\tau V_F}{R}$$

or

$$C_{min} = \frac{\tau}{R} \frac{V_F}{V_F + V_R}$$

when $C > C_{min}$ the Δv_o will be smaller.

20/30

1. The silicon transistor in Figure 1 has a β of 50 and R_E = [illegible] ohms. Select the values of R_C and R_B so that the quiescent operating point for the transistor is V_{CE} = [illegible] volts, I_C = 10 milliamps.

R_C = ____________

R_B = ____________

2. What difficulty is encountered if the value of R_E is too small?

3. What difficulty is encountered if the value of R_E is too large?

4. What is the primary purpose for using R_E in the circuit of Fig. 1?

5. Why is C_E used in the circuit of Fig. 2?

6. Why is R_2 used in the circuit of Fig. 2?

7. In the circuit of Fig. 2 the germanium transistor has a β of [illegible] and the values of R_2 and R_3 are 10,000 and 1000 ohms, respectively. Select the values of R_L and R_1 so that the quiescent operating point for the transistor is V_{CE} = 5 volts and I_C = [illegible] milliamperes.

R_L = ____________

R_1 = ____________

8. A type 2N[illegible] transistor is used in the circuit of Fig. 1, [illegible] with V_{CC} [illegible] 5 volts. [illegible] which is [illegible] when R_L = 500 ohms and R_E = [illegible] ohms.

9. [illegible] for problem 8 if R_B is selected so that I_B [illegible] required.

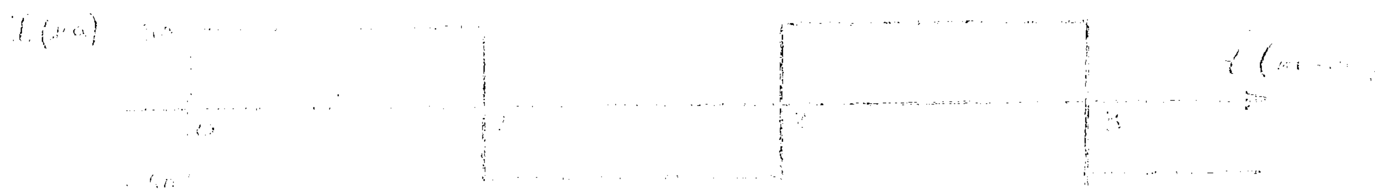
10. If the circuit of problem 8 is operated as a sine-wave amplifier, what is the maximum undistorted value of the peak-to-peak, output voltage swing?

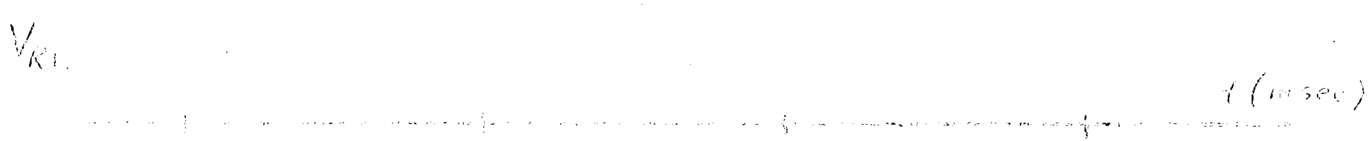
$V_{o(p-p)}$ = ____________

11. What is the approximate value of β at the operating point of the transistor in problem 8?

β = ____________

12. The circuit of Prob. 8 is driven from a square-wave current source of 100 microamperes peak-to-peak as shown below. Sketch the waveshape of the voltage across R_L showing any significant time constants. R_L = [illegible]





[illegible]

[illegible] the instantaneous [illegible] of the transistor.

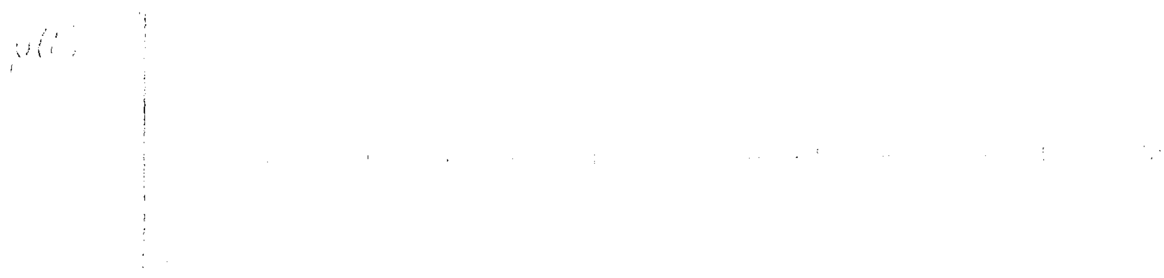


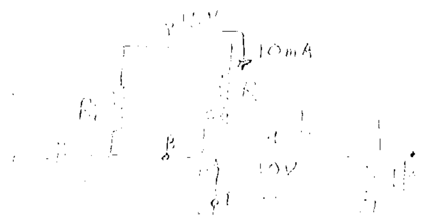
Fig. 1

Fig. 2

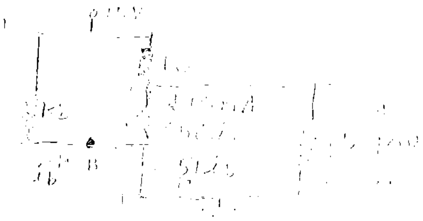
[illegible] HARRIS
DIGITAL ELECTRONICS

9-[illegible]-71

1)



MODEL



R_c [illegible] 10 [illegible] k

$\beta =$ [illegible] [illegible] .2 mA

$R_b = \frac{15}{.2} = 75\ k$

2) REACTANCE WILL INCREASE, ATTENUATING AMPLIFIED SIGNAL, ESPECIALLY AT LOW [illegible]

3) LARGE C [illegible] LARGE STRAY CAPAC. (ALSO BULKY CAPACITOR)
→ KILLS H.F. RESPONSE WITH STRAY CAPAC.

4) R_3 IS USED TO STABALIZE [illegible] OF [illegible] DUE TO CHANGES IN TEMP. AND β

5) TO PROVIDE A SHORT TO GROUND [illegible]

6) R_1 AND R_2 PROVIDE A VOLTAGE DIVIDER [illegible] TO BIAS BASE

[illegible]

[illegible] HIGH FREQUENCY [illegible]

[illegible] CIRCUIT DUE TO CHANGE IN [illegible] PARAMETERS AT DIFFERENT [illegible]

[illegible]

[illegible]

[illegible]

8) [illegible]
(SEE GRAPH)

9) [illegible] 10 (SEE GRAPH)

10) [illegible]

11) [illegible]

$-V_{RL}$

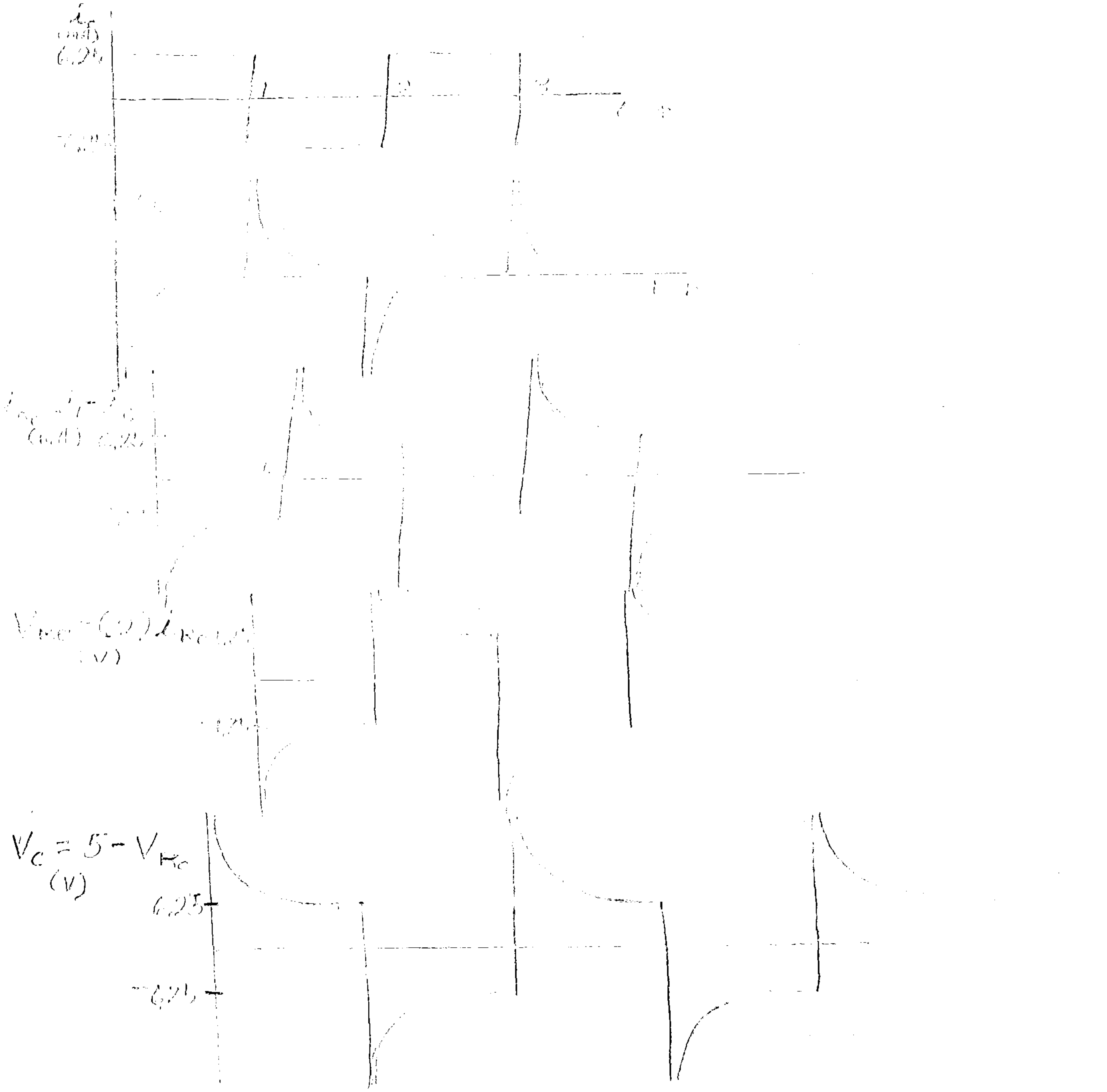
$\tau = 38\ \mu sec \rightarrow$ peak value?

~3

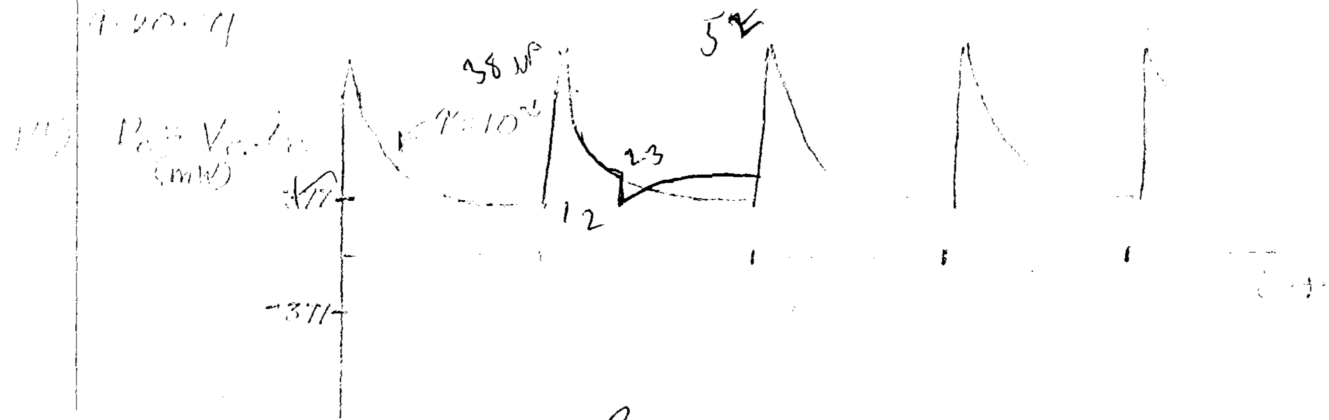
9-27-71

3) [illegible]

$\therefore i_c = 6.26$ mA $\quad$ [illegible] $\quad n = 0, 1, 2, \ldots$

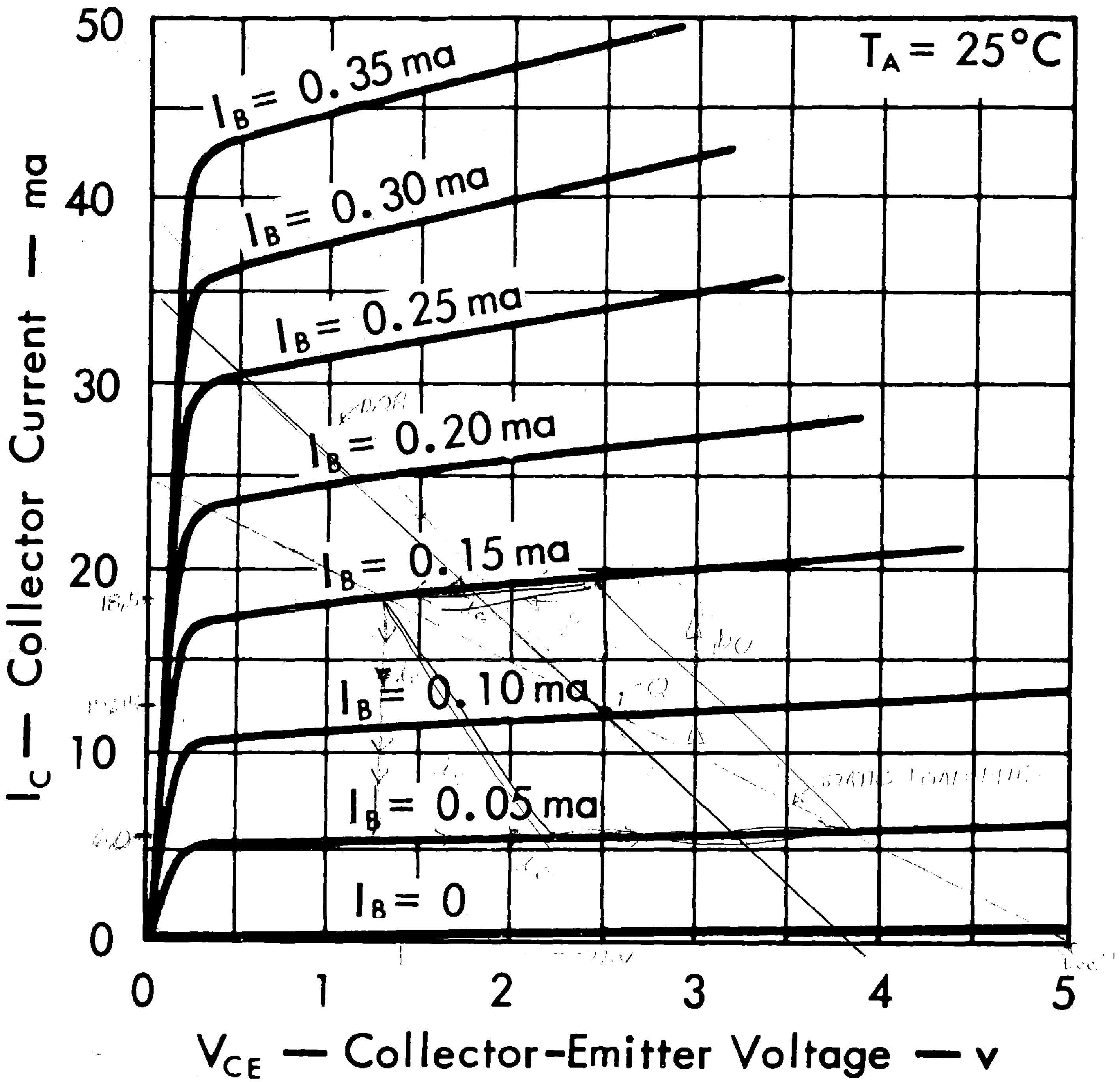


4-20-71



,3

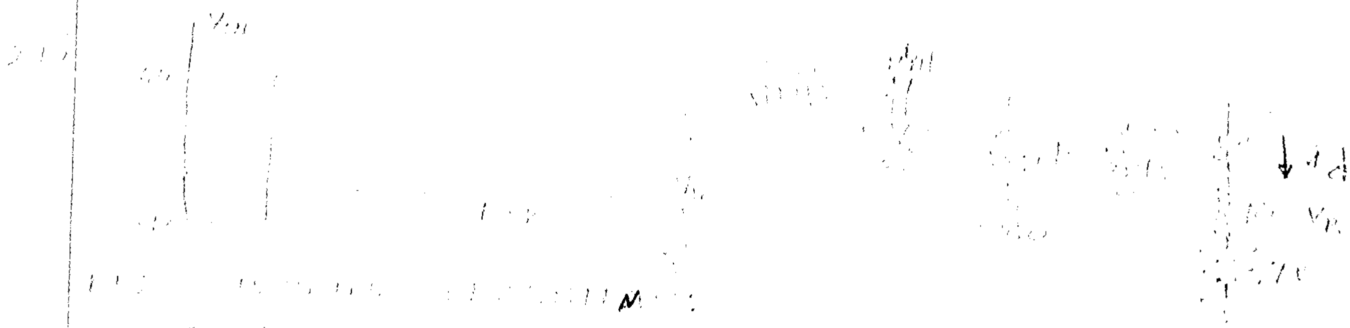
2N1304



$T_A = 25°C$
$I_B = 0.35$ ma
$I_B = 0.30$ ma
$I_B = 0.25$ ma
$I_B = 0.20$ ma
$I_B = 0.15$ ma
$I_B = 0.10$ ma
$I_B = 0.05$ ma
$I_B = 0$
50
40
30
20
10
0
0
1
2
3
4
5
I_C — Collector Current — ma
V_{CE} — Collector-Emitter Voltage — v

-4

13/20



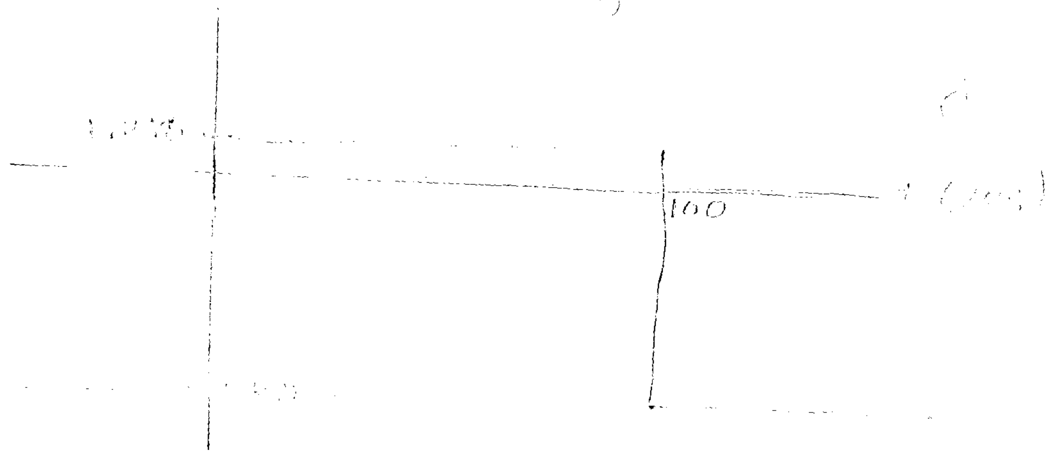
[illegible] $\bar{M}$:

[illegible]

$I_d = \frac{24.8}{10} = 5.65$ mA [illegible]

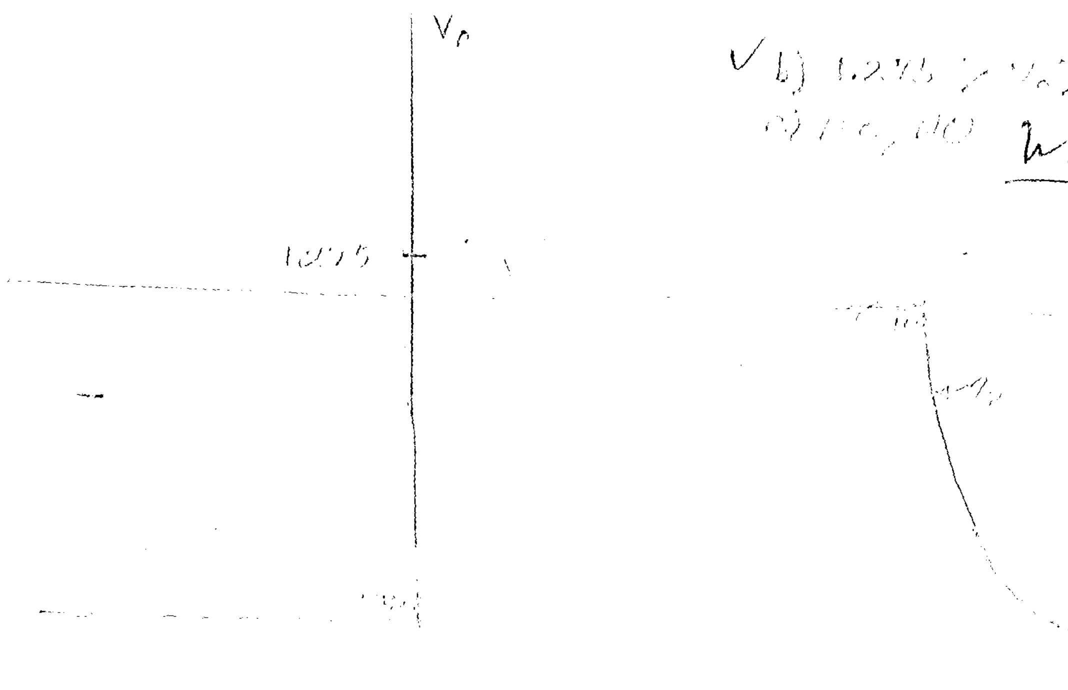
$V_{bc} =$ [illegible] V $\therefore V_0 = 1.275$ V

8



$\tau_1 =$ [illegible] $= 12.75 \times 10^{-6}$ [illegible] ✓

$\tau_2 = 2.5 \times 10^{3} \times$ [illegible] $= 6.25 \times 10^{-6}$ [illegible] ✓

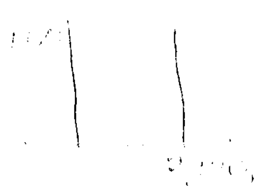


✓ b) 1.275 [illegible]

c) [illegible] **WHY?**

5

a) CAPACITOR WILL CHARGE [illegible] TO INPUT. WHY? [illegible] NEGATIVE [illegible] AT V_2 WILL FORWARD [illegible]

b) 

[illegible]

c) [illegible]

✓

EE 563 Digital Electronics

Oct. 18, 1971

PDJ

Correction to homework Assignment

Problem 4-2 O.K. as is.

Problem 4-8 Transistor Data should be

$\beta = 50$

$V_D = V_{BE}(\text{active}) = 0.6^V$

$V_{CE,sat} = 0.3^V$

$V_{BE,sat} = 0.7^V$

$V_{BE}(\text{cut-off}) = 0.5^V$

$r_{BC} = 0\ \Omega$

Problem 4-20 Transistor Data should be

$\beta = 40$

V_{BE} active $= 0.6^V$

$V_{CE,sat} = 0.3^V$

$V_{BE,sat} = 0.7^V$

$V_{BE,\text{cut-off}} = 0.5^V$

$r_{BC} = 0^V$

$V_{Ref} = -1.15\ V.$

[illegible] Digital Electronics

Nov. 4, 19[illegible]

P8-5

Homework Problems

5-18 p. 261 of Strauss

part (a) Assume $V_T = -4^V$

$I_D = -5\,\mu A$ at $V_{GS} = -5^V$ for Q_A [illegible]

$$\left(\frac{W}{L}\right)_A = 25\left(\frac{W}{L}\right)_L$$

neglect 25^M load resistance

part (b) Use 10% - 90% rise (or fall) time.

5-23

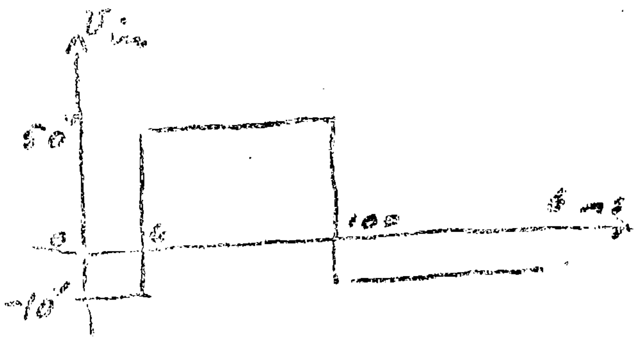
TTL Levels

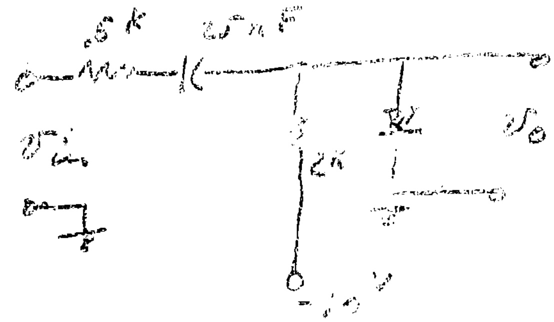
Logical "1" > ~~3~~ 3.5^V

Logical "0" < 0.5^V

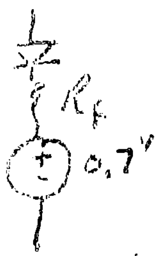
Chris Panitzke

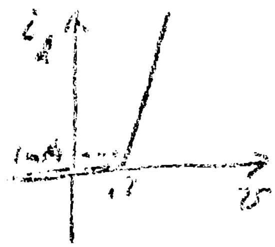
2-10





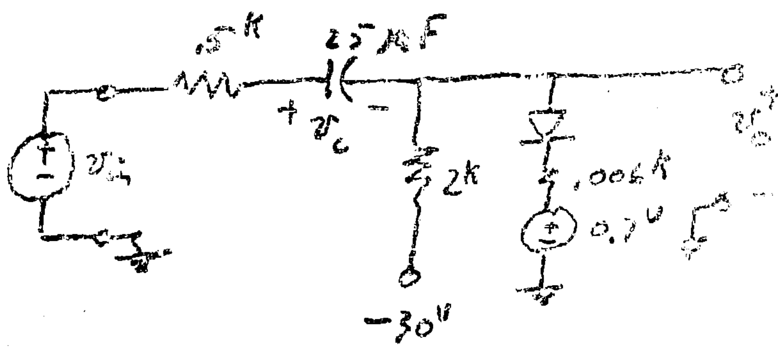
Diode Model





$$R_f \approx \frac{60\,mV}{I_d} = \frac{60}{10} = 6\,\Omega \quad \text{for } I_d \text{ average about } 10\,mA$$

Circuit Model



For $t < 0$

$$v_o(0) = -30$$

$$v_c(0^-) = -10 - (-30) = 20\,V$$

For $t > 0$ (assuming $v_o > 0.7$)

$$v_o(0^+) = \frac{(\overset{50}{v_{in}} - \overset{20}{v_c})\frac{1}{.5} - 30\frac{1}{2} + 0.7\frac{1}{.006}}{\frac{1}{.5} + \frac{1}{2} + \frac{1}{.006}}$$

$$= \frac{60 - 15 + \frac{700}{6}}{2.5 + \frac{1000}{6}} = \frac{270 + 700}{15 + 1000} = \frac{970}{1015} = 0.957\,V$$

which is greater than 0.7 as assumed

3-10 cont

The voltage then decays from 0.957 V to 0.7 volts approaching the pseudo-final value

$$v_o(\infty) = \frac{-\frac{30}{2} + .7\frac{1}{.005}}{\frac{1}{2} + \frac{1}{.005}} = \frac{-15 \times 2 + 700}{3 + 1000} = \frac{610}{1003} = 0.61^V$$

with a time constant

$$\tau_1 = (.5 + \underbrace{.005 \| 2}_{small})\, 25 \times 10^{-6} = 12.5\ \mu sec.$$

v_o reaches 0.7 at time T_1 computed as follows:

$$v = V_{Final} - (V_{Final} - V_o)\, e^{-t/\tau}$$

$$0.7 = 0.61 - (0.61 - .957)\, e^{-T_1/12.5}$$

$$T_1 = 12.5 \ln \frac{.957 - .61}{.7 - .61} = 12.5 \ln \overbrace{\frac{.35}{.09}}^{1.36} = \underline{17\ \mu sec}$$

<u>For $t > T_1$</u> the diode ceases to conduct and the v_o decays toward −30 volts with a time constant $\tau_2 = (2^K + .5^K)\, 25\,\mu F = \underline{62.5\ \mu sec}$. However, only $100 - 17 = 83\ \mu sec$ remain before v_{in} switches.

$$v = V_F - (V_F - V_o)\, e^{-t/\tau}$$

$$v_o(100^-) = -30 - (-30 - 0.7)\, e^{-\frac{83}{62.5}}$$

$$= -30 + 30.7 \times .265 = \underline{-21.9^V}$$

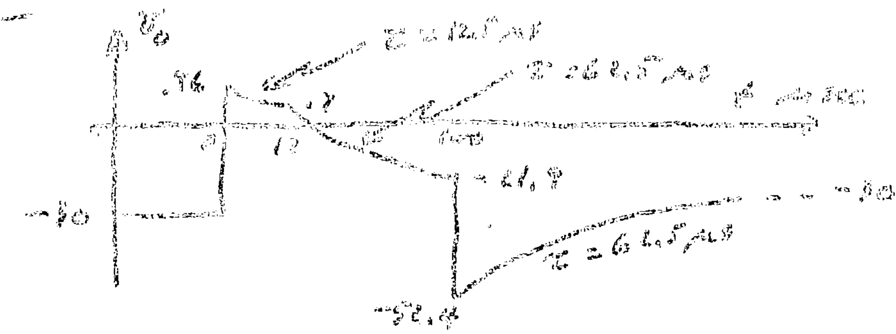
$$v_c(100^-) = 50 - .5^K\, i_{2K} = 50 - .5\,\frac{30 - 21.9}{2} = \underline{48^V}$$

<u>For $t > 100\ \mu sec$</u>

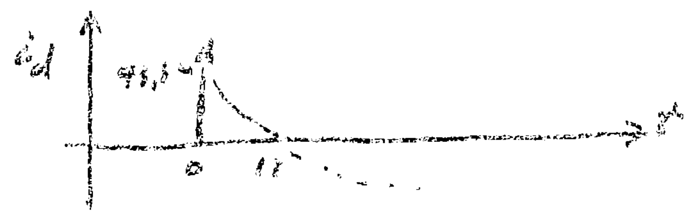
$$v_o(100^+) = \frac{(\overset{-10}{v_{in}} - \overset{48}{v_c})\frac{1}{.5} - 30\frac{1}{2}}{\frac{1}{.5} + \frac{1}{2}} = \frac{-58 \times 2 - 15}{2.5} = \underline{-52.4^V}$$

v_o decays from −52.4 to −30 volts with $\tau_2 = 62.5\ \mu sec.$

2-40 Cont



$i_d(0^+) = \frac{.96 - .7}{6} = 43.3$ mA



(b) For $v_d = .96^V$ $\quad i_d = I_0\, e^{\frac{.96}{.026}}$

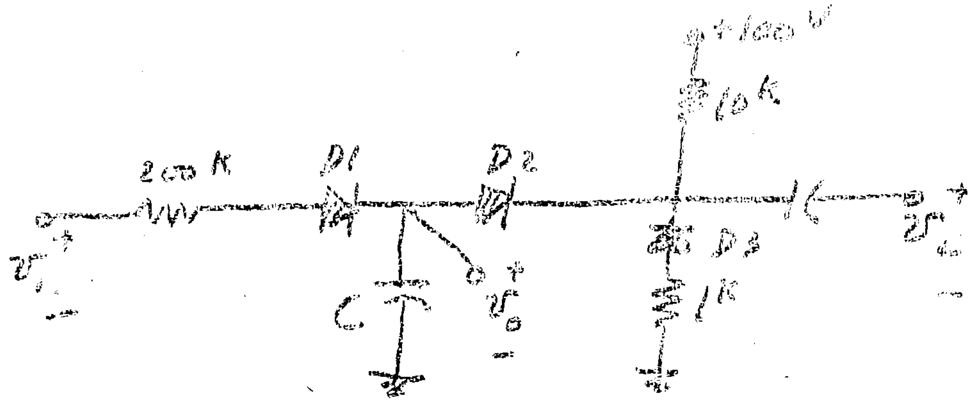
where $I_0 = \frac{1\,mA}{e^{.7/.026}}$ $\quad \therefore i_d = e^{\frac{.96-.7}{.026}}$ mA

$= e^{10} \geq 22{,}000$ mA

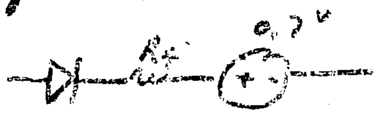
which is much too large. The value of R_f must be too large to be realistic. Of course this diode equation does not allow for the "ohmic" resistance of the diode and its leads.

(c) A smaller value of R_f might give slightly better values.

2-12

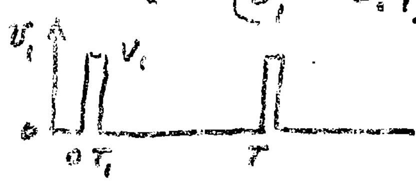


a) With no pulse on v_c, D2 will not conduct until $v_o > 100$ Volts. Thus, $+v_i$ pulses will charge C. If D1 is modelled as



($R_f << 200K$)

and $(v_i - 0.7) >> v_o$ then each $+v_i$ pulse



will increase the charge on C by $\frac{V_1 - 0.7}{200K} T_1 = \Delta Q$ Coulombs. Thus v_o will increase by $\Delta V_o = \frac{1}{C} \Delta Q$ with each pulse.

A negative pulse on v_c will discharge C through D2. D3 in combination with D2 sets the basic level of v_o approximately at 0 volts.

b) For $\Delta v_o = 1$ volt, $V_1 = 100$ Volts, $T_1 = 2\mu sec$

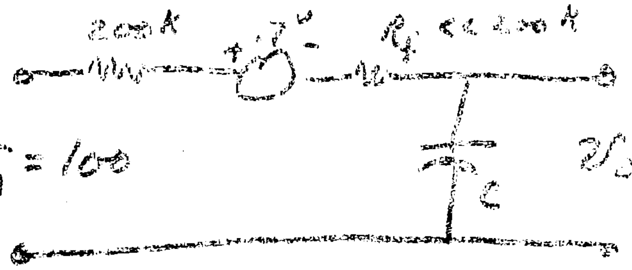
$$C = \frac{\Delta Q}{\Delta v_o} = \frac{100 - .7}{200K} 2 \times 10^{-6} = 99.3 \times 10 \; pF = 993 \; pF$$

~~= 993 pF~~

Note: When $v_o \approx 10$ volts $C \approx \frac{100 - .7 - 10}{[illegible]} 2 \times 10^{-6} \approx [illegible]$

2-12 Cont.

c) Since the reverse resistance of the diode D is assumed to be ∞, the time between pulses can be ignored in computing the actual v_o. Each 2 μsec interval represents 1 input pulse.



$\tau_1 = RC = .2^{-6} \times 1000\ pF = 200\ \mu s$
$\tau_2 = RC = .2^{-6} \times 950\ pF = 190\ \mu s$
$V_o = 99.3\,(1 - e^{-t/\tau})$

Monroe Program

store τ = 200 (or 190) in β(1)

Load program in 0

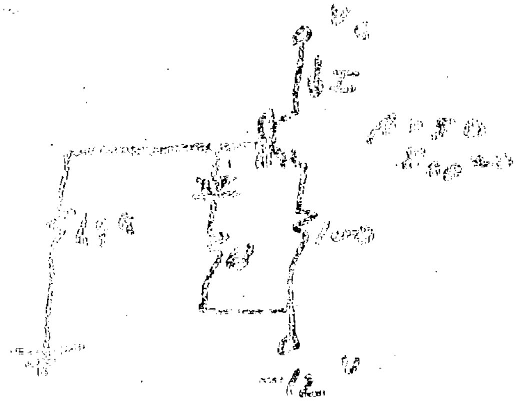
0 Halt
÷
β(1)
=
β(0)
e
a^x
β(0)
ch sign
=
ch sign
+
1
×
99.3
=
T_o(0)

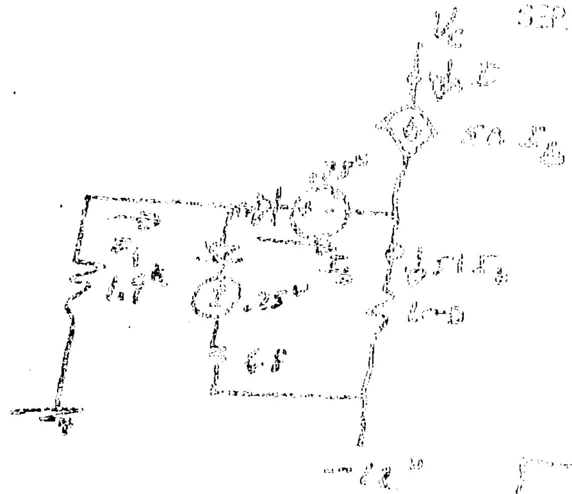
Enter t in μsec

Results

Pulses	t, μs	V 1000 pF	V 950 pF
1	2		1.04
5	10	4.85	5.09
6	12	5.78	
10	20	9.45	
14	25	12.9	
(15)	30	13.86	(14.5)
(16)	32	(14.6)	15.4
17	34	15.52	

↑ For C = 1000 pF ↑ For C = 950 pF





a) $I = 50\, I_b$

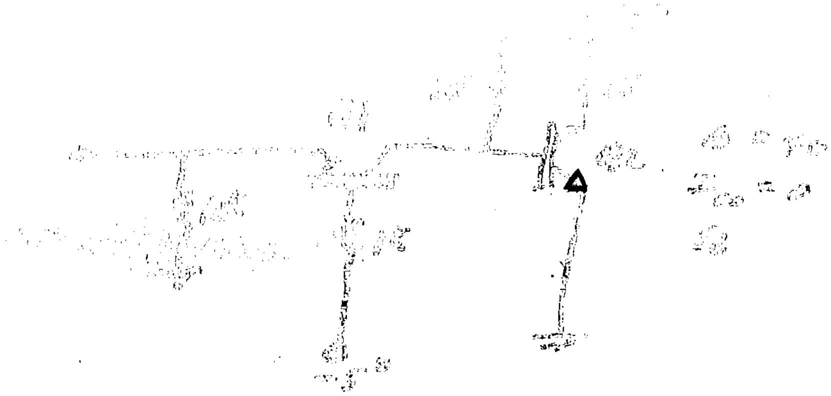
$$I_1\,(1.9^k + 68\|5.1^k) + .75 = 12$$

$$I_b = \frac{68}{5168}\, I_1$$

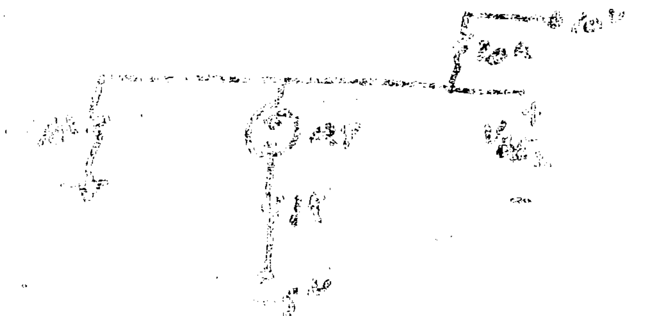
$$\therefore\ I = 50\ \frac{68}{5168}\ \frac{12 - .75^{V_{BE}}}{1968} = \underline{3.76\ mA}$$

b) $$\frac{\partial I}{\partial T} = 50\ \frac{68}{5168}\ (-)\left(\frac{\partial V_{BE}}{\partial T}\right)^{\to(-2.5\ mV/C°)}\ \frac{1}{1968} = +\ \underline{.836}\ \frac{\mu A}{C°}$$

c) $$S = \frac{\partial I_c}{\partial V_{BE}} = -50\ \frac{68}{5168}\ \frac{1}{1968} = -\ \underline{.000334}$$



c) We assume that both the emitter and the collector of Q1 are forward biased. Assuming $V_{CE}=0$ for Q1 and that Q2 is cut off ($I_{B2}=0$)



$$V_{B2} = \frac{(-0.7-9)\frac{1}{1} + \frac{10}{20}}{1+\frac{1}{20}+\frac{1}{20}} = \frac{-10.3+0.5}{1.15} = \frac{-9.8}{1.15}$$

$= -8.5^V$ which verifies that Q2 is cut-off.

<u>Equivalent operating conditions</u>

Q2 $V_{BE2} = -8.5^V$, [illegible]

$I_{C2} = 0$

$V_{CE2} = 10^V$

$I_{B2} = 0$

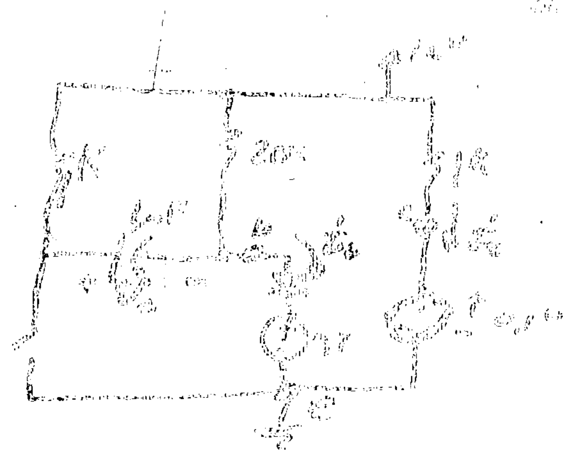
Q1 $V_{BE1} = -0.7^V$

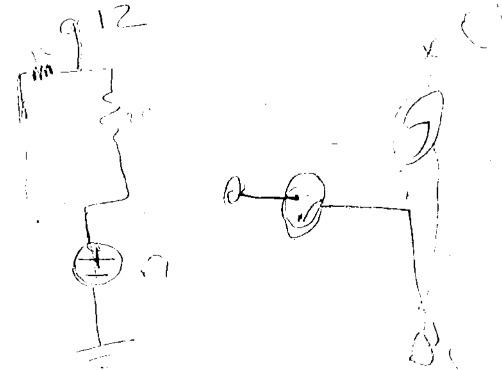
$V_{CE1} = 0^V$

$I_{B1} = \frac{[illegible]}{1k} = [illegible]$ mA

$I_{C1} = [illegible] = [illegible] = 0.667$ mA

$I_{E1} = [illegible] = [illegible]$ mA





$i_C(0^-) = \frac{12 - .1}{1k} = 11.9$ mA

$v_{CE}(0^-) =$ [illegible] $= 0.1^V$

$v_{BE}(0^-) = 0.7$

$i_B(0^-) = \frac{12 - .7}{20k} = \frac{11.3}{20k} = .565$ mA

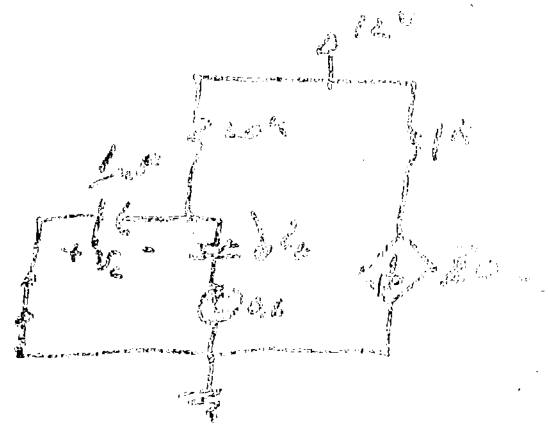
$v_C(0^-) = 12 - .7 = 11.3^V$

@ $t = 0^+$ $\quad v_C(0^+) = 11.3^V$

$v_{BE}(0^+) = -11.3^V$

$i_B(0^+) = 0$

$i_C(0^+) = 0$



Then v_{BE} charges toward 12^V with a time constant $\tau = 20$ ms until $v_{BE} = 0.6^V$ at $t = T_1$ ms

$$v_{BE}(T_1) = 0.6 = 12 - \overset{23.3}{(12 + 11.3)}\, e^{-T_1/20}$$

$$T_1 = 20 \ln \frac{23.3}{12 - .6} = 20 \ln \frac{23.3}{11.4} = 14.3 \text{ ms}$$

Then $i_B(T_1^+) = \frac{12 - .6}{20k} = 0.57$ mA and $i_C(T_1^+) = 30\, i_B = 17.1$ mA

which is too high so the transistor [illegible] saturation [illegible]

$\beta = 50$

$V_{BE} = 0.7$ (base)

$\tau_B = 10$ ns

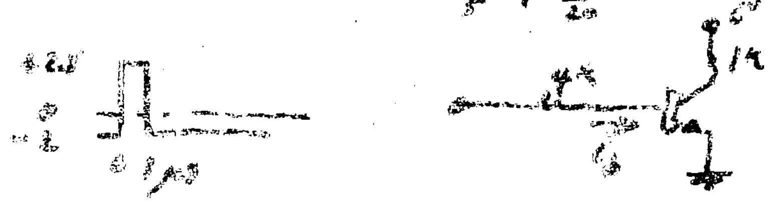
$C_D = 10$ pF

Thev. equiv. of base drive

$$R = 5 \| 20k = \frac{5 \times 20}{25} = 4k$$

$$V_{base} = -10 \frac{5}{25} = -2\,V$$

$$V_{high} = \frac{\frac{6}{5} - \frac{10}{20}}{\frac{1}{5} + \frac{1}{20}} = \frac{1.2 - .5}{.25} = \frac{.7}{.25} = 2.8\,V$$



@ $t = 0^-$

$v_{BE}(0^-) = -2\,V$, $i_b(0^-) = 0$, $i_c(0^-) = 0$

$v_o(0^-) = 6\,V$

for $0 \le t \le t_1$ $\tau_D = 4k\, C_D = 40$ ns

~~$t_1 = t_D$ …~~

$$v_{BE}(t) = 2.8 - (2.8 + 2)\, e^{-t/\tau_D}$$

@ t_1 , $v_{BE}(t_1) = .6\,V$

$$t_1 = \tau_D \ln \frac{2.8 + 2}{2.8 - .6} = 31.2 \text{ ns}$$

for $t_1 \le t < t_2$

The base current is

the base current required for saturation is

$$I_{B,sat} = \frac{I_{C,sat}}{\beta} = \frac{1}{50} \frac{6 - .2}{1} = .116 \text{ mA}$$

From Equation 9-6

$$t_{on} = \tau_B \ln \frac{I_{B_1}}{I_{B_1} - I_{B,sat}} = 10 \ln \frac{.55}{.55 - .116} = 2.\ldots$$

$t_i = t_j + t_{[illegible]} = [illegible]$ ns

[illegible]

$$T_{[illegible]} = \frac{[illegible]}{[illegible]} = -\frac{[illegible]}{[illegible]} [illegible] = -[illegible] [illegible]$$

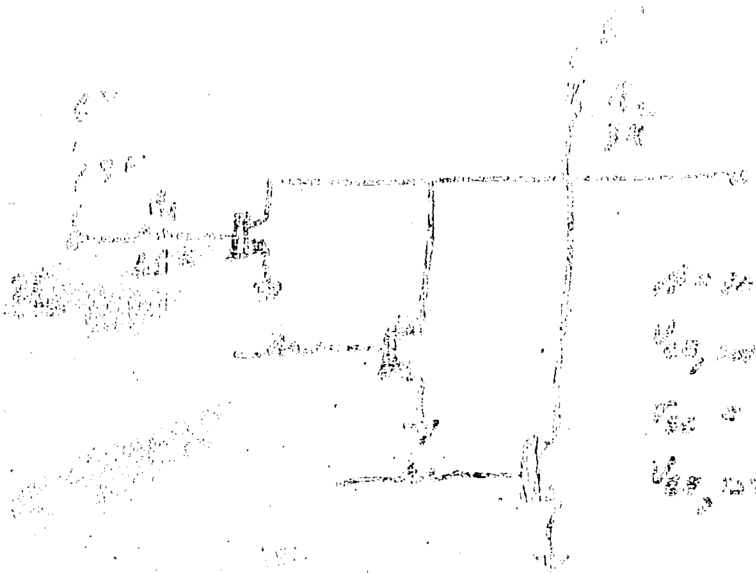
[illegible] $\quad t_j = \tau_{[illegible]} \ln \frac{V_{[illegible]} - V_{[illegible]}}{V_{[illegible]} - V_{[illegible]}} = 10 \ln \frac{[illegible] 1.195}{[illegible]} = [illegible]$

-785

$$t_{[illegible]} = \tau_{[illegible]} \ln \frac{V_{[illegible]} - V_{[illegible]}}{V_{[illegible]}} = 10 \ln \frac{1.195}{[illegible]} = [illegible]$$

$t_j = [illegible] + t_j = 8009.55$ ns

$t_i = t_j + t_{[illegible]} = 61$ ns



$V_{CE,sat} = 0.1V$

$\beta_F = 30$

$V_{BE,on} = 0.7V$

i) No load transfer characteristic

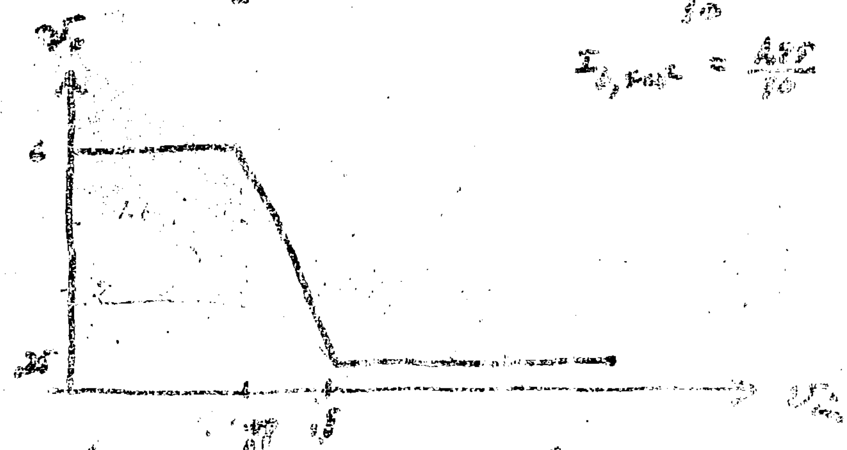
$V_{in,L} = V_{BE} = 0.7V$

$V_{in,H} = V_{BE} + \frac{I_{C,sat}}{\beta} R_1$

$I_{C,sat} = \frac{6-0.1}{1.05k} = \frac{5.9}{1.05} = 5.6 mA$

$V_{in,H} = 0.7 + \frac{5.5 \times 1.5}{30} = 0.7 + 0.28 = 1V$

$I_{B,max} = \frac{5.5}{30} = 0.185 mA$

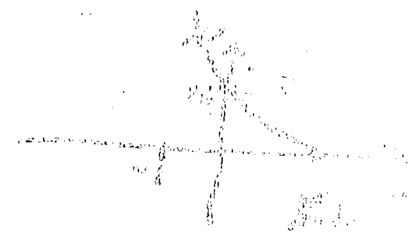


ii) loaded with N gates

$v_{o,H} = 6 - \frac{6-.7}{3+\frac{1.5}{N}} 3 = 6 - \frac{5.3 \times 3}{3+\frac{1.5}{N}}$

$v_{o,L} = \dots$

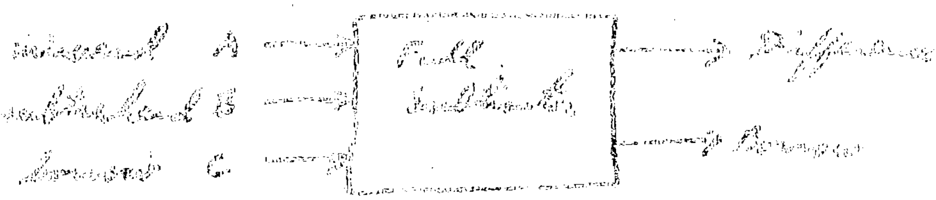
For $N = 2$



c) with all these ... light

Collecting ...

7-2 p. 198



$$\text{Difference} = (A\bar{B} + \bar{A}B)\bar{C} + (AB + \bar{A}\bar{B})C$$

$$\text{Borrow} = (AB + \bar{A}\bar{B})C + \bar{A}B$$

a)

C	A	B	Difference	Borrow
0	0	0	0	0
0	1	0	1	0
0	0	1	1	1
0	1	1	0	0
1	0	0	1	1
1	1	0	0	0
1	0	1	0	1
1	1	1	1	1

From [redacted]

Difference

B \ A	1	0
1	0	1
0	1	0

Borrow

B \ A	1	0
1	0	1
0	0	0

b) Note that $D \equiv A\bar{B} + \bar{A}B = \overline{(AB + \bar{A}\bar{B})}$

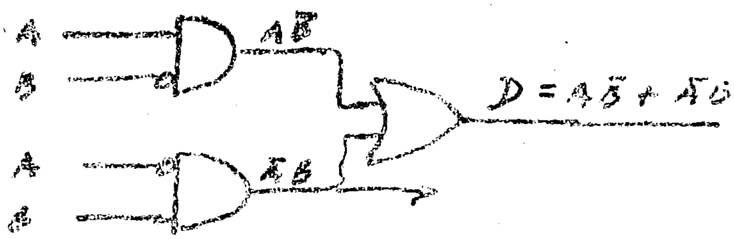
then

$$\text{Difference} = D\bar{C} + \bar{D}C = \overline{DC + \bar{D}\bar{C}}$$

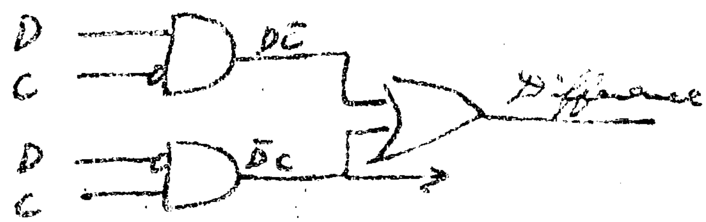
$$\text{Borrow} = \bar{D}C + \bar{A}B$$

Q-2 Continued

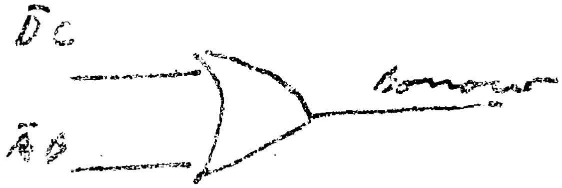
i) Basic Logic



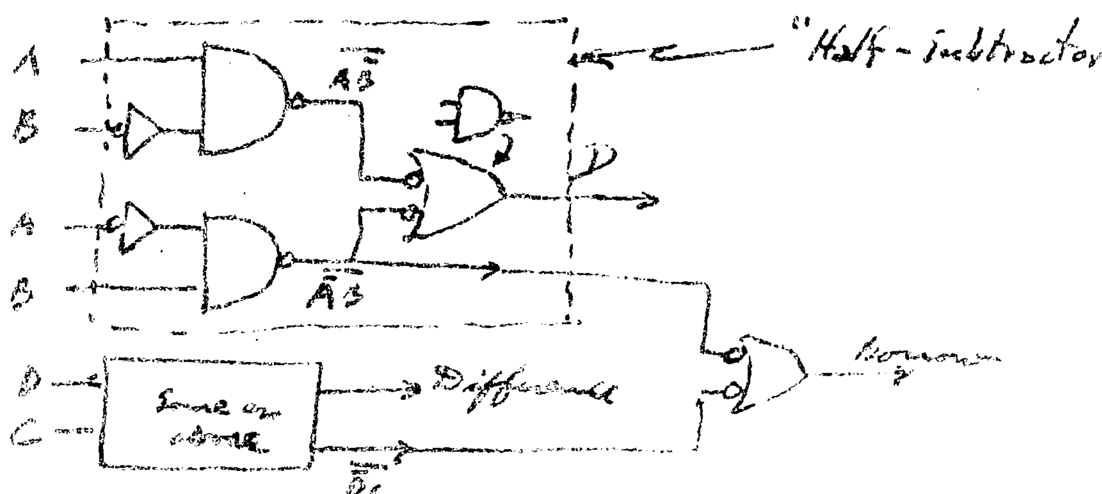
Similarly for the Difference output



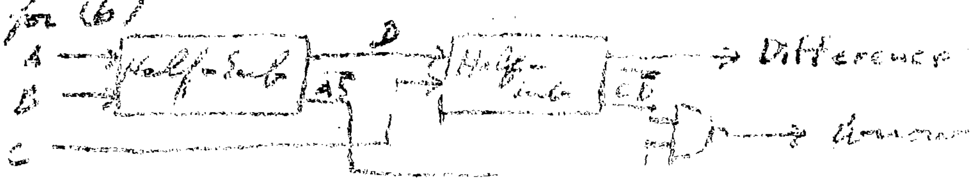
The Borrow is obtained from the two above



ii) Conversion to NAND:

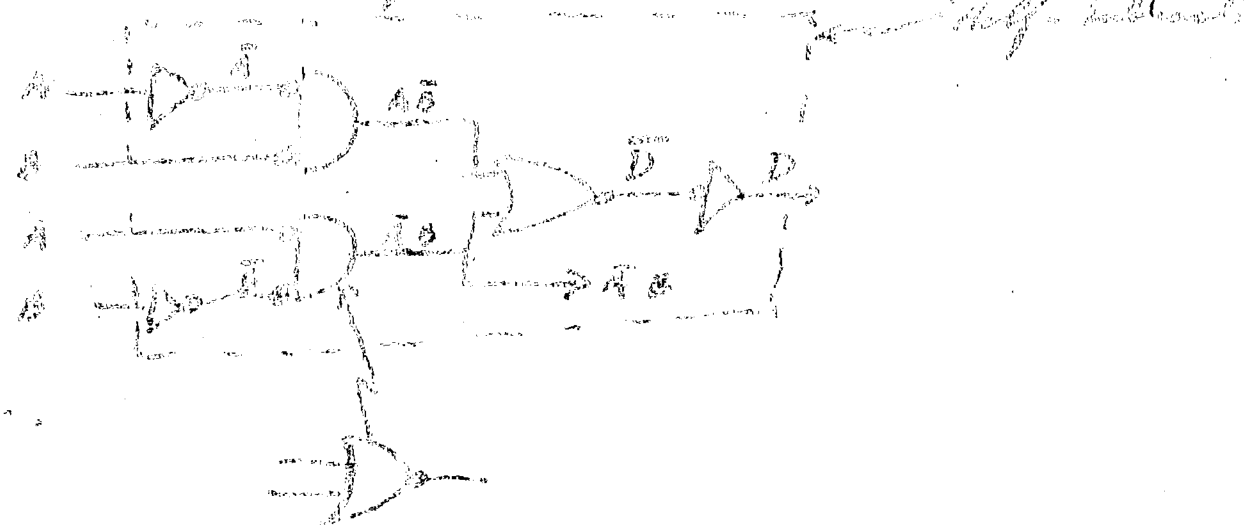


Solution for (b)

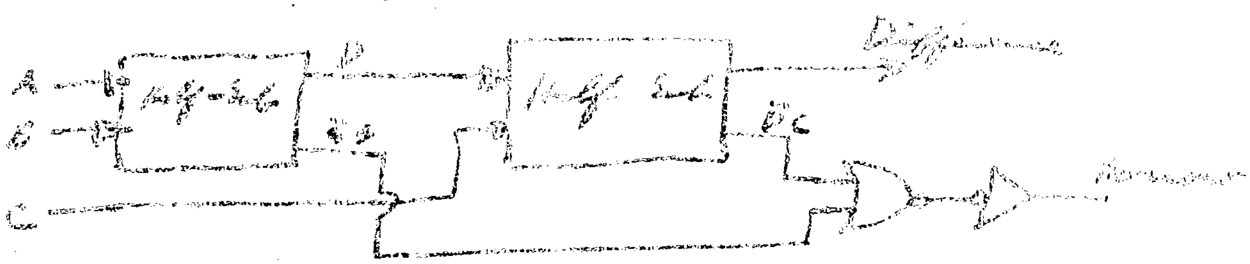


4-2 Continued

c) By moving the inverter and replacing the NAND's ... a NOR the half subtractor becomes



The solution using NOR's is



Note that in the solution for (b) the inverter is ... while in the solution for (c) the inverter is ...

High-Level (Positive) Logic has been used throughout.

7-8 p.188

$\beta = 50$

$V_D = 0.6^V$

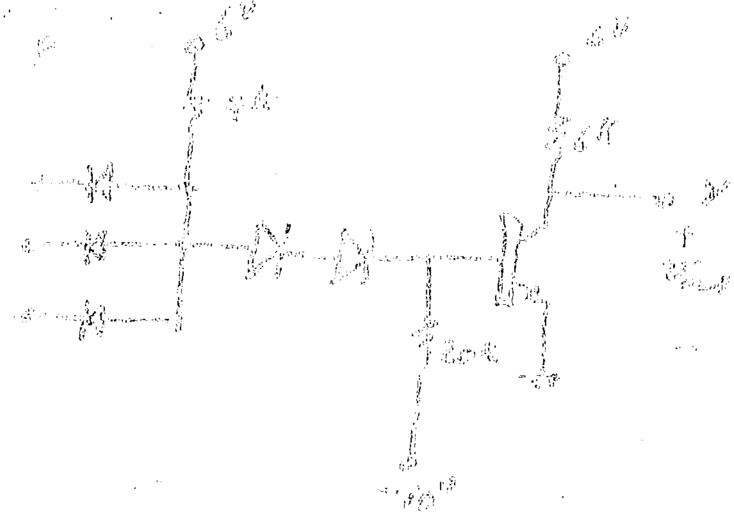
$V_{BE\ act} = 0.7^V$

$V_{BE\ edge} = 0.6^V$

$V_{BE\ sat} = 0.8^V$

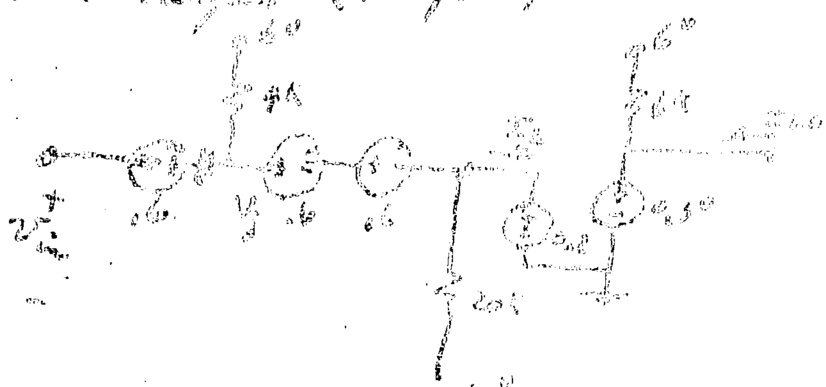
$V_{CE\ sat} = 0.2$

$V_\gamma = 0$



a) Transfer characteristic

i) Model for 0 output (1 input)



$$V_{in} = V_{BE} + 2V_D - V_D$$

$$= .7 + 1.2 - .6 = 1.3^V$$

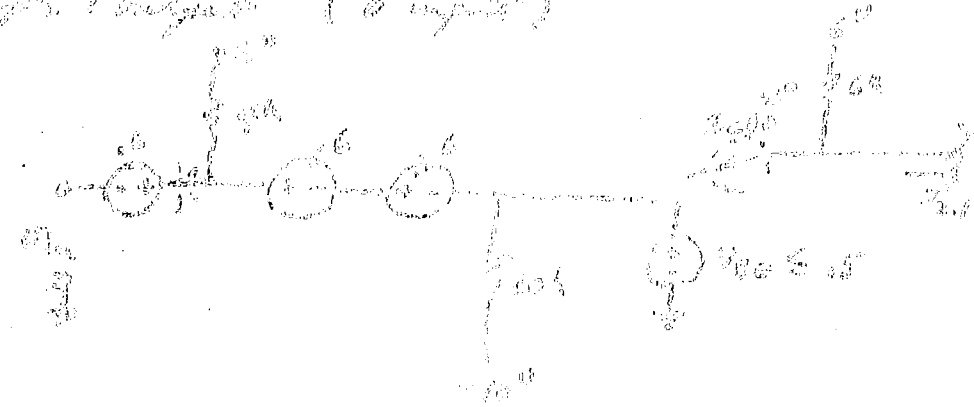
$$I_{B\,min} = \frac{6 - 1.2 - .7}{4k} - \frac{.7 + 10}{20k}$$

$$= \frac{4.1}{4k} - \frac{10.7}{20k} = 1.025 - .535 = .49$$

$$\therefore I_{C} = \beta I_B - \frac{6 - .2}{6k}$$

(cont'd) contd.

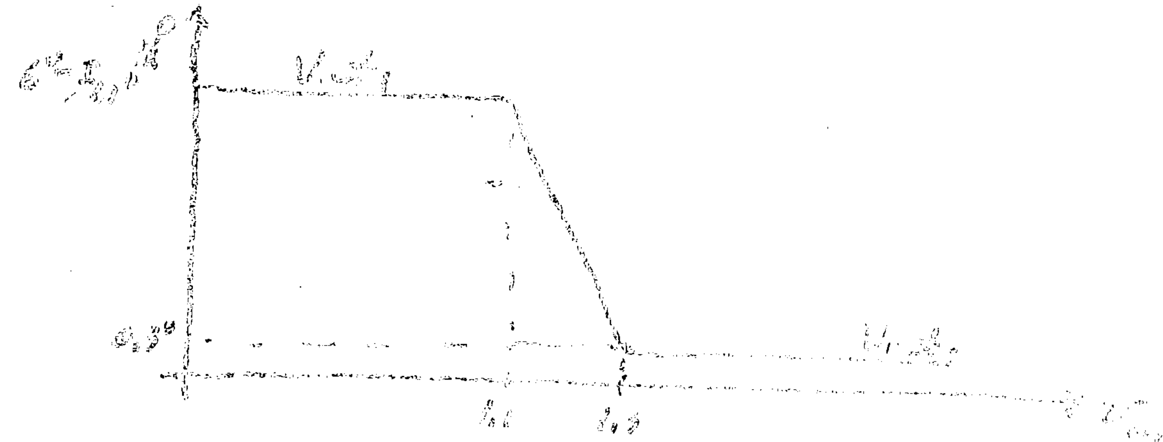
iii) Model for 1 output (0 input)



V_{in} ≤ V_{in_0} = $-V_D + 2V_D + V_{BE}$

= −0.6 + 1.2 + 0.8 = ...

a.)



b) For 1 volt noise immunity

i) This is not possible for noise immunity in logic 0 since

$V_{in_0} - V_{out_0} = 1.1 - 0.3 = 0.8 < 1$ V

and it can't [illegible] be improved by reducing the [illegible]

ii) For noise immunity in the other direction

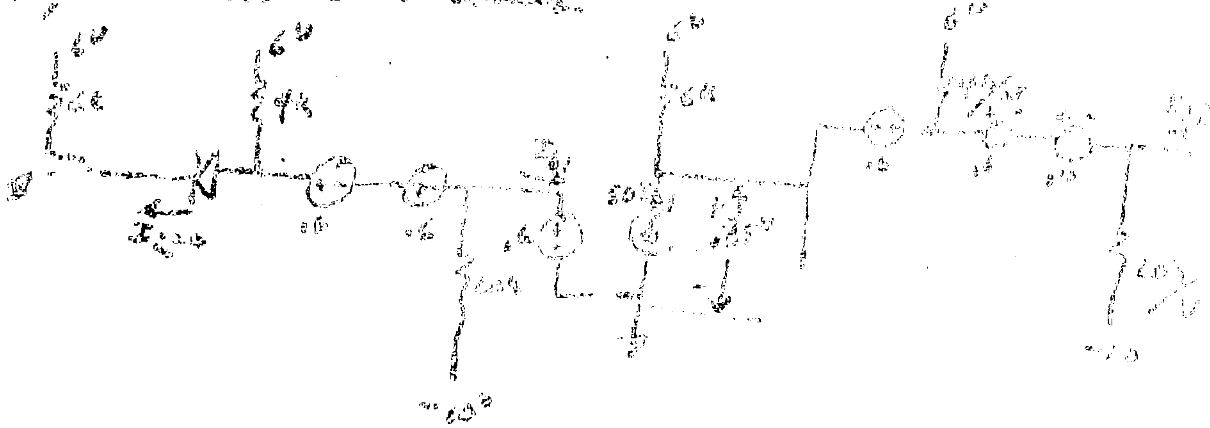
$V_{out_1} - V_{in_1} = 6 - ... - 1.1 = ... > 1$

b) For 250 mV noise immunity

The current required to drive the input to a logical 0 will eventually pull the transistor out of saturation as the fan-out is increased. However, the noise immunity will not be reduced to .65 volt until $V_{out_0} = .85$ volt so that

$$V_{in_0} - V_{out_0} = 1.1 - .85 = .25 \text{ volt}$$

Thus, the model becomes



$$I_{B_1} = \frac{6-1.8}{4k} - \frac{10.6}{20k} = \frac{4.2}{4k} - .53 = 1.05 - .53 = .52$$

$$50\, I_{B_1} = \frac{6-.85}{6k} + \left(\frac{6-.6-.85}{4k} N - \frac{.85+10.6}{20k} N\right)$$

$$50(.52) = \frac{5.15}{6} + N\left(\frac{4.55}{4} - \frac{10.25}{20}\right)$$

$$26 = .859 + N(.625)$$

$$N = \frac{26-.859}{.625} = \frac{25.1}{.625} = 40.1 \approx 40$$

c) The only change will be in the 250 mV [illegible]

[illegible]

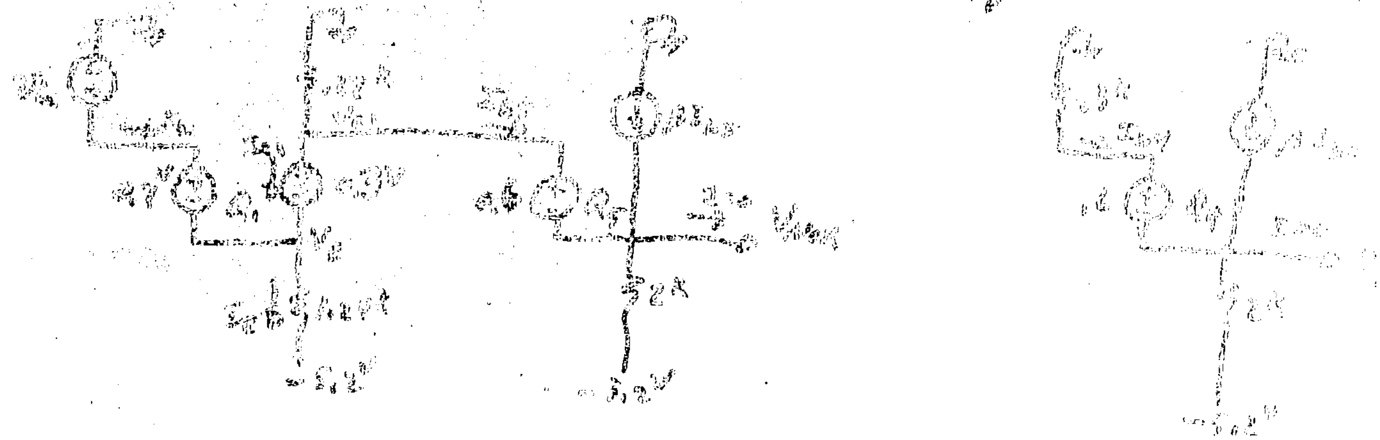
Use $V_{BE} = 0.75^V$ $\quad V_{BE,active} = 0.6^V$

$\beta = 50$ $\quad V_{BE,sat} = 0.7^V$

$V_{CE,sat} = 0.2^V$ $\quad V_{BE,cut\text{-}off} = 0.5^V$

a) Transfer characteristic (one input, no load on output)

i) model for ... (Q_1 saturated, Q_3 off, Q_4 & Q_5 active)



(1)

For this circuit condition

$$I_{B4} \cdot 3^k + 0.6 + (1+\beta) I_{B4} 2^k - 5.2 = 0$$

$$I_{B4} = \frac{5.2 - 0.6}{3^k + (1+\beta) 2^k} = \frac{4.6}{105^k} = 0.044 \text{ mA}$$

(2)

$$V_{OR} = (1+\beta) I_{B4} 2^k - 5.2 = 51(2)(.044) - 5.2 = -0.72^V$$

$$\boxed{V_{NOR} = v_{in} - 0.7 + 0.3 - 0.6 = v_{in} - 1.0}$$

$$I_{B5} = \frac{V_{NOR} + 5.2}{2^k(1+\beta)} = \frac{v_{in} - 1 + 5.2}{2^k(1+\beta)} = \frac{v_{in} + 4.2}{(1+\beta)2^k}$$

$V_{E1} = v_{in} - .7 + .2 = v_{in} - .5$

$I_{E1} = \frac{-V_{E1}}{.27k} - I_{B5}$

$= \frac{.5 - v_{in}}{.27k} - \frac{v_{in} + 4.2}{(1+\beta)\,2^k}$

$\beta I_{B1} \geq I_{C1}$ for saturation

$\beta (I_E - I_{E1}) \geq I_{E1}$

$\beta I_E \geq (1+\beta)\, I_{C1}$

$\frac{v_{in} + 4.5}{1.24k} \geq \frac{(1+\beta)}{\beta} \frac{.5 - v_{in}}{.27k} - \frac{1}{\beta} \frac{v_{in} + 4.2}{2^k}$

$v_{in}\left(\frac{1}{1.24} + \left(\frac{1+\beta}{\beta}\right)\frac{1}{.27} + \frac{1}{\beta 2}\right) \geq \left(\frac{1+\beta}{\beta}\right)\frac{.5}{.27} - \frac{4.2}{2\beta} - \frac{4.5}{1.24}$

for $\beta = 40$

$v_{in} \geq \frac{\frac{41}{40}\frac{.5}{.27} - \frac{4.2}{80} - \frac{4.5}{1.24}}{\frac{1}{1.24} + \frac{41}{40}\frac{1}{.27} + \frac{1}{80}}$

1.92   .0525   3.63

.805   3.8   .0125 small

$v_{in} \geq \frac{-2.16}{4.6} = -0.47$

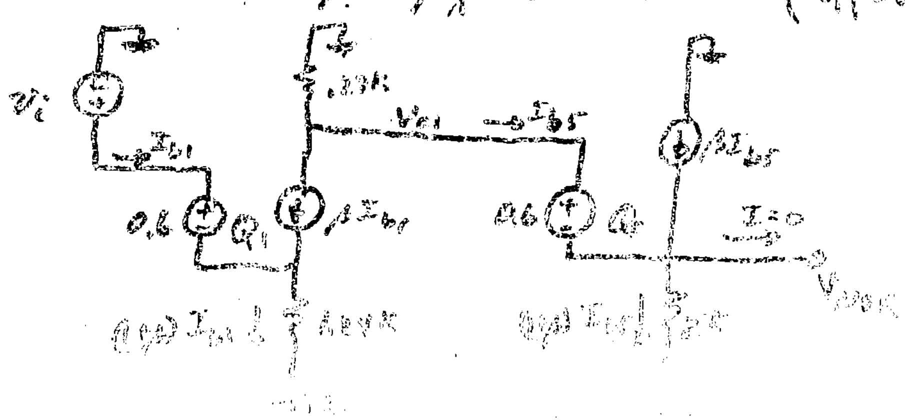
3.63 + .052 = 3.68; − 1.92 = 1.76   3.8 + .80 = 4.6

3)

$\therefore Q_1$ saturated for $-.47 < v_{in} < 0$

ii) model for high, but $v_{in} < -.47^v$ (Q_1 active, Q_5 off, Q_{Off} active)

$V_{OUT} = -4.5 + \ldots$



Q_3 is cut off for $V_E > -1.65$ but now $V_{BE\,Q_1}$ is different so that

$V_E = v_{in} - .6$ and

4) $v_{in} > -1.65 + .6 = -1.05\ V$ for Q_3 is cut off

Equation (4) replaces Equation (3)!

To solve for $V_{WOR} = f(v_{in})$

$(1+\beta)\, I_{b1}\, 1.24^K + .6 - v_{in} - 5.2 = 0$

Four equations:

$$\Rightarrow I_{b1} = \frac{5.2 - .6 + v_{in}}{41 \times 1.24^K} = \frac{4.6 + v_{in}}{50.9^K}$$

$$-\frac{V_{C1}}{.27^K} - \beta I_{b1} = I_{b5}$$

$$(1+\beta)\, I_{b5}\, 2^K = V_{WOR} + 5.2 \Rightarrow I_{b5} = \frac{V_{WOR} + 5.2}{41 \times 2^K}$$

$$V_{C1} = V_{WOR} + .6$$

$$-\left(\frac{V_{WOR} + .6}{.27^K}\right) - 40\left(\frac{4.6 + v_{in}}{50.9^K}\right) = \frac{V_{WOR} + 5.2}{41 \times 2^K}$$

$$V_{WOR}\left(-\frac{1}{.27} - \frac{1}{41 \times 2}\right) = \frac{40}{50.9}\left(4.6 + v_{in}\right) + \frac{5.2}{41 \times 2} + \frac{.6}{.27}$$

(3.7, .0122, .063, 2.22 written above terms)

$$-3.71\, V_{WOR} = 3.86 + .787\, v_{in} + 2.22$$

5)
$$\boxed{V_{WOR} = \frac{6.19 + .787\, v_{in}}{-3.71} = -1.66 - .212\, v_{in}}$$

@ $v_{in} = +.47$ $\quad V_{WOR} = -1.66 - .212 \times (+.47) = \underline{-1.76}$ (+.1 written above)

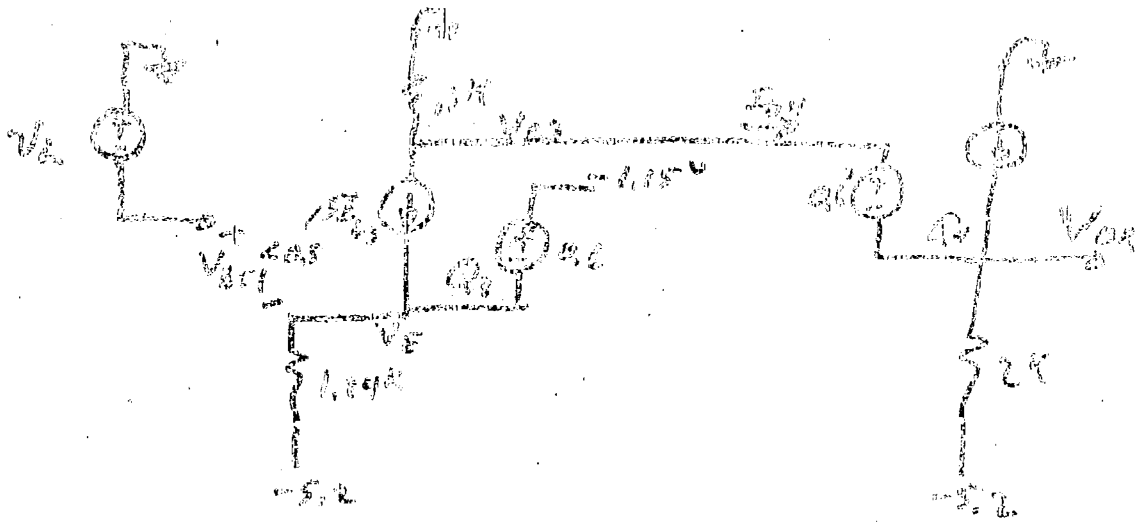
Calculated diagram result from estimation are quite ... [illegible]

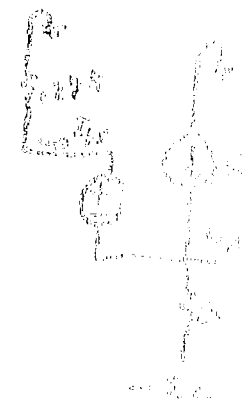
@ $v_{in} = -1.05$

$V_{WOR} = -1.66 - .212\,(-1.05)$ [illegible] (+.22 written above)

$= -1.44$ [illegible]

(ii) model for v_i low negative (Q_1 cut off; Q_2, Q_3, Q_4 on)





$V_E = -1.15 - .6 = -1.75$ V

for cut-off of Q_1

$v_i - V_E < 0.5$

$v_i < .5 + V_E = .5 - 1.75 =$

$v_i < -1.25$

$$I_{B3} = \frac{V_E + 5.2}{(1+\beta)\,1.24^K} = \frac{-1.75 + 5.2}{41 \times 1.24^K} = .0678 \text{ mA}$$

$$\begin{cases} \beta I_{B3} + I_{B4} = \dfrac{-V_{B3}}{.3^K} \\ V_{B3} = V_{o4} + .6 \\ V_{o4} = -5.2 + (1+\beta) I_{B4}\, 2^K \end{cases} \Longrightarrow I_{B4} = \frac{V_{o4} + 5.2}{(1+\beta)\,2^K}$$

$$40 \times .0678 \text{ mA} + \frac{V_{o4} + 5.2}{41 \times 2^K} = -\left(\frac{V_{o4} + .6}{.3^K}\right)$$

$$V_{o4}\left(\frac{1}{82} + \frac{1}{.3}\right) = -\frac{.6}{.3} - \frac{5.2}{82} - 40 \times .0678$$

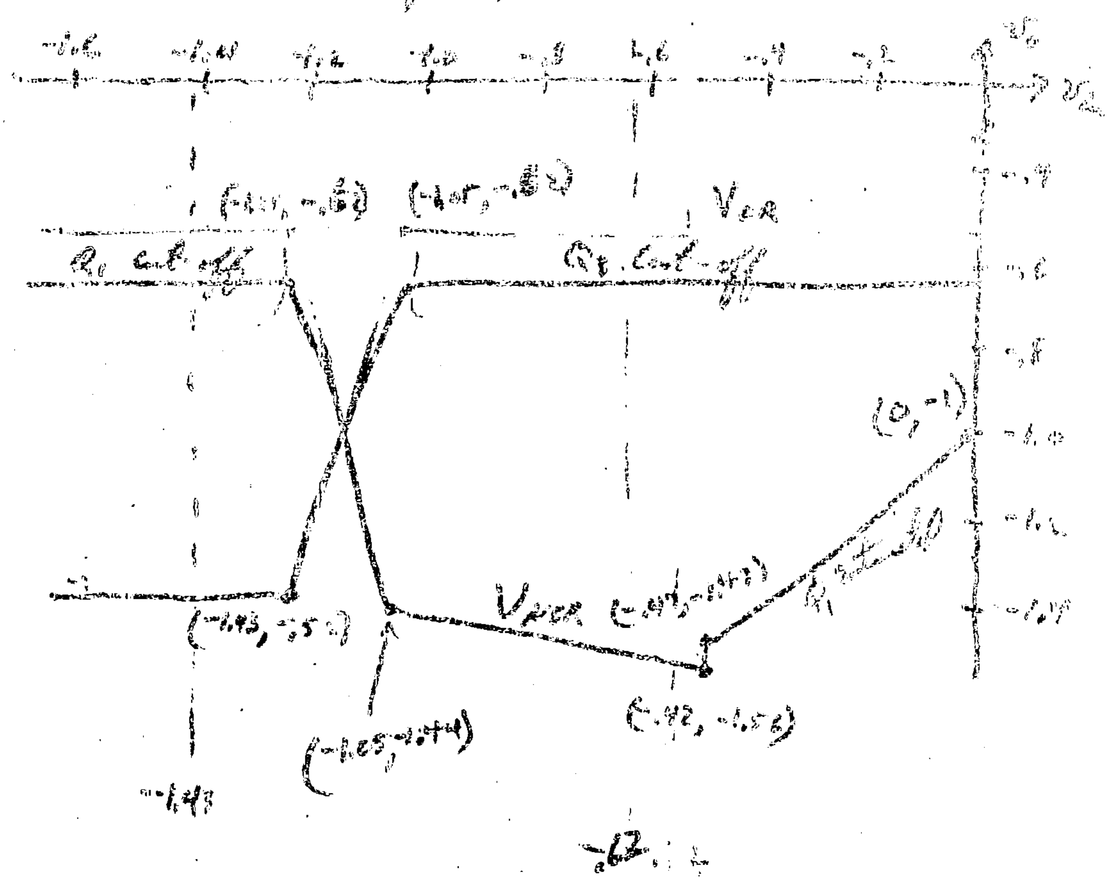
$V_{o4} = -\dfrac{\ }{\ } = -1.42$

V_{BON} can be determined as in Equation (1) for V_{OH}

$$I_{E5} = \frac{5.2 - .6}{.29k + 2.6k} = \frac{4.6}{[illegible]k} = [illegible]\text{ mA}$$ [illegible]

$\therefore V_{BON} = -.82\,V$

Thus, the transfer functions are



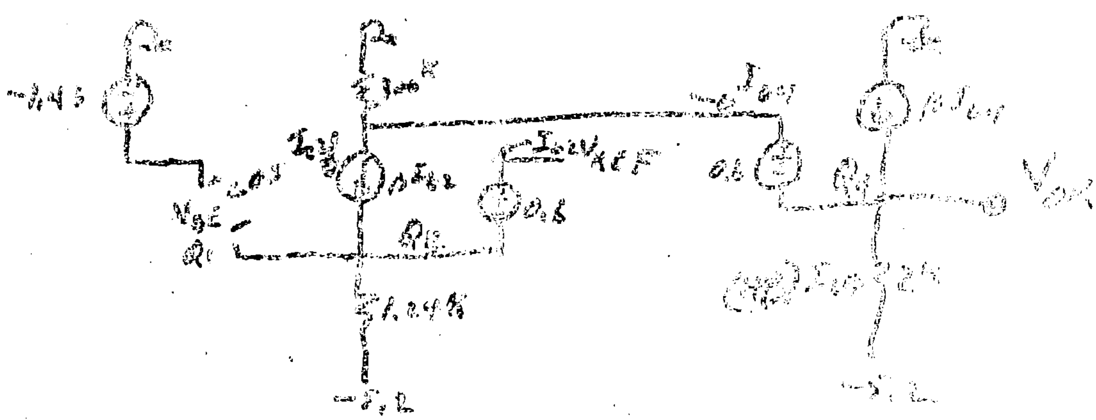
b) Find ... for noise-immunity of 0.5V

From the transfer characteristics the worst low-level is -1.475V and the worst high-level is -.62V when a gate is driven from a similar gate. The noise-immunity for a logical 0 (-1.475V) input is |-1.48 - (-1.05)| = .43V while the NM for logical 1 (-.62V) input is |-.62 - (-1.05)| = .43V

A noise immunity of 0.5 volt is not possible!

c) Saturation caused by V_{REF} variation.

i) For logical 0 input ($v_i = -1.48V$) the model is



Q_1 can not be saturated. Q_3 will saturate if V_{REF} is big (toward positive) enough. Then $V_{BC_3} = 0.5$ and $V_{BE} = 0.7V$ which [illegible]

[illegible] condition.

$V_{08} = V_{BEQ} - \ldots = V_{BEP} - 1.9$

$$\begin{cases} I_{B4} = \dfrac{V_{08} + 8.6}{(1+\beta)\,2K} = \dfrac{V_{BEP} + 7.7}{(1+\beta)\,2K} \\ I_{B2} = \dfrac{V_{BEP} + \ldots}{(1+\beta)\,1.29K} \\ I_{C2} = \dfrac{-(V_{BEP} + 6.2)}{1K} - I_{B4} = -\dfrac{(V_{BEP} + 3)}{1K} - I_{B4} \end{cases}$$

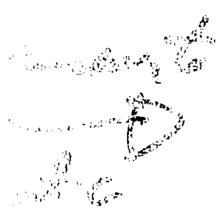
$\beta I_{B2} = I_{C2} = -\left(\dfrac{V_{BEP} + 3}{1K}\right) - \left(\dfrac{V_{BEP} + 7.7}{(1+\beta)\,2K}\right)$

$\beta \left(\dfrac{V_{BEP} + 8.6}{(1+\beta)\,1.29K}\right) =$

$V_{BEP}\left(\dfrac{\ldots}{\ldots} + \dfrac{1}{1} + \dfrac{1}{\ldots}\right) = \dfrac{\ldots \times 8.6}{\ldots} + \dfrac{3}{1} - \dfrac{7.7}{\ldots}$

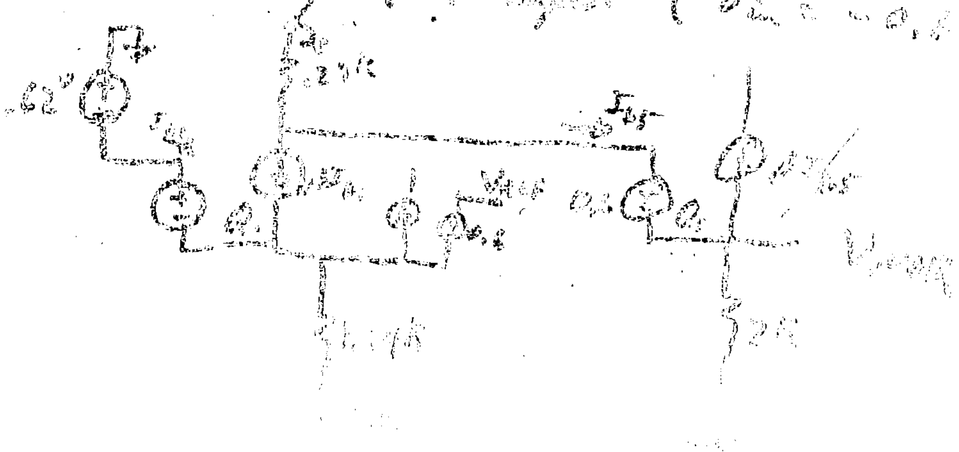
$V_{BEP}\,(4.13) = -2.67$

$V_{BEP} = -\dfrac{2.67}{4.13} = -0.65^{V}$



for saturation of Q_3

ii) For limit 1 input ($v_{in} = -0.62\,V$) the analysis



the V_{BEP} goes negative ... cut off ...

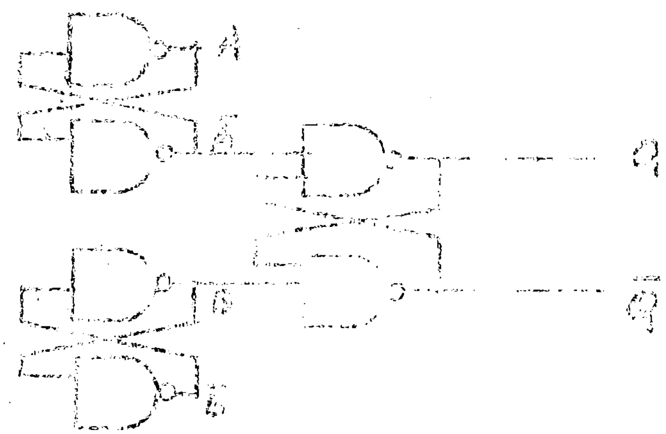
NOV 3 1971

EE [illegible] Digital Electronics II
Homework Problem

a) Construct the Truth Table for the D-type edge-triggered flip-flop on page 113 A of the notes. Use high-level logic ("H" = "1", "L" = "0")

b) Discuss the operation of the "preset" and "clear" inputs. A truth table would suffice.

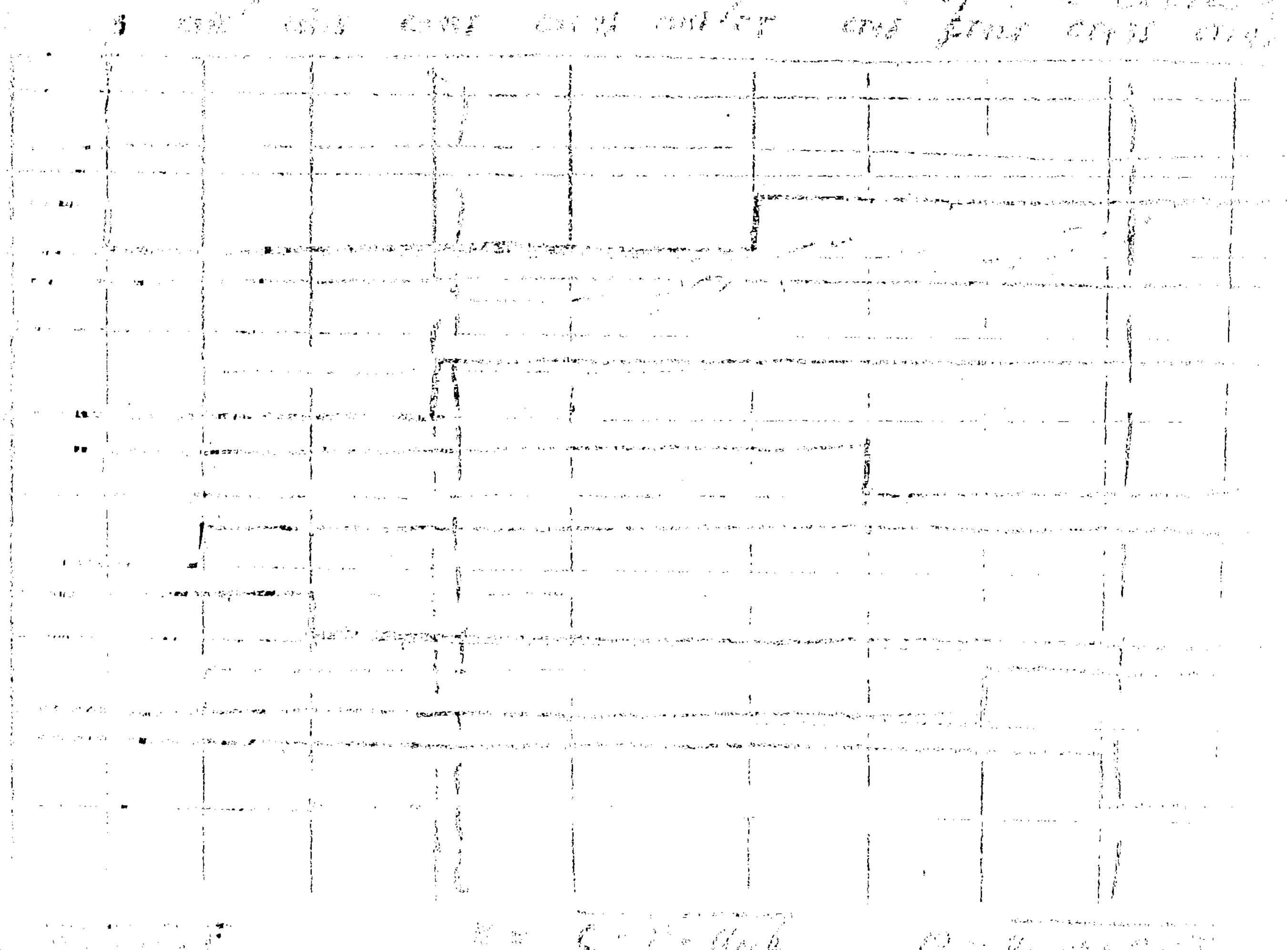
c) Are there any restrictions on the length of the clock pulse?



D	Clock	A		B		Q	

d) Discuss the operation of the "clear" and "preset" when a "clock pulse" is present.

[illegible] the [illegible] have been cleared and is [illegible] in the [illegible] A = 0, C = 1, B = 0, F = 1, Q = 0, [illegible] = 1 and [illegible] = 1. Assume that [illegible] normally that is [illegible] than DS [illegible]. [illegible] on the front edge of the clock pulse and CP on the trailing edge of the clock pulse. The following [illegible] diagram describes the operation of the [illegible]



[illegible] [illegible] = C · [illegible] Clock [illegible] Q = Preset · C · [illegible]

[illegible] C = B · [illegible] Clear [illegible] Q = [illegible]

Logic Equations:

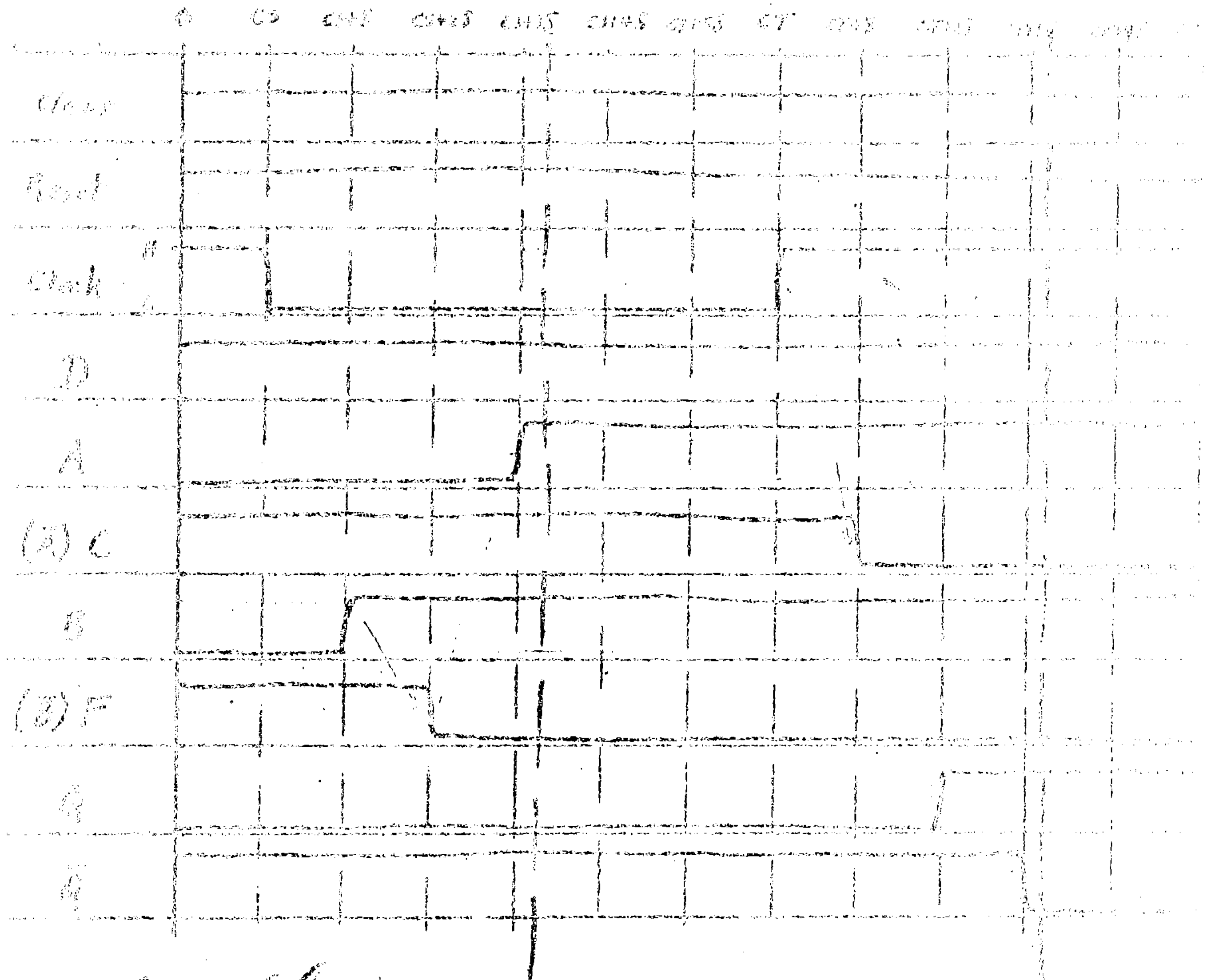
$A = \overline{B \cdot C \cdot F}$ [illegible]

$C = \overline{A \cdot Clear \cdot Clock}$ [illegible]

Initial Conditions:

A = 0 B = 0 Q = 0 Clear = 1 D = 1

C = 1 F = 1 $\bar{Q}$ = 1 Reset = 1



Final Conditions:

A = 1 B = 1 Q = 1

C = 0 F = 0 $\bar{Q}$ = 0

D-type Edge Triggered F/F

Logic Equations:

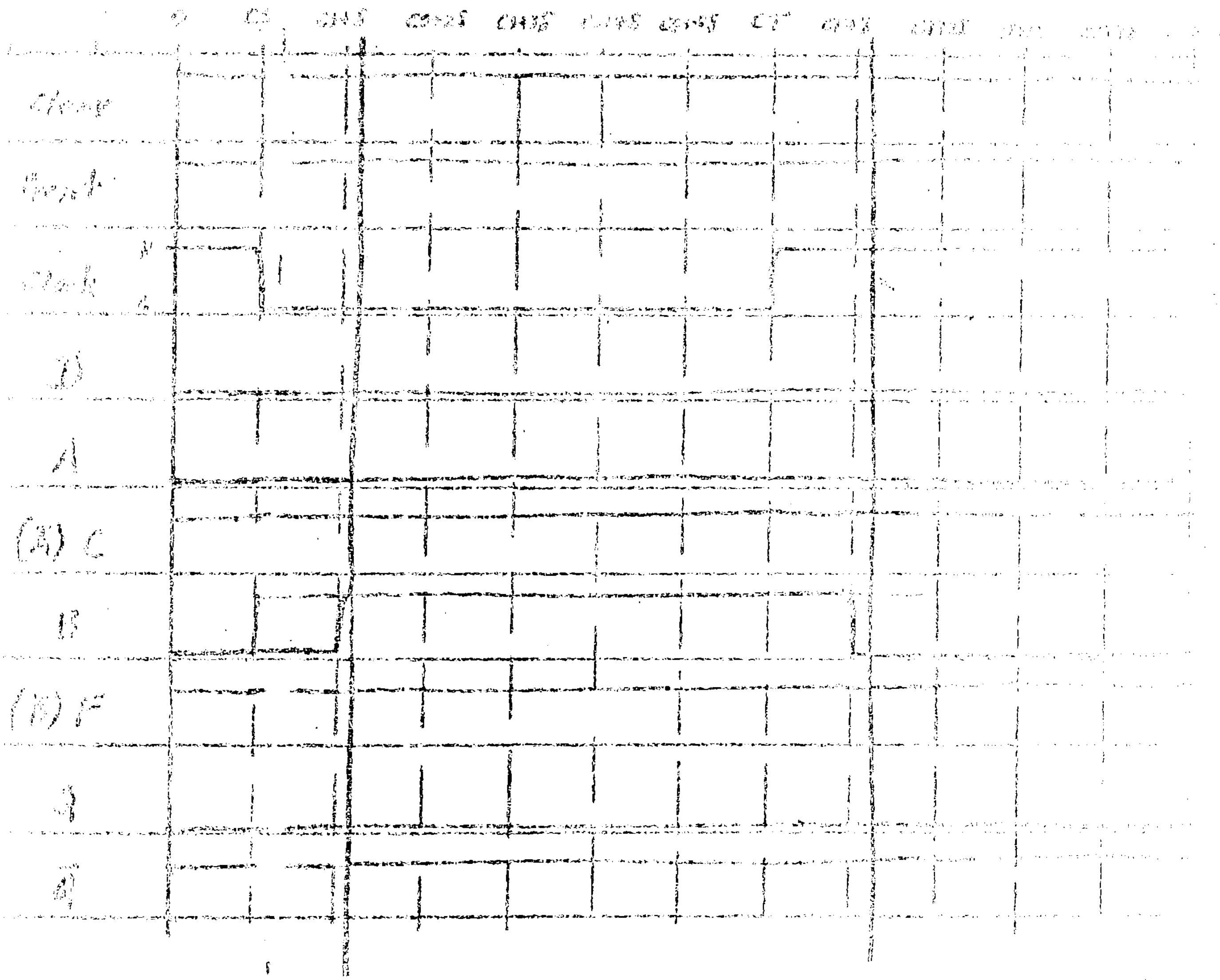
$A = \overline{Pre \cdot C \cdot F}$ $\quad B =$ $\quad Q =$

$C =$ $\quad F =$ $\quad \bar{Q} =$

Initial Conditions:

$A = 0 \quad B = 0 \quad Q = 0 \quad Clear = 1$

$C = 1 \quad F = 1 \quad \bar{Q} = 1 \quad Preset = 1$



Final Conditions:

$A = 0 \quad B = 0 \quad Q = 0$

$C = 1 \quad F = 1 \quad \bar{Q} = 1$

[illegible] D-type [illegible]

Logic Equations:

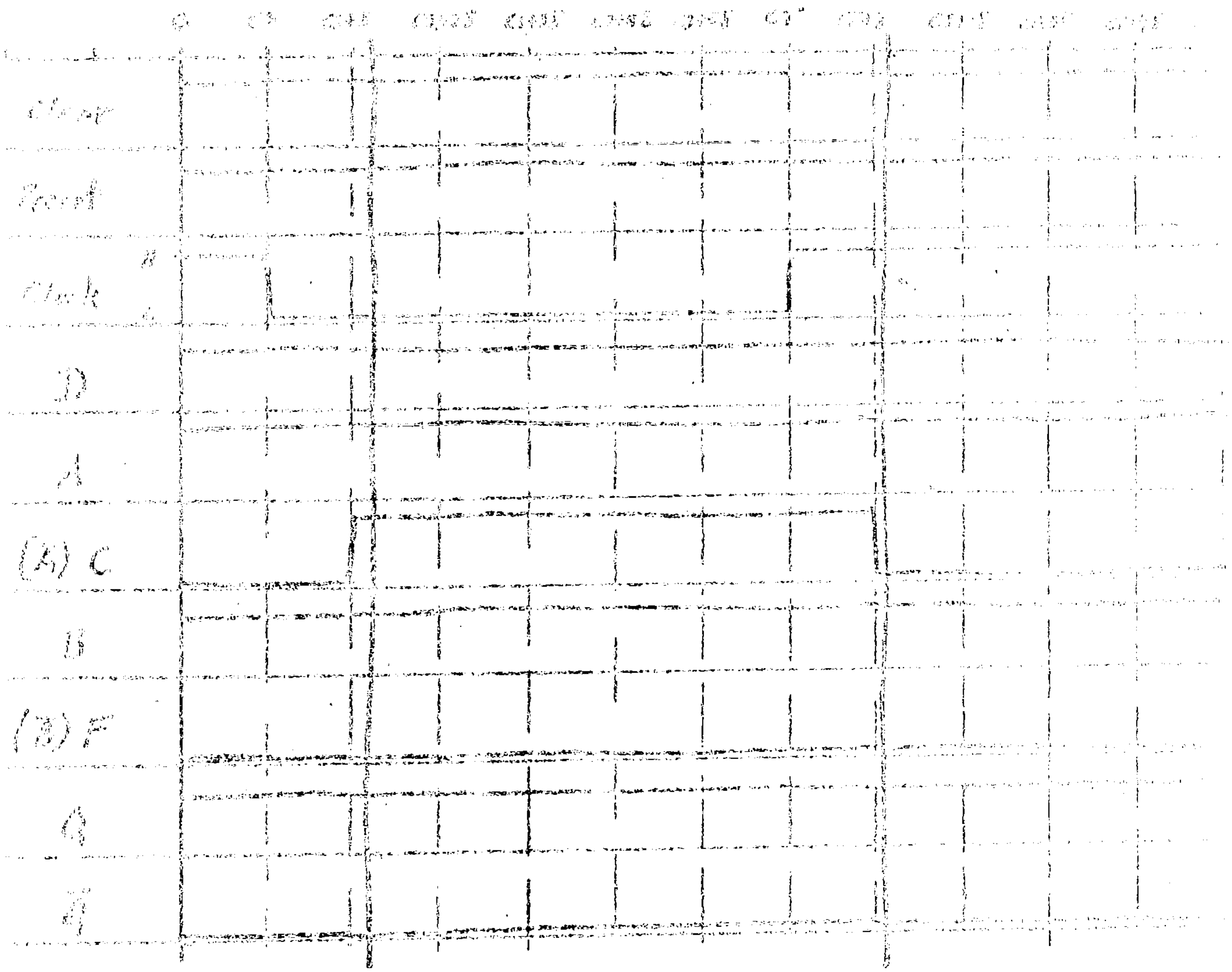
$A = \overline{[illegible]}$ $B =$ $Q =$

$C =$ $F =$ $\bar{Q} =$

Initial Conditions:

$A = 1$ $B = 1$ $Q = 1$ Clear = 1 [illegible]

$C = 0$ $F = 0$ $\bar{Q} = 0$ Preset = 1



Final Condition:

$A = 1$ $B = 1$ $Q = 1$

$C = 0$ $F = 0$ $\bar{Q} = 0$

[illegible]

Logic Equations:

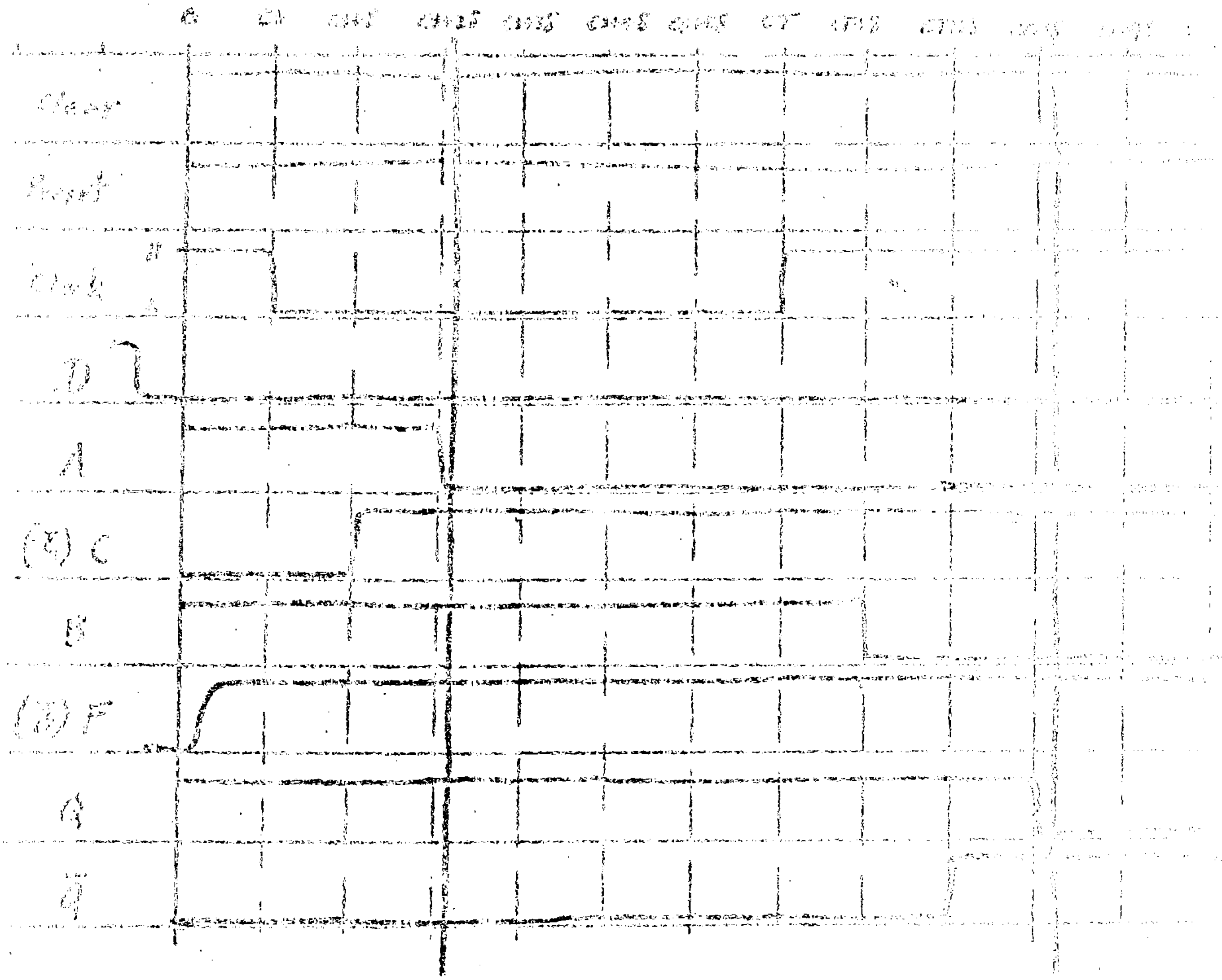
$A = \overline{Pre \cdot C \cdot F}$ B = Q =

C = F = $\overline{Q}$ =

Initial Conditions:

A = 1 B = 1 Q = 1 Clear = 1 D = [illegible]

C = 0 F = 1/[illegible] B = 0 Preset = 1



Final Conditions:

A = 0 B = 0 Q = 0

C = 1 F = 1 $\overline{Q}$ = 1

[illegible]	[illegible]	[illegible]	D	[illegible]	[illegible]	[illegible]
0	1 0	0	1	1	1	1
1	1	1	0	1	1	1
1	1	1	0	0	0	0
0	0	0	0	0	0	0

Inspection of the diagram indicates that the value of D at time (CT − ts) determines the resulting state.

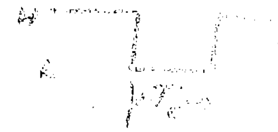
b) Preset and Clear (operate from the [illegible])

Clock	Preset	Clear	Q	A	B	C	F
1	1	1	Q_n	A_n	B_n	$\bar{A}_n$	$\bar{B}_n$
1	1	0	0	0	0	1	1
1	0	1	1	1	1	0	0
1	0	0	1	1	0	1	1

this should not be allowed

[illegible]

c) The clock pulse must be longer than 3δ, also the "clock pulse" is a three level signal



d) The table for part (b) on page 5 can be continued in the presence of a clock pulse to determine the behavior of reset, set, clear with a clock pulse

Clk	Reset	Clear	P	Q	A	B	C	F	$\bar{Q}$
0	1	1	0	Q_n	Q	1	1	1	$\bar{Q}_n$
			1	Q_n	1	1	1	0	$\bar{Q}_n$
0	1	0	(0/1)	0	0	1	1	1	1
0	0	1	0	1	1	1	1	1	0
			1	1	1	1	1	0	0
0	0	0	(1)	1	1	1	1	1	1

[illegible]

The reset (and clear) take precedence over the D and clock signal. If the clock returns to 1 then it will remain in the reset (or clear) state.

[illegible] (continued) [illegible]

with the D = 0 and [illegible] = 0 [illegible] = 0

with D = 1 and [illegible] = 0 [illegible] = 1

with D = 0 and [illegible] = 0 the [illegible] diagram can be investigated to determine the [illegible] (Case i).

with D = 1 and Clear = 0 the [illegible] diagram can be investigated to determine the [illegible] (Case ii).

[illegible] D Type Edge Triggered [illegible]

Logic Equations:

$A = \overline{[illegible] \cdot C \cdot F}$ $B =$ $Q =$

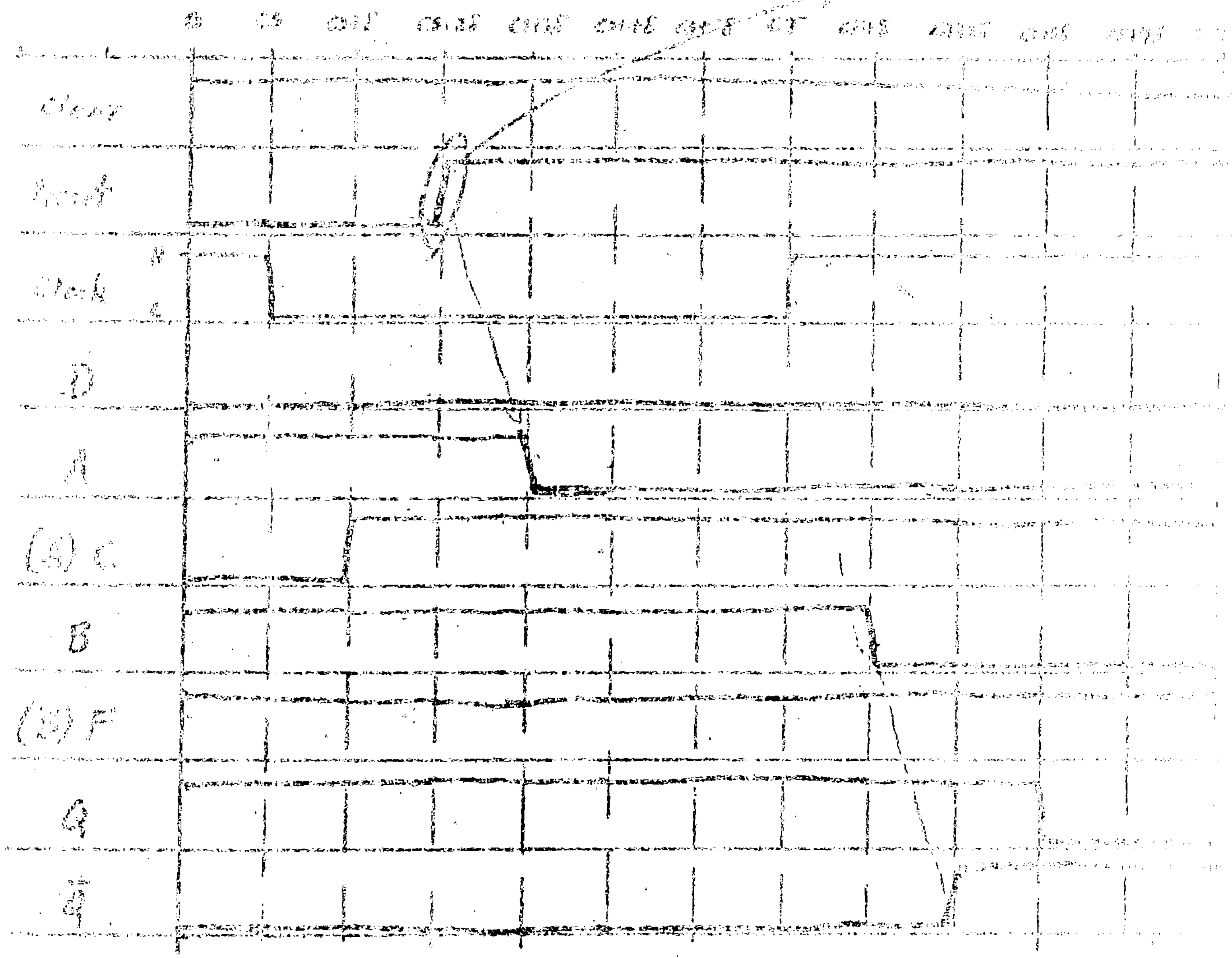
$C =$ $F =$ $\bar{Q} =$

Case (b) [illegible] (d)

Initial Conditions:

$A =$ $B =$ $Q =$ Clear = 1   D = 0

$C =$ $F =$ $\bar{Q} =$ Reset = $Q \rightarrow 1$



Final State:

$A = 0$ $B = 0$ $Q = 0$

$C = 1$ $F = 1$ $\bar{Q} = 1$

The [illegible] input [illegible]

[illegible]

Logic Equations:

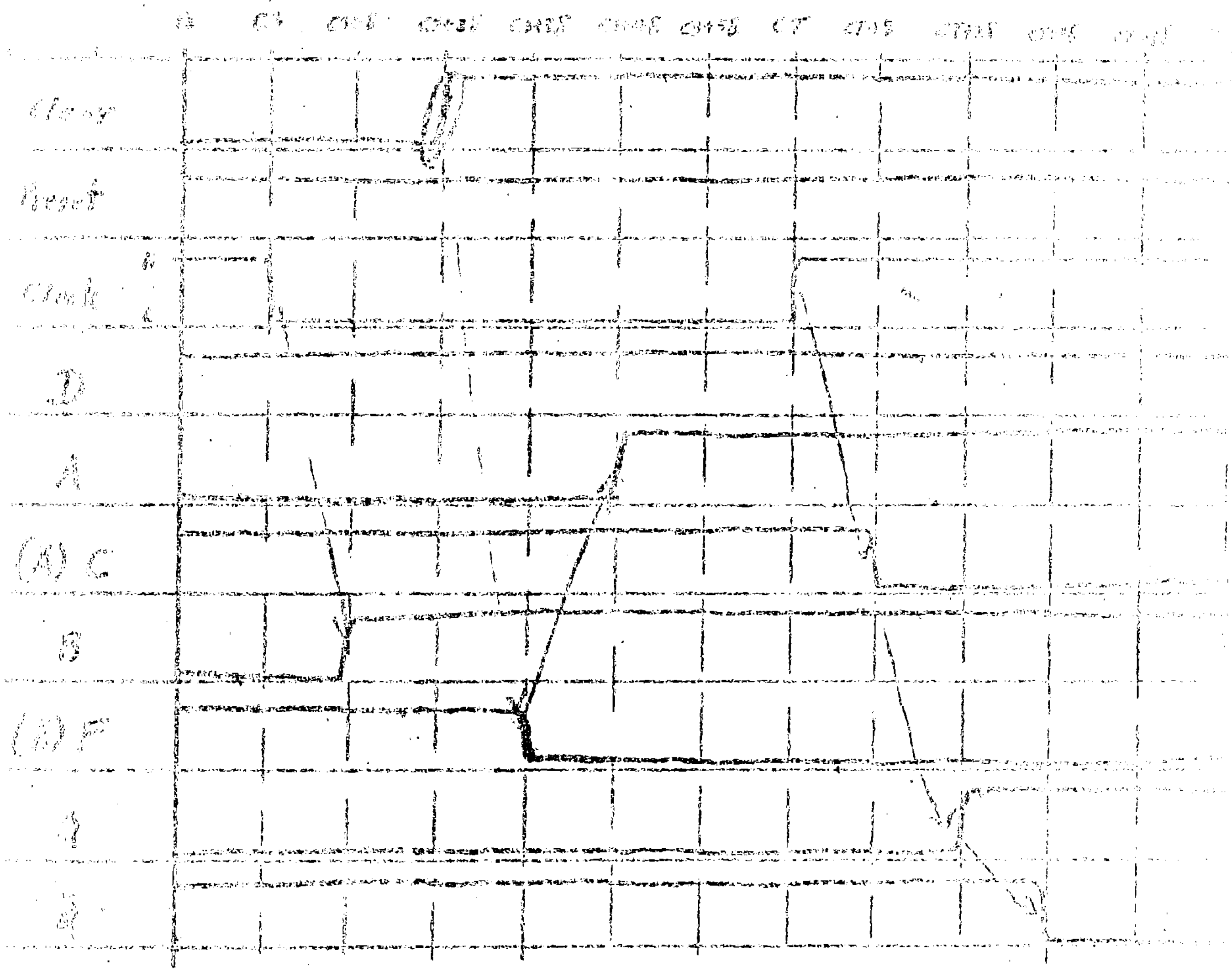
$A = \overline{B \cdot C \cdot F}$ $B =$ $Q =$

$C =$ $F =$ $\bar{Q} =$

Initial Conditions:

$A =$ $B =$ $Q =$ Clear $= 0 \to 1$ $D = 1$

$C =$ $F =$ $\bar{Q} =$ Reset $= 1$



Final State:

$A = 1$ $B = 1$ $Q = 1$

$C = 0$ $F = 0$ $\bar{Q} = 0$

EE 5?? Digital Electronics
Mid-Term Exam
Three Problems

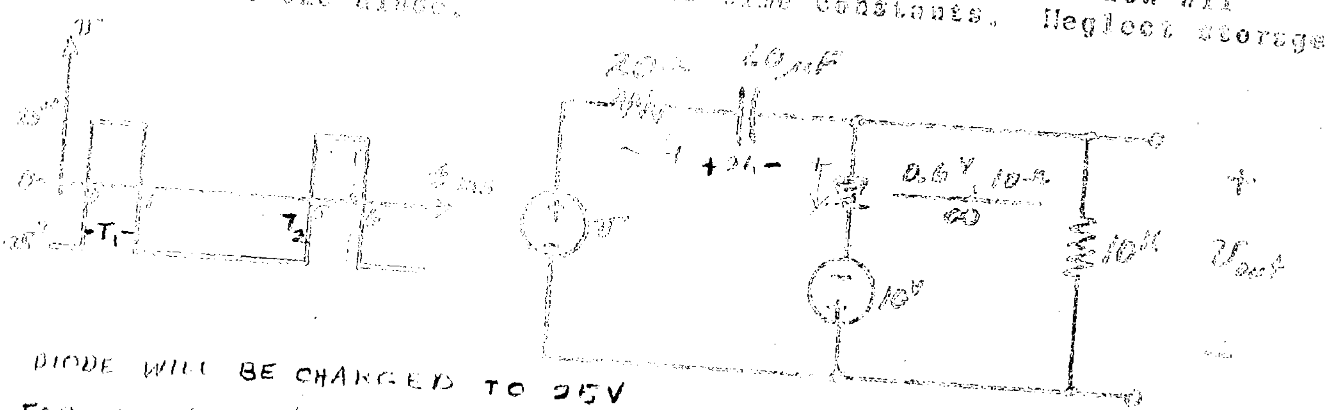
October 12, 197?
3 Periods

OPEN BOOKS & NOTES

7/10

30

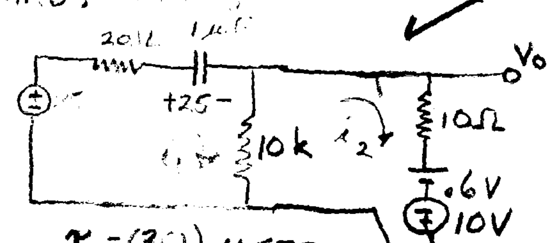
1. For the circuit shown, determine the output voltage waveform over one 5-millisecond interval. The input is a repetitive waveform which has been present for a long time. Show all significant voltage points and time constants. Neglect storage time in the diode.



2

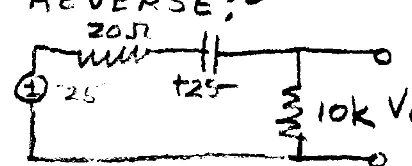
DIODE WILL BE CHARGED TO 25V

FORWARD:

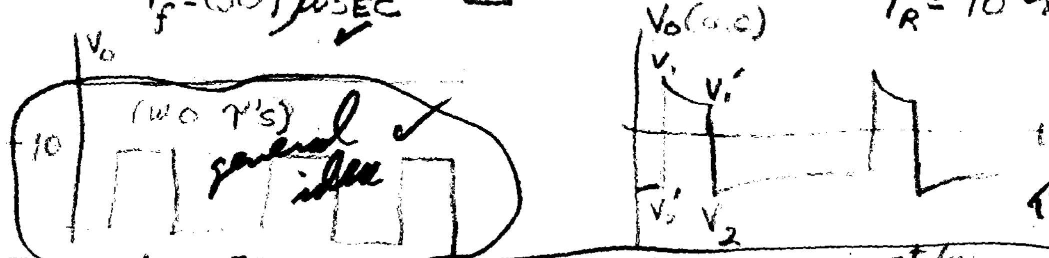


$\tau_f = (30)\ \mu SEC$

$1<t<5$ REVERSE:



$\tau_R = 10^{-6} \times 10^4 = 10^4\ \mu SEC$



these equations were derived without the 10V and Vγ!

EQ → $V = \frac{30}{10}V_1 - V_2' \Rightarrow V = 3V_1 - V_2'$ | $v_{o1} = V_1 e^{-t/\tau_f}$ $0<t<1$

$V = 3V_1' - V_2 \ni V = 50$ | $v_{o2} = V_2 e^{-t/\tau_r}$ $1<t<5$

2 EQ 2 UNKNOWNS

$V_1' = \frac{50}{3} + \frac{1}{3}V_2 = V_1(1 - e^{-1/\tau_f})$ $V_1' = V_1(1 - e^{-1/\tau_f})$; $V_2' = V_2(e^{-1/\tau_r} - e^{-5/\tau_r})$

$V_2' = 3V_1 + 50 = V_2(e^{-1/\tau_r} - e^{-5/\tau_r})$

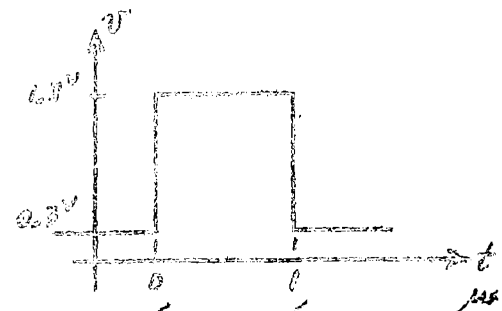
SOLVE FOR V_1 AND V_2, ~~THEN GO FOR V_1', V_2'~~

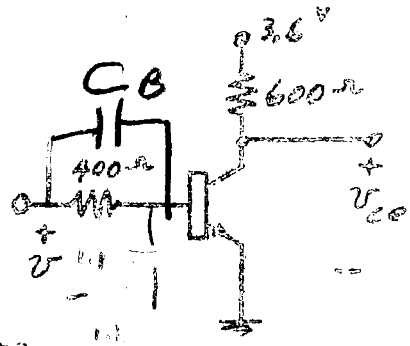
...tion?? $v_o(t) = v_o(t+6) = \begin{cases} V_1 e^{-t/\tau_f} - 35 & 0<t<1\ ms \\ V_2 e^{-t/\tau_r} - 35 & 1<t<5\ ms \end{cases}$

2. The storage-time response of the RTL gate is to be investigated.

a) For the input voltage wave shown and the transistor parameters as indicated, determine the numerical values of t_D, t_{ON}, t_S and t_{OFF} as defined in Section 3-7 of Strauss.

b) What minimum value of speed-up capacitor across the 400-ohm resistor would improve the response of this circuit? (NORMALLY)





~~a) $\tau_0 = R_B C_{BC} = (4\times10^2)(10^{-10}) = 4\times10^{-8} = 40$ nsec~~

~~$.7 = V_b(t) \; 1.5 + 2.1 e^{-t/\tau_B}$~~

~~$\frac{.7-1.5}{2.1} = e^{-t/40}$~~

~~$t_D = (\ln \frac{.8}{2.1})40 = (\ln \frac{2.1}{.8})40 = 52$ nsec~~

~~$t_{on} = \tau_0 \ln \frac{I_{b1}}{I_{b1} - I_{bsat}} = 40 \ln \frac{2.1}{.4} = 40 \ln 5.8 = 102$ nsec~~

$V_{CE,sat} = 0.3^V$

$V_{BE,sat} = 0.7^V$

$\tau_B = 100$ nsec.

$\beta = 10$

$C_{BE} = 100$ pF $= C_D$

$r_{ce} = 0$

a) $V_b(t) = 1.8 - (5.7) e^{-t/\tau}$

$\tau_0 = 4\times10^2 \times 10^{-10} = 4\times10^{-8} = 40$ n

$\Rightarrow .7 = 1.8 - 5.7 e^{-t/40}$

$-40 \ln \frac{1.1}{5.7} = t_0 = 6~~5.7~~$ n s

$I_{b1} = \frac{1.8 - .7}{.4\times10^3} = \frac{1.1}{4} = 2.75$ mA ; $I_{CSAT} = \frac{3.6 - .3}{.6} = 6$ mA; $I_{bs} = \frac{I_{cs}}{\beta} = .6$

$\Rightarrow t_{ON} = 10^2 \ln \frac{2.75}{2.15} = 24.6$ nS

$I_{b2} = -\frac{-1.50 + .7}{.4} = 6.25$ mA

$t_S = 10^2 \ln \frac{-6.25 - 2.75}{-6.25 - .6} = 10^2 \ln \frac{9.00}{6.85} = 27.3$ nS

$t_{off} = \tau_B \ln \frac{I_{b2} - I_{bs}}{I_{B2}} = \tau_B \ln \frac{I_{b2} - I_{bs}}{Q_B/\tau_B} = \tau_B \ln \frac{I_{b2}}{I_{bs}} \;\; \frac{I_{b2}}{I_{bs}}$

$= 10^2 \ln \frac{-6.25 + .6}{-.6} = 10^2 \ln \frac{6.85}{.6} = 3~~X~~4$ nS (ARG!)

b) $R_B C_B = \tau_B = 10^{-7}$

$C_B = \frac{1}{4\times10^3} \times 10^{-7} = .25\times10^{-9} = 250$ pF

5. Three identical networks as shown in Figure 1 are connected to external sources and to each other as shown in Figure 2.

a) What is the numerical value of $V_{Y1} = V_{B2}$?

b) What is the numerical value of $V_{Y2} = V_{C3}$ if R is very large?

c) What is the numerical value of V_{Y3} if R is very large?

d) As R is reduced in value, at what value of R will the answer to part (b) start to change?

e) As R is reduced in value, at what value of R will the answer to part (c) start to change?

$\overline{Y} = \overline{B}\cdot A + C\overline{D}$

Figure 1

Y =

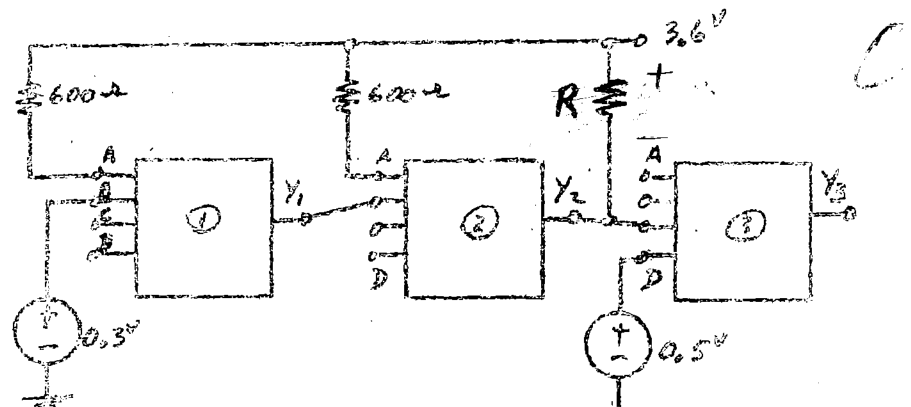


Figure 2

Silicon

$V_{BE,sat} = 0.7^V$

$V_{CE,sat} = 0.3^V$

$I_{CO} = 0$

$\beta = 10$

$V_{BE,cut\text{-}off} = 0.5^V$

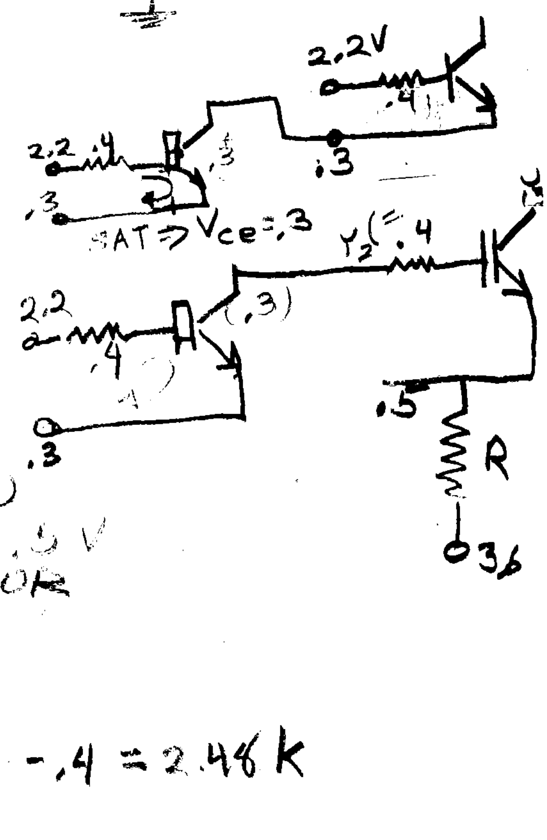
a) $V_A = (.6)(3.6) = 2.16\,V$

$\overline{Y} = \overline{B}\cdot A + C\overline{D}$

$A\cdot\overline{B} \Rightarrow \overline{Y} \Rightarrow V_{Y1} = .3\,V$

b) $V_{Y2} = .7$

c) $V_{Y3} = .5$

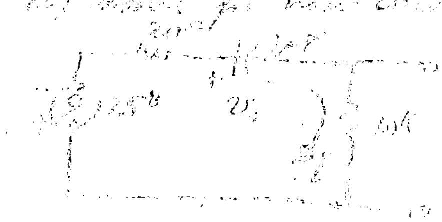


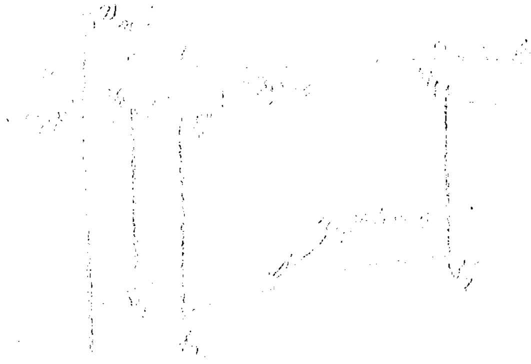
e) R SHOULD BE REDUCED

⇒ $V_{BE} > V_{BE\ CUTOFF} = .5\,V$ FOR CHANGE TO OCCUR

$$.5 = \left(\frac{.4}{.4+R}\right)3.6$$

$$R = \frac{(.4)(3.6)}{.5} - .4 = 2.48\,K$$





([illegible] diode)

$v_c(0^-) = v_c(\infty) = 34.4^V$

at $t = 0^+$ (reverse diode)

$v_c(0^+) = v_c(0^-) = 34.4^V$

$$i = \frac{-25 - v_c(0^+)}{10.02^K} = -\frac{59.4}{10.02^K} = -5.93\ mA$$

$V_2 = i\,10^K = \underline{\underline{-59.3^V}}$

$$V_2' = V_2\, e^{-\frac{4\,ms}{10\,ms}} = -59.3\, e^{-4/10} = \underline{\underline{-39.7^V}}$$

at $t = 5^-$ (or 0^-) (reverse diode)

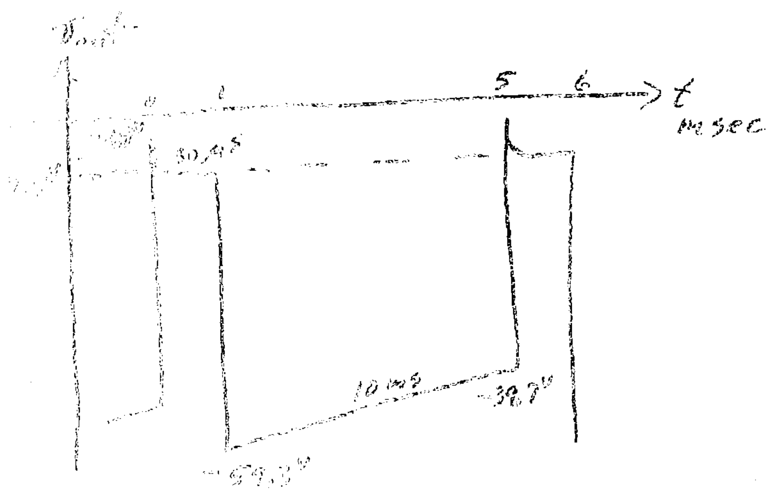
$$\begin{aligned} v_c(5^-) = v_c(0^-) &= -25 - 20i - V_2' \\ &= -25 - \frac{V_2'}{10^K} 20 - V_2' \\ &= -(25 + [1 + .002] V_2') \\ &= -(25 + 1.002\,(-39.7)) = \underline{\underline{14.8^V}} \end{aligned}$$

at $t = 5^+$ (or 0^+) (forward diode)

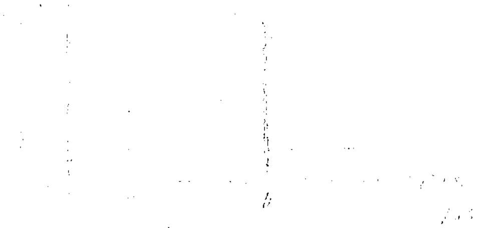
$v_c(0^+) = v_c(5^+) = v_c(5^-) = 14.8^V$

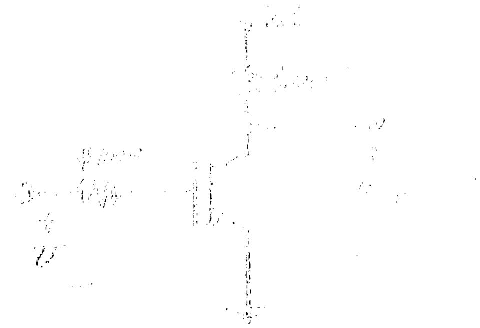
$$v_o(5^+) = V_1 = \frac{(25 - 14.8)\frac{1}{20} - 9.4\frac{1}{10}}{\frac{1}{20} + \frac{1}{10} + \frac{1}{10^K}}$$

$$= \frac{10.2 - 9.4 \times 2}{1 + 2 + \frac{20}{10^K}} = \underline{\underline{-2.9^V}}$$



… Section 3-7 of …





$\tau_p = 100\,pF \cdot 400\,\Omega = 40$ nsec

$v_b(t) = 1.8 - (-3+1.8)\,e^{-t/\tau_p}$ (text 3-58)

$= 0.7^V$ at turn-on

solving for t_D

$t_D = \tau_p \ln \frac{1.8-.3}{1.8-.7} = 40 \ln\frac{1.5}{1.1} = \underline{12.3 \text{ nsec}}$

$V_{CE,sat} = \ldots$

$V_{BE,sat} = 0.\ldots$

$\tau_B = 100$ nsec

$\beta = 50$

$C_{\ldots} = 100\,pF$

$V_{BE} = \ldots$

$I_{b1} = \ldots = \ldots = 2.25$ mA

$I_{b,sat} = \frac{1}{50}\left(\ldots\right) = 0.55$ mA

$t_{on} = \tau_B \ln \frac{I_{b1}}{I_{b1}-I_{b,sat}} = 100 \ln\frac{2.25}{2.25-.55} = \underline{22.3 \text{ nsec}}$ (text …)

$I_{b2} = \ldots = -1$ mA

$Q_B(t_S) = Q_{B,sat} = I_{b,sat}\,\tau_B = I_{b2}\tau_B - (I_{b2}\tau_B - I_{b1}\tau_B)\,e^{-t_S/\tau_B}$ (text …)

solving for t_S

$t_S = \tau_B \ln \frac{I_{b2}-I_{b1}}{I_{b2}-I_{b,sat}} = 100 \ln\frac{-1-2.25}{-1-.55} = 100 \ln\frac{3.25}{1.55} = \underline{88 \text{ nsec}}$

finally

$t_{off} = \tau_B \ln \frac{I_{b2}-I_{b,sat}}{I_{b2}} = 100 \ln\frac{-1-.55}{-1} = \underline{43.8 \text{ nsec}}$

To reduce the storage time t_S set $RC = \tau_B$ or

$C = \frac{100 \text{ nsec}}{400} = \underline{250\,pF}$

[illegible] circuit is shown in Figure 2.

(a) What is the quiescent value of $V_{E1} - V_{E2}$?

(b) What is the quiescent value of $V_{E2} - V_{E3}$ if R is very large?

(c) What is the quiescent value of V_{E3} if R is very large?

(d) If R is reduced in value, at what value of R will the answer to part (b) start to change?

(e) If R is reduced in value, at what value of R will the answer to part (c) start to change?

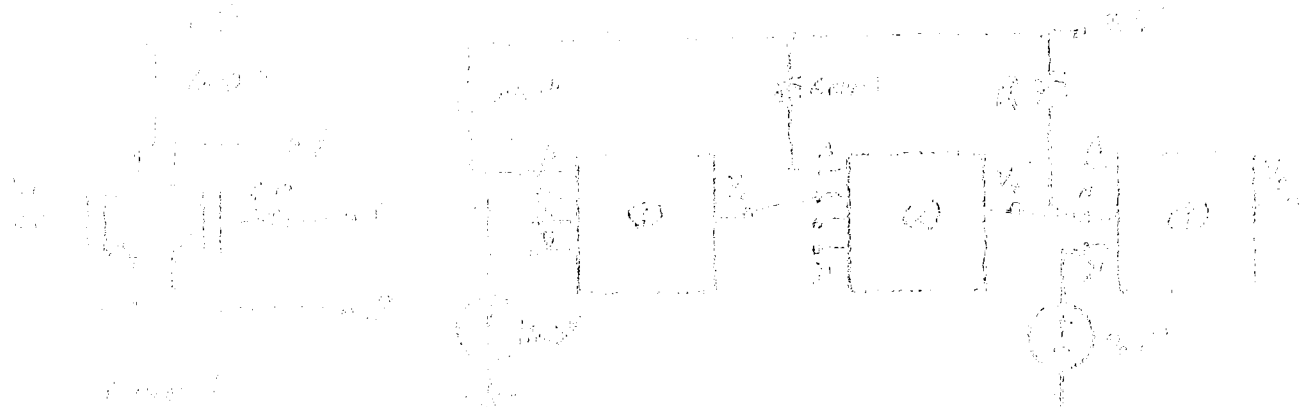
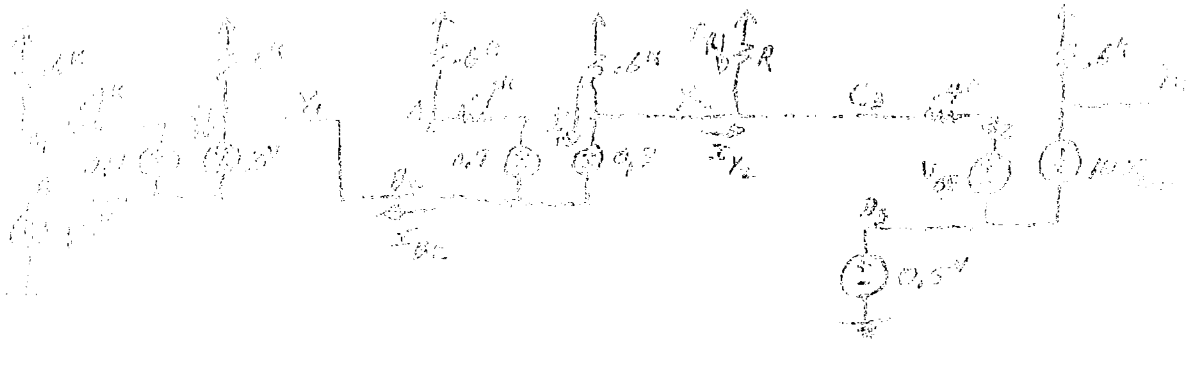


Figure 2

Solution:

From inputs on bases of stages ① and ②, assume that [illegible] are conducting and [illegible]. For R very large assume that [illegible] is cut off. From the circuit model below it is seen that these assumptions are valid.



Verification of assumptions: For $I_{Y_2} = 0$, the collector current in stage ② is

(1) $$I_2 = \frac{3.6 - .3 - .3 - .3}{.6^K} = \frac{2.7}{.6^K} = 4.5\ mA$$

(2) $$I_{A_2} = \frac{3.6 - .7 - .3 - .3}{.6^K + .4^K} = \frac{2.3}{1^K} = 2.3\ mA$$

(3) and $I_2 < \beta I_{A_2} = 10 \times 2.3 = 23\ mA$ is satisfied.

(4) $$I_{B2} = I_2 + I_{A_2} = 6.8\ mA$$

(5) $$I_1 = \frac{3.6 - .3 - .3}{.6^K} + I_{B2} = \frac{3}{.6^K} + 6.8 = 11.8\ mA$$

(6) $$I_{A1} = \frac{3.6 - .7 - .3}{.6^K + .4^K} = \frac{2.6}{1^K} = 2.6\ mA$$

(7) and $I_1 < \beta I_{A1} = 10 \times 2.6 = 26\ mA$ is satisfied

Thus,
a) $V_{Y_1} = 0.3 + 0.3 = \underline{\underline{0.6}}^V$

b) $V_{Y_2} = 0.6 + 0.3 = \underline{\underline{0.9}}^V$

The voltage between C_3 and D_3 is

$$V_{CD_3} = V_{Y_2} - 0.5 = .9 - .5 = 0.4 < V_{BE}(\text{cut-off}) = 0.$$

so that the stage ③ is cut-off and

c) $V_{Y3} = \underline{\underline{3.6}}^V$

To answer part (d) V_{Y_2} will start to change if either stage ② or stage ① comes out of cut-off. ~~[illegible]~~ From equations (7) & (5), above,

$$I_{B2} \leq 26 - 5 = 21\ mA$$

From equations (3) & (1) ~~[illegible]~~ with the inclusion of the current I_R

$$I_R \leq 23 - 4.5 = 18.5\ mA$$

Hence, $I_{B2} = I_{A2} + I_{2A} \overset{+I_R}{=} 2.3 + 4.5 + I_R$

$= 6.8 + I_R$

and from equation (12)

$I_R \le 21 - 6.8 = 14.2 \text{ mA}$

Selecting the smaller of equations (15) and (13) yields $I_R \le 14.2 \text{ mA}$ from which

(d) $R = \frac{3.6 - 0.9}{14.2 \text{ mA}} = \frac{2.7}{14.2}^{K} = \underline{190\ \Omega}$

The third stage will come out of cut-off when $V_{CD3} \ge 0.5^V$ or when $V_{Y2} = 0.5 + 0.5 = 1.0^V$

From the previous analysis both stage ① and stage ② will be in the active regions with $V_{BE} = 0.6^V$ and collector currents equal to β times the base currents.

$I_{A1} = \frac{3.6 - .6 - .3}{1^K} = 2.7 \text{ mA}$

$10\, I_{A1} = 27 \text{ mA} = \frac{3.6 - V_{Y1}}{.6^K} + (1+\beta)\, I_{A2}$

$= \frac{3.6 - V_{Y1}}{.6^K} + 11\, \frac{3.6 - .6 - V_{Y1}}{1^K}$

Solving for V_{Y1}

$27 = 6 - \frac{V_{Y1}}{.6} + 33 - V_{Y1}\, 11$

$V_{Y1} = \frac{39 - 27}{11 + \frac{1}{.6}} = 0.95^V$

From which

$I_{A2} = \frac{3 - V_{Y1}}{1^K} = 2.05 \text{ mA}$

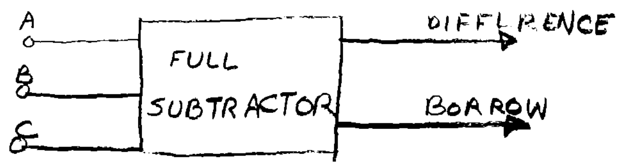
$I_R = 10\, I_{A2} - \frac{3.6 - 1}{.6^K} = 20.5 - 4.33 = 16.17 \text{ mA}$

e) $R = \frac{3.6 - 1}{I_R} = \frac{2.6}{16.2}^{K} = \underline{161\ \Omega}$

MARKS

16 / 10

4-2)



A - MINUEND ; B = SUBTRAHEND ; C = BORROW

A	B	C	D	B_o
0	0	0	0	0
1	0	0	1	0
0	1	0	1	1
1	1	0	0	0
0	0	1	1	1
1	0	1	0	0
0	1	1	0	1
1	1	1	1	1

DIFFERENCE = D_i

B \ A	1	0
1	0	1
0	1	0

BORROW = B_o

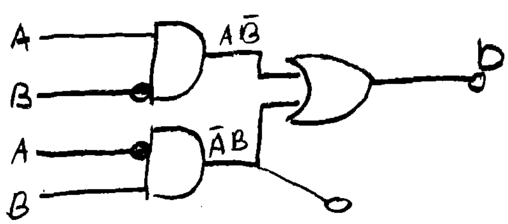
B \ A	1	0
1	0	1
0	0	0

$D = A\bar{B} + \bar{A}B = \overline{AB + \bar{A}\bar{B}}$

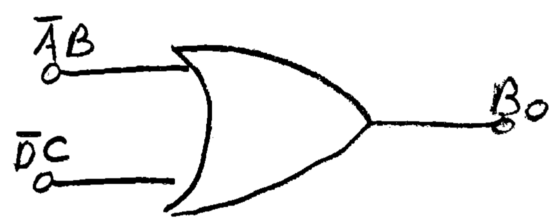
✓ $D_i = D\bar{C} + \bar{D}C = \overline{DC + \bar{D}\bar{C}}$

✓ $B_o = \bar{D}C + \bar{A}B$

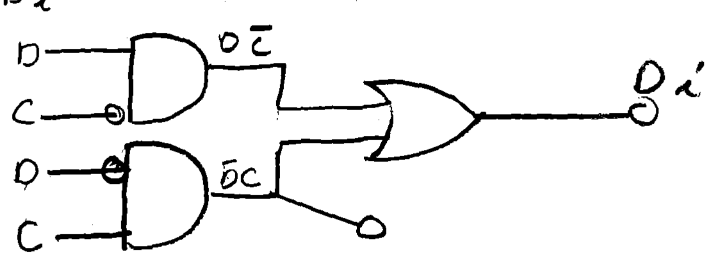
FOR D



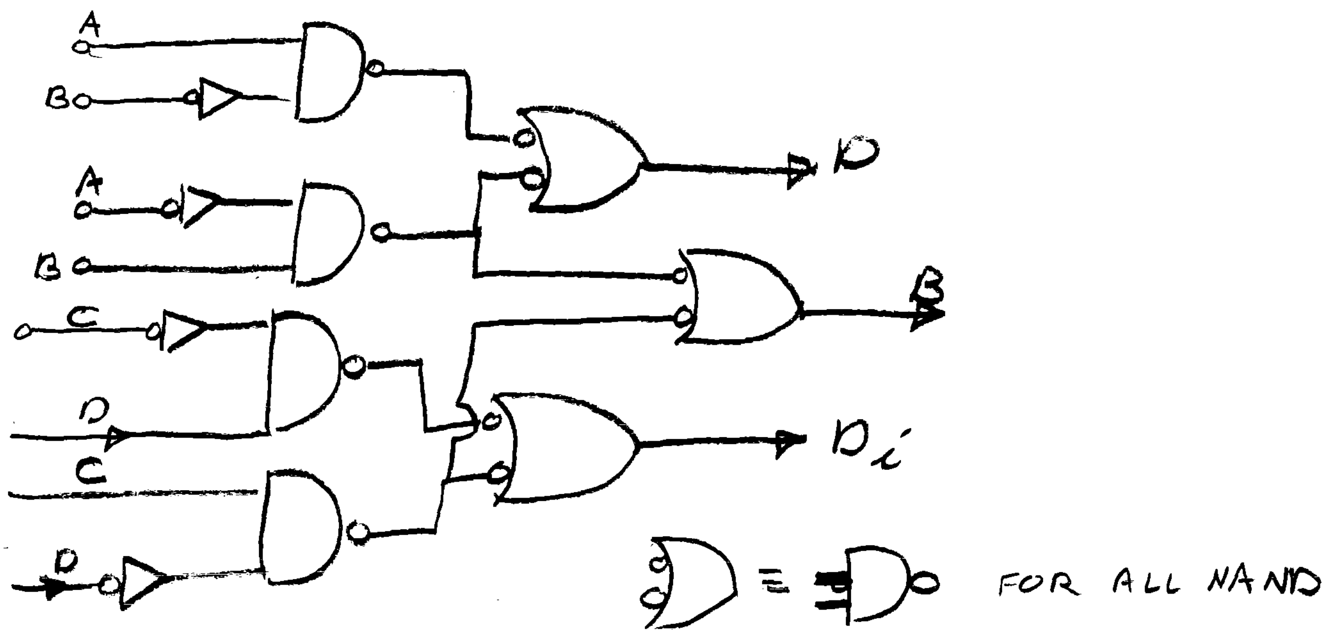
FOR B_o



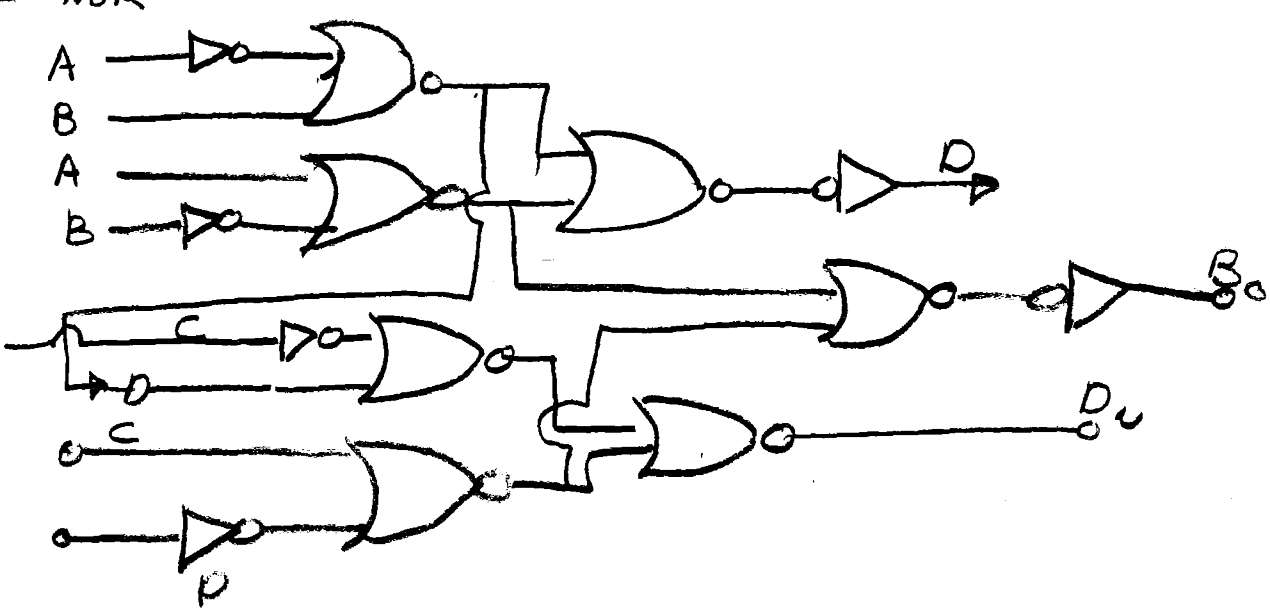
FOR D_i



CONVERTING TO NAND



FOR NOR

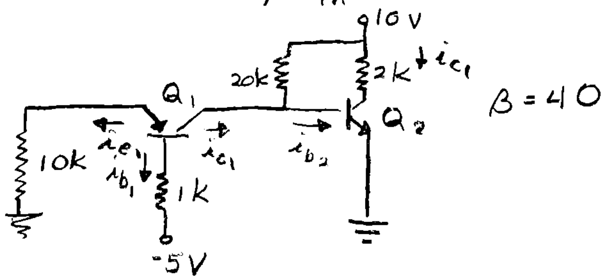


✓

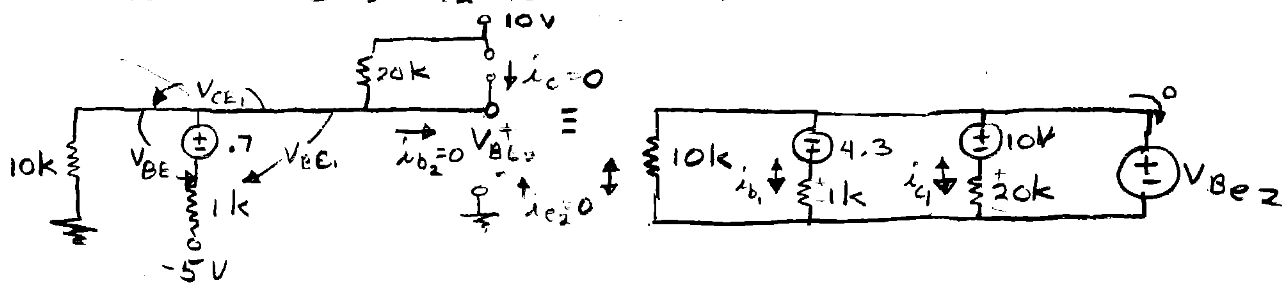
ROB MAR(?)

10/10

3·9) a) @ QUIESCENCE, $i_{in} = 0$ (PRO



EMITTER-BASE AND COLLECTOR BASE JUNCTIONS FORWARD BIASED, Q_2 IS CUT-OFF



$$\frac{V_{BE}}{10} + \frac{V_{BE} - 4.3}{1} + \frac{V_{BE} + 10}{20} = 0$$

$$V_{BE}(.1 + 1 + .05) = 4.3 + -.5 \Rightarrow V_{BE} = -3.3\,V$$

$$i_{b_1} = \frac{-V_{BE_2} - 4.3}{1} = \frac{+3.3 - 4.3}{1} = -1.0\ mA$$

$$i_{c_1} = \frac{10 - V_{BE_2}}{20} = \frac{10 + 3.3}{20} = .667\,mA$$

$$i_{e_1} = i_{b_1} + i_{c_1} = .333\ mA$$

QUIESCENT CONDITIONS

$i_{e_2} = i_{c_2} = i_{b_1} = 0$ } Q_1

$V_{BE_1} = .7\ V$ $V_{CE_1} = 0$

$i_{b_1} = -1\ mA$

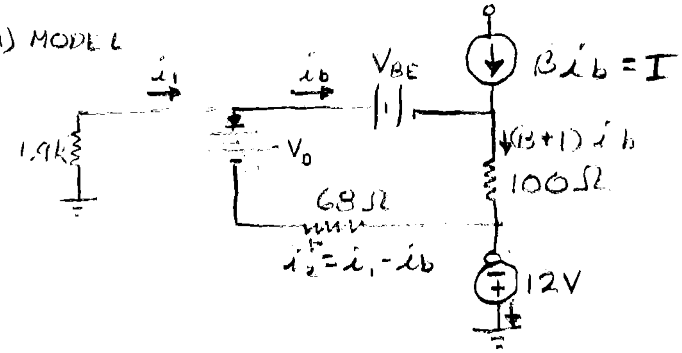
$i_{c_1} = .667\ mA$

$i_{e_1} = .333\ mA$ } Q_2

$V_{BE_2} = -3.3\ V$

$V_{CE_2} = 10\ V$ ✓

5.8) a) MODEL



$\beta = 50$
$V_{BE} = V_D = .75$

4/10

$12 = 1.9k\,i_1 + V_{BE} + 10^2(\beta+1)\,i_b \Rightarrow i_1 = (11.25 - 51\times10^2 i_b)/1.9k$

$12 = 1.9k\,i_1 + V_{BE} + 68 i_1 - 68 i_b$

$11.25 = (1.9k + 68) i_1 - 68 i_b \Rightarrow i_1 = (11.25 + 68 i_b)/1.968k$

$\therefore \quad \frac{11.25}{1.9k} - \frac{51\times10^2}{1.9k} i_b = \frac{11.25}{1968} + \frac{68}{1968} i_b$

$i_b\left(\frac{68}{1968} + \frac{5.1k}{1.9k}\right) = \frac{11.25}{1968} - \frac{11.25}{1.9k}$

$i_b(3.46\times10^{-3} + 2.68) = .573\times10^{-3} - .593\times10^{-3}$

$i_b = \frac{200\times10^{-6}}{2.68} = 44.6\,\mu A$

$\therefore I = \beta i_b$

$= 50(44.6) = 2.30\,mA$

b) FROM ABOVE:

$i_1 = (12 - V_{BE} + 68 i_b)/1968$

$i_1 = (12 - V_{BE} - 51\times10^2 i_b/1.9k$

$(12 - V_{BE} + 68 i_b)(1.9k) = (12 - V_{BE} - 51\times10^2 i_b)(1968)$

$(68)(1.9k) i_b + 1.9k(12 - V_{BE}) = -(51\times10^2)(1968) i_b + (1968)(12 - V_{BE})$

$i_b((68)(1.9k) + (51\times10^2)(1968)) = 68(12 - V_{BE})$

$\Rightarrow i_b = \frac{68(12 - V_{BE})}{((68)(1.9k) + (5.1\times10^3)(1968))} \simeq \frac{68(12 - V_{BE})}{(10.1\times10^6)}$

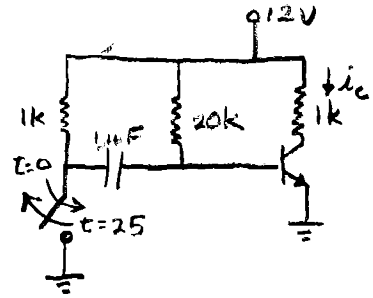
$\frac{\partial I}{\partial t}? = \frac{810 - 68 V_{BE}}{10^7} = 810\times10^{-7} - 68 V_{BE}\times10^{-7}$

FOR 100°C DROPS ABOVE & BELOW $V_{BE} = .75V$, @ $\Delta V_{BE} = 2.5\,mV/°C$

$742 < i_b < 776$ (PRETTY STABLE)

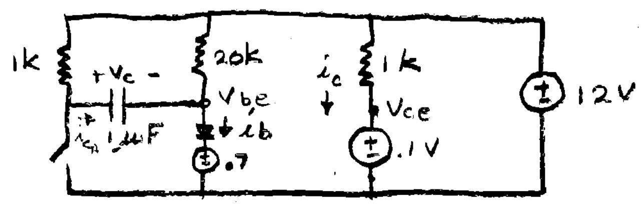
c) $S_e = \frac{dI}{dV_{BE}} = \frac{d(\beta i_b)}{dV_{BE}} = 3.400\times10^{-3}$ ✓

3-21)



$V_{BE} = .7V$; $B = 30$; $I_e = 1\ mA$, $V_{CESAT} = 100mV$

10/10



$i_c(0^-) = \frac{12-.1}{1} = 11.9\ mA$

$V_{ce}(0^-) = .1\ V$

$V_{be}(0^-) = .7\ V$

$i_b(0^-) = \frac{12-.7}{20} = \frac{11.4}{20} = .57\ mA$

$V_c(0^-) = 11.3 \quad (i_{c_1} = 0)$

$V_c(0+) = 11.3V \Rightarrow V_{be}^{(0+)} = -11.3\ V \Rightarrow i_b(0+) = 0$; $i_c(0+) = 0\ (= B\, i_b(0+))$

$V_{be}(\infty) = 12V$ (W/O DIODE)

$\tau = RC = 20k\ 1\mu F = 20ms$

$\Rightarrow V_{be}(t) = 12 - 23.3\, e^{-t/20}$ UNTIL $V_{be} = .6\ V$

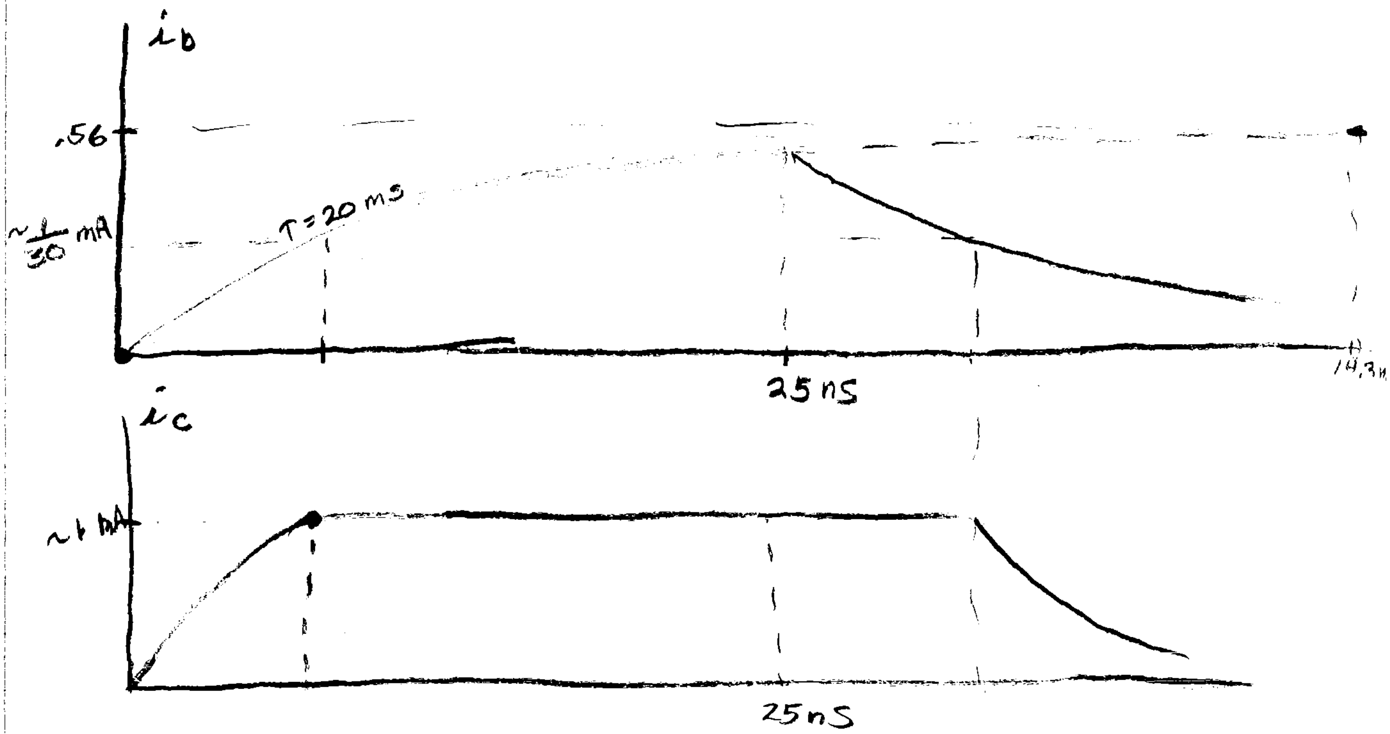
@ $t = t_1$, $V_{BE}(t_1) = .6 \Rightarrow t_1 = 20 \ln \frac{23.3}{11.4} = 14.3\ mS$

AT WHICH POINT DIODE WILL BE FORWARD BIASED

$i_b(t_1^+) = \frac{12-.7}{20k} = .56\ mA$

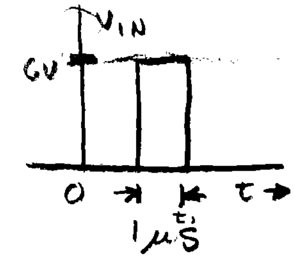
$i_c(t_1^+) = B\, i_b(t_1^+) = 17\ mA$

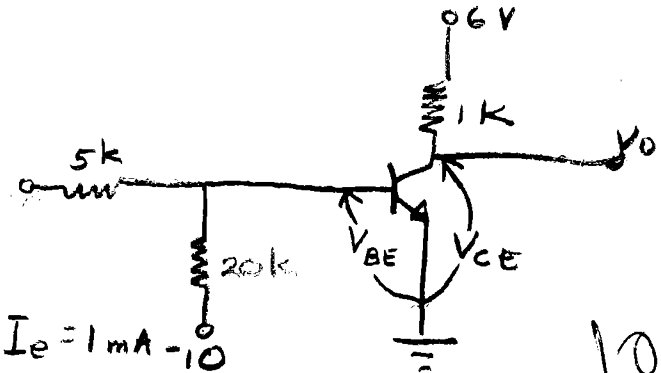
HOWEVER, TRANSISTOR BECOMES SATURATED @ $i_c \sim 1\ mA$



i_b
.56
$\sim\frac{1}{30}$ mA
$\tau = 20$ ms
25 ns
14.3
i_c
~1 mA
25 ns

3-25)





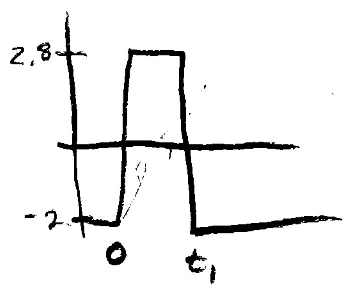
$\beta = 50$, $V_{BE} = .7V$; @ $I_e = 1mA$
$\tau_B = 10\,nS$, $C_D = 10pF$ @ $V_{BE} = -1V$

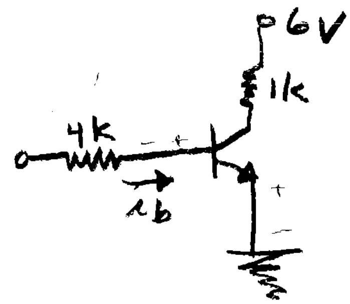
10/10

$5k \| 20k = \frac{100}{25} = 4k$

$V(0-) = \frac{5}{25}(-10) = -2V = V(t_1+)$

$V(0+ < t < t_1^-) = \frac{6/5 + 10/20}{1/5 + 1/20} = 2.8V$





$V_{be}(0-) = -2V$, $i_b(0-) = 0$ (BE REVERSE BIASED)

FOR $0 < t < t_1$, $\tau_0 = 4k\, C_0 = 40nS$

$V_{be}(0^+) = -2$, $V_{be}(\infty) = 2.8$

$\Rightarrow V_{be} = 2.8 - (2.8 + 2)e^{-t/40}$

WILL FORWARD BIAS @ $V_{be} = .6V$ @ t_1

$t_1 = 20 \ln \frac{3}{2.2} = 31.2\,nS$

$t_1 = 31.2\,nS$

$I_{b1} = \frac{2.2}{4k} = .55\,mA$

$I_{bSAT} = \frac{I_{cSAT}}{\beta} = \frac{1}{50}(5.7) = .114\,mA$

$t_{ON} = \tau_B \ln \frac{I_{b1}}{I_{b1} - I_{bSAT}} = 10 \ln 1.26 = 2.1\,nS$

$t_2 = t_1 + t_{ON} = 33.5\,nS$

$t_s = \tau_B \ln (I_{b2} - I_{b1}) / (I_{b2} - I_{bSAT})$

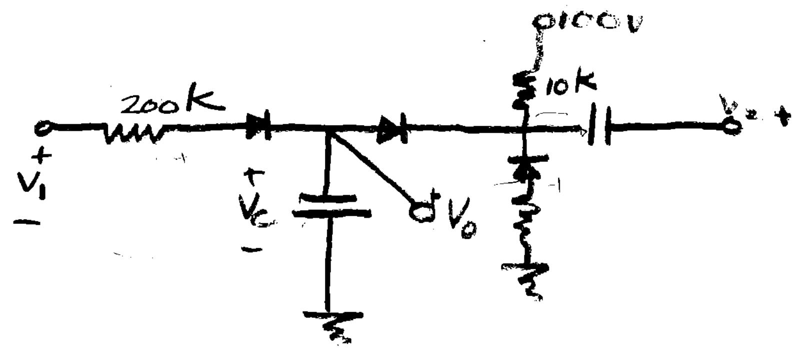
$I_{b2} = -2.6/4k = -.65\,mA \Rightarrow t_s = \tau_B \ln 1.575 = 4.5\,nS$

$t_{OFF} = \tau_B \ln \frac{I_{b2} - I_{bSAT}}{I_{b2}} = 10 \ln 1.17 = 1.6\,\mu S$

$t_3 = 1\mu S + t_s = 1\mu S$

$t_4 = t_3 + t_{OFF} = 6.1\,\mu S$

2-12)

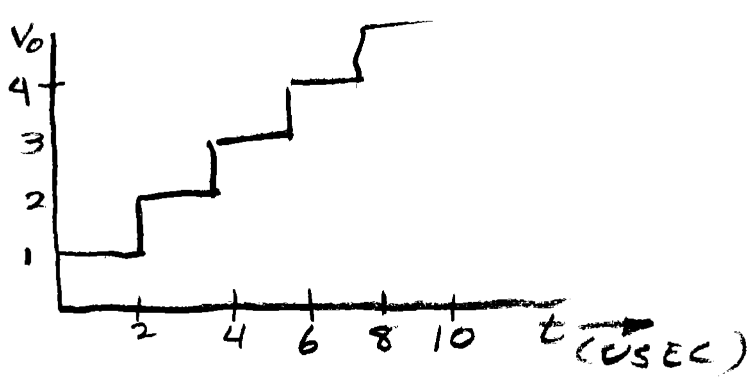


$V_c = V_o$

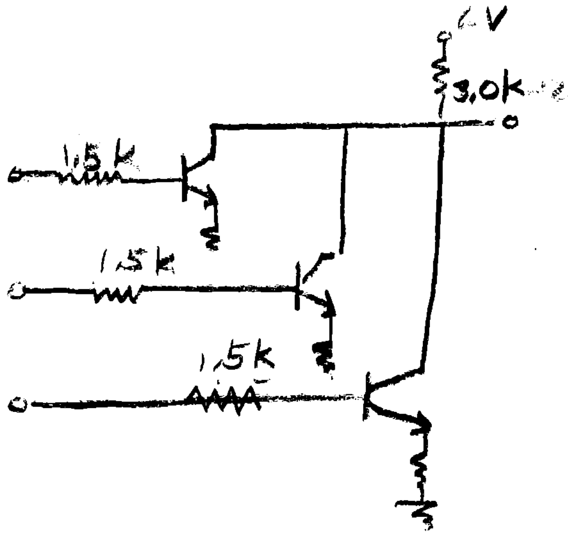
V_o WILL CHARGE IN PROPORTION TO NUMBER OF PULSES BECAUSE ~~VOLTAGE~~ POSITIVE VOLTAGE CHARGES ON THE CAPACITOR ARE KEPT FROM DRAINING AWAY 'CAUSE OF THE DIODE BIAS. A NEGATIVE PULSE OF SUFFICIENT AMPLITUDE @ V_2 WILL FORWARD BIAS DIODES, ALLOWING A PATH O'ER WHICH THE DIODE MAY DRAIN.

b) FOR $\Delta V_0 = 1V$, $V_1 = 100V$, $T = 2\mu SEC$

$$C = \frac{\Delta Q}{\Delta V_s} = (99.3/.2)(2\times10^{-6}) = 993\,pF$$



4-10)



$\beta = 30$

$V_{ce_{SAT}} = 150\,mV$

$r_{sc} = 50\,\Omega$

$V_{BE} = .7V$

5/10

a) WITH NO LOAD

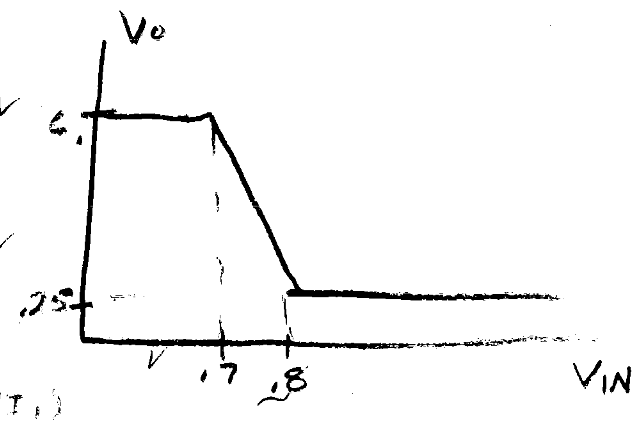
$V_{IN_L} = V_{BE} = .7V$

$I_{CSAT} = \frac{6-.15}{3.05k} = 1.9\,mA$

$V_{IN_H} = V_{BE} + \frac{I_{CSAT}\,R_1}{\beta}$

$= .7 + \frac{1.75 \times 1.5}{30} = .8V$

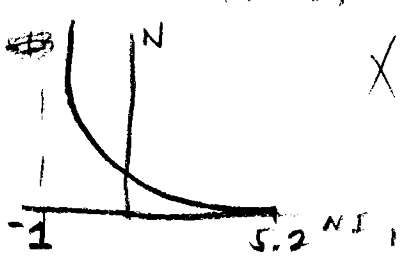
$I_{b,SAT} = \frac{1.90}{30} = 65\,\mu A$



b) $N = \frac{R_1 (V_{CC} - V_{BE} - R_1 I_{bSAT} - NI_1)}{R_2 (R_1 I_{bSAT} + NI_1)}$

$= \frac{1.5}{3} \cdot \frac{6 - .7 - .15 + .065 - NI_1}{.098 + NI_1}$

$\approx \frac{1}{2} \cdot \frac{5.2 - NI_1}{.1 + NI_1}$



X $N = 1$ or 2

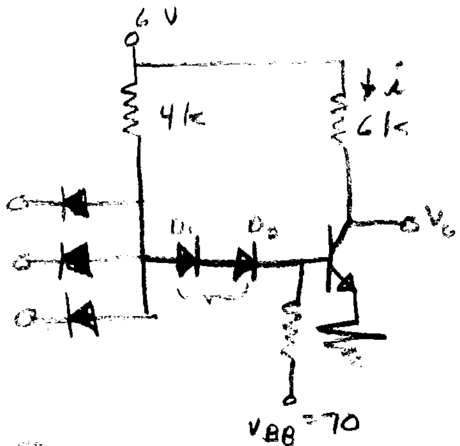
c) WITH ALL 3 INPUTS

$P_o = 3 \frac{(6-.7)}{(3+1.5)} \left(\frac{6-.7}{3+1.5} 3 + .7\right) + 5.85 \times 2 = 26.5\,mW$

X

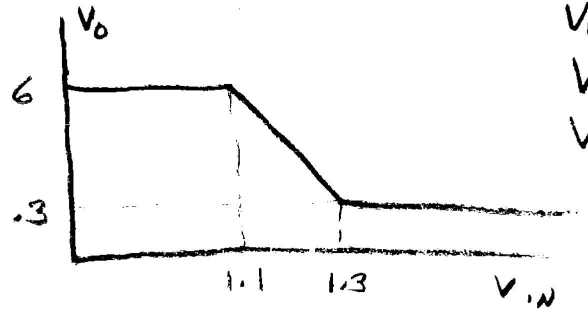
0/10

4.8)



$\beta = 50$, $V_D = .6$, $V_{BES} = .7$
$V_{BEA} = .6$, $V_{BEO} = .5$
$V_{CES} = .5$ $V_{CESAT} = .3$

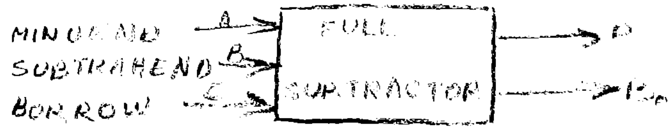
(a) $V_{IN} = 0$, D_1 & D_2 REVERSE BIASED $\Rightarrow i \sim 0 \Rightarrow V_o = V_{CC} = 6V$



$V_{INL} = 2V_D - V_D + V_{BEO} = 1.1$
$V_{INH} = 2V_D - V_D + V_{BE} = 1.3$
$V_{O_{LOW}} = V_{CESAT} = .3\ V$

b) (ARG!)

4-2)



(HI LEVEL LOGIC

$$\text{DIFFER} = (A\bar{B} + \bar{A}B)\bar{C} + (AB + \bar{A}\bar{B})C$$

C	A	B	D	B_o
0	0	0	0	0
0	1	0	1	0
0	0	1	1	1
0	1	1	0	0
1	0	0	1	1
1	1	0	0	0
1	0	1	0	1
1	1	1	1	1

D

B \ A	1	0
1	0	1
0	1	0

B_o

B \ A	1	0
1	0	1
0	0	0

$$D = D\bar{C} + \bar{D}C = \overline{DC + \overline{DC}}$$

$$B_o = \bar{D}C + \bar{A}B$$

BOB MARKS

(4L) 21/50

[illegible] Digital Electronics
Final Examination

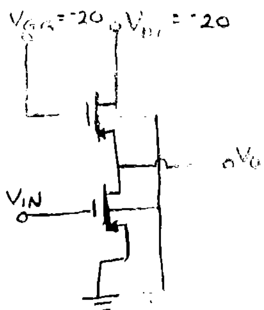
4 Hours

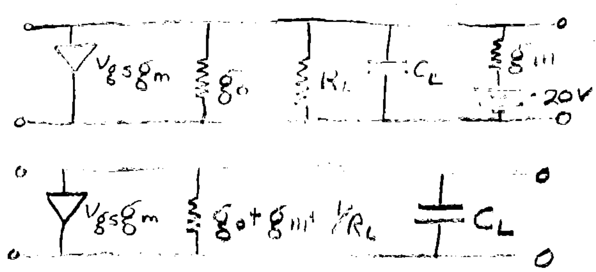
Open books and notes

Nov. [illegible], 1971

1. In problem 5-18 it was found that the response time was too slow.
   a) Which aspect ratio (load or driver) must be changed to significantly improve the response and by how much should it be changed to spped up the response by a factor of 10?

   b) Should the aspect ratio of the other transistor be changed also? Why of why not?





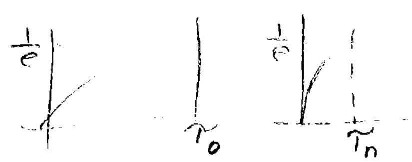
$C_L = 10pF$
$R_L = 25M\Omega$

~~TYPICALLY $r_o = 20K$; $g_m = 5mA/V$~~
~~$A = -\frac{g_{mA}}{g_{mL}}$~~

$\tau = \frac{C}{K_L|V_{DD}-V_T|}$ ⇒ INCREASING K_L (LOAD ASPECT RATIO), DECREASES τ YIELDING QUICKER SWITCHING TIME.

NOW: $V_o(\text{"0"}) = \frac{(V_{DD}-V_T)^2}{2K_r^2(V_{DD}-2T)}$ ⇒ $K_r = \sqrt{K_A/K_L}$, SO INCREASING K_L DECREASES STAGE GAIN, AND THUS INCREASES $V(\text{"0"})$. K_A SHOULD ALSO BE INCREASED TO BRING LOGIC LEVEL BACK ~~UP~~ down

$\tau_n = 10\tau_0$



∴ TO INCREASE RESPONSE TIME BY 10, THE LOAD ASPECT RATIO SHOULD BE ~~REDUCED~~ BY A FACTOR OF 10 increased!

8

[illegible] 4-2 a half-subtracter was determined to be a [illegible]. The equation of the half-subtracter is

$$\text{Difference} = A\overline{B} + \overline{A}B$$

$$\text{Borrow} = \overline{A}B$$

a) Show the schematic of a MOS with MOS load (saturated) circuit for realizing the half-subtracter function. Use p-channel symbols with the substrate connected to ground. Assume that the A and the B inputs are available.

b) If an aspect ratio of 2 is used for the MOS load transistors, what equivalent aspect ratios should be used for the active (or driver) transistors in order that the effective voltage gain of each gate section is 3?

c) Show the proper aspect ratios of all of the active transistors in your circuit so that the effective aspect ratio determined in part b is obtained in each case (under worst-case conditions).

a) DIFFERENCE

B \ A	1	0
1	0	1
0	1	0

BORROW

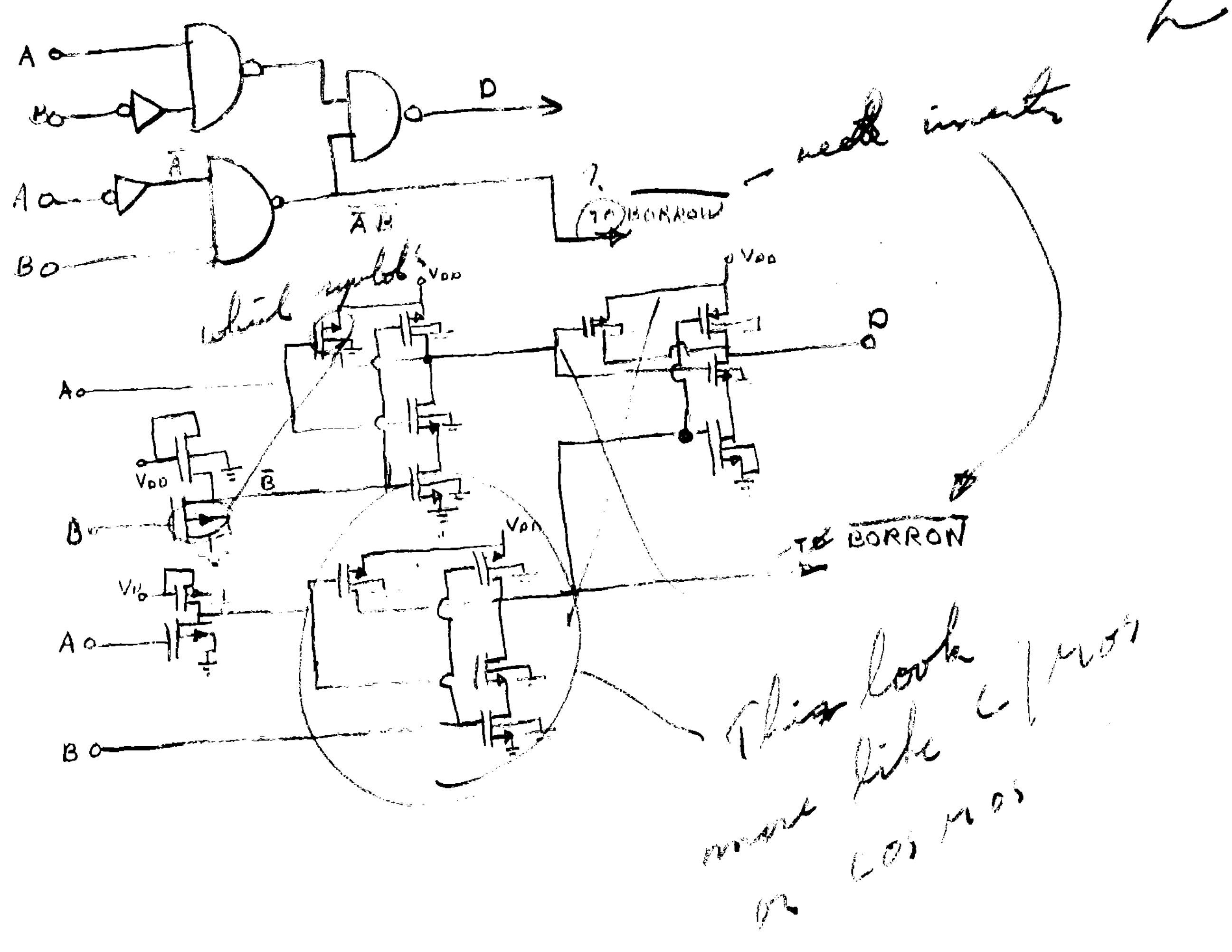
B \ A	1	0
1	0	1
0	0	0

b) $K_A^2 = \sqrt{K_L/K_{r_1}}$

$9 = \sqrt{2/K_r}$

$K_r = 2/81 = .0405$

2



1. In [illegible] a half-subtracter was determined to be a [illegible] device. The equation of the half-subtracter is

$$\text{Difference} = A\bar{B} + \bar{A}B$$

$$\text{Borrow} = \bar{A}B$$

a) Show the schematic of a MOS with MOS load (saturated) circuit for realizing the half-subtracter function. Use p-channel symbols with the substrate connected to ground. Assume that the A and the B inputs are available.

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a) DIFFERENCE

B \ A	1	0
1	0	1
0	1	0

BORROW

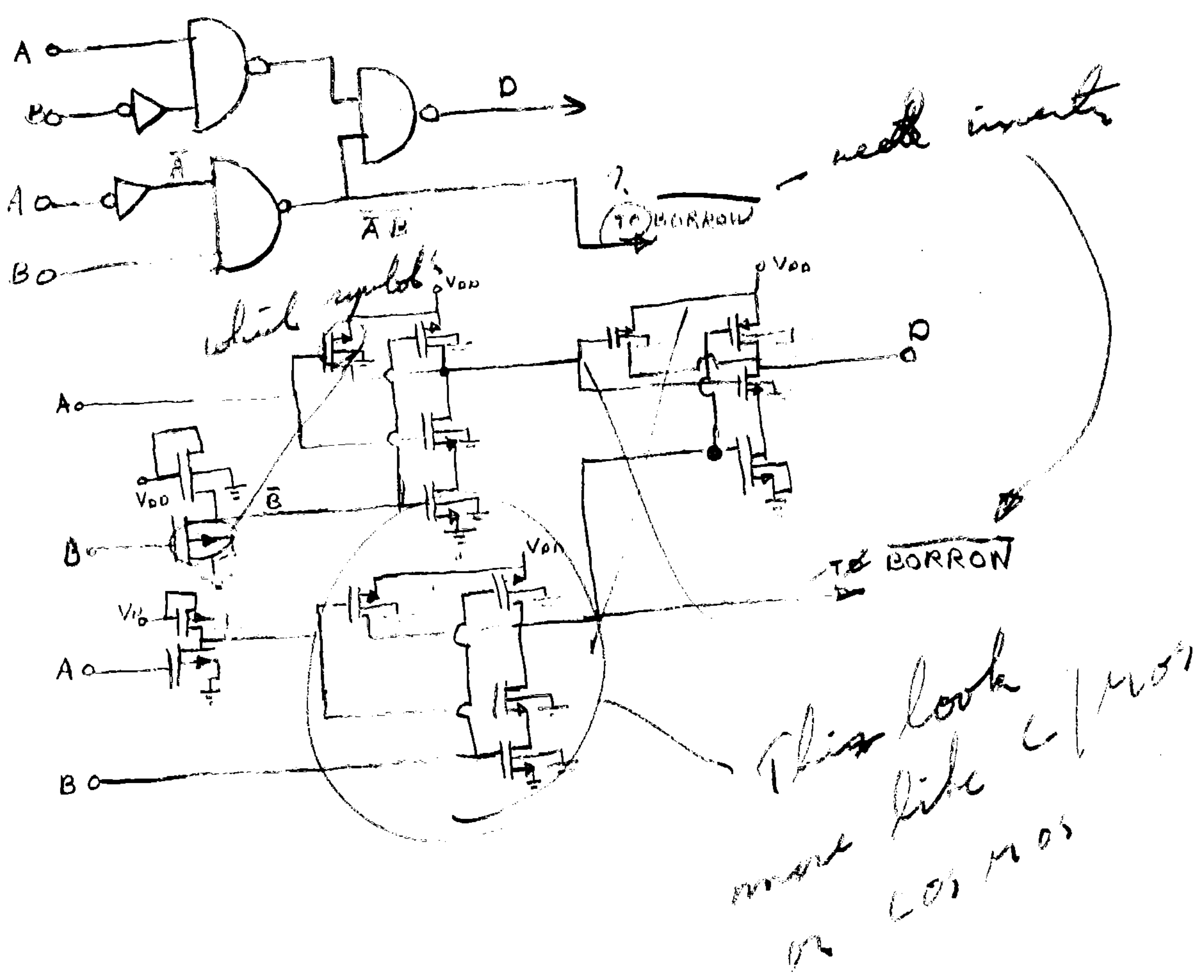
B \ A	1	0
1	0	1
0	0	0

b) $K_A^2 = \sqrt{K_L/K_{r_1}}$

$9 = \sqrt{2/K_r}$

$K_r = 2/81 = .0405$

2

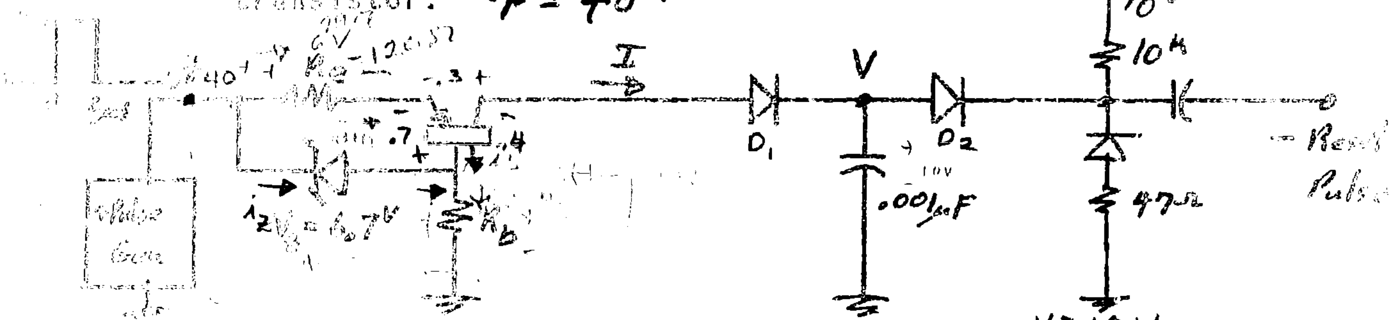


[illegible] A constant-current pulsing arrangement is shown (probably similar to the one which you constructed in the laboratory experiment).

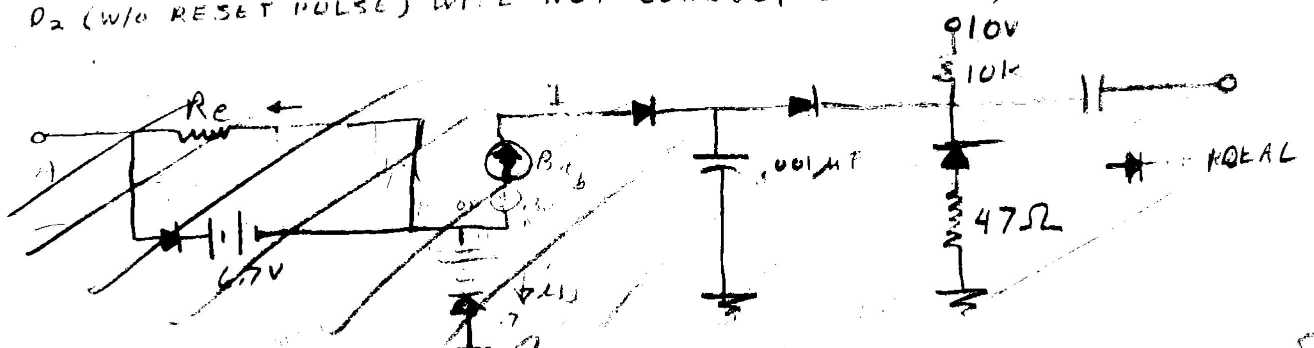
a) What is the minimum value of the positive-pulse amplitude V_p such that the voltage V can be "stair-stepped" up to a maximum of 10 Volts while the transistor continues to act as a constant-current source. Assume saturation values of $V_{CE,SAT}$ = 0.3 Volt and $V_{BE,SAT}$ = 0.7 Volt for the transistor.

b) What value of R_e should be used so that the current pulses, I, have an amplitude of 0.5 mA?

c) What value of R_b should be used so that the zenor diode current is 20 microamperes? Assume beta = 40 for the transistor. $V_p = 40^V$



D2 (W/O RESET PULSE) WILL NOT CONDUCT UNTIL V>10V



a) $V_p = 6 - .3 + 10 = 15.7V$?

b) $I = I_c = \beta I_b$; $I_{Re} = I_e = (\beta+1) I_b = I_e + \frac{I_c}{\beta} = .5\left(1+\frac{1}{\beta}\right) \doteq 50 mA$?

$V_{Re} = 6V \Rightarrow R_e = \frac{V_{Re}}{I_e} = \frac{6V}{50mA} = 120\Omega$

c) $i_z = .02$ $\quad i_e = \frac{29.3}{.120} \cong 250 mA$?

$\Rightarrow i_b = \frac{i_e}{41} = \frac{250}{41} = 6.1 mA$

$V_{R_b} = 33.3 V \Rightarrow i_b = \frac{33.3}{R_b}$

$\Rightarrow .02 + 6.1 = \frac{33.3}{R_b}$

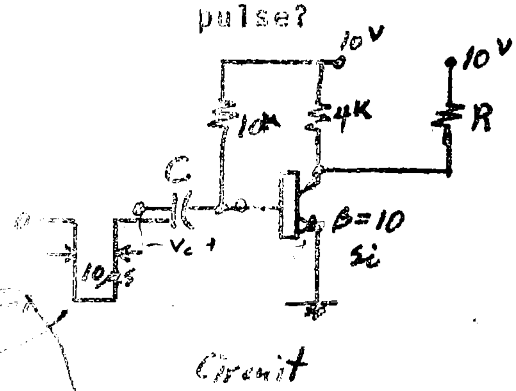
$\Rightarrow R_b = \frac{33.3}{6.12} = 5.45k$

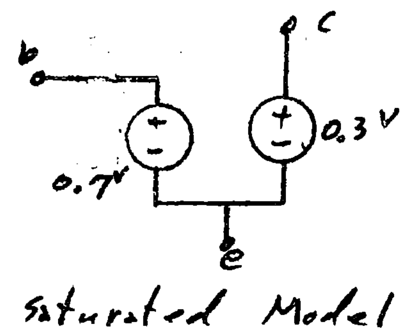
3

4. In the circuit shown below the transistor is to be saturated in the normal state and turned off during the 10-microsecond negative pulse. A saturated model for the transistor is shown, also.

a) What is the minimum value of R such that the transistor will be saturated?

b) If the input pulse is supplied by a pulse generator with an internal resistance of 0 ohms, what is the minimum value of C so that the transistor will remain in cut-off ($V_{be,cut\text{-}off}=0.5$) for the full 10 microseconds of the pulse?

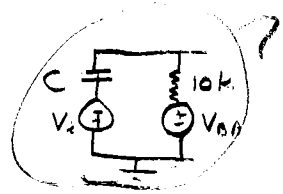


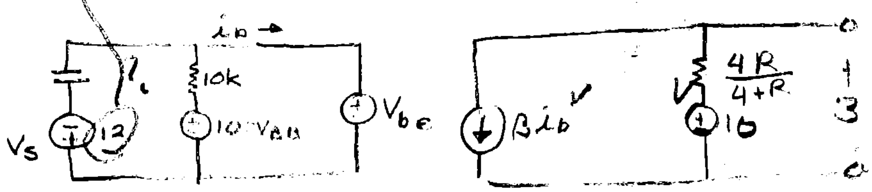


IN SATURATION $V_{CE} = .3V$ or $I_B > 0$

$V_{CC} = V_{4k} + V_{CE}$

$10 = I_c 4k + .3 \Rightarrow I_c = \frac{9.7}{4} = 2.425\ mA$





WILL SATURATE FOR V_{bo} POSITIVE, WHEN $V_s = 0$, IF $V_s < 0$ STARTS GOING ACTIVE

$V_{BB} = R_b I_b + V_o$

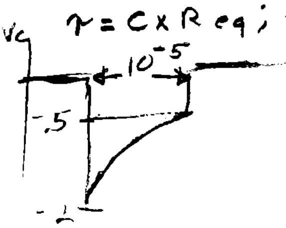
$10 = 10 I_b + .7 \Rightarrow I_b = \frac{9.3}{10} = .93\ mA \Rightarrow I_{c_{MAX}} = 10 I_b = 9.3\ mA$

NOW $10 - \left(\frac{4R}{4+R}\right) I_c = .3 \Rightarrow \frac{4R}{4+R} = 9.7/9.3 = 1.04$

$4R = 4(1.04) + 1.04R$

$R(4-1.04) = 4.16 \Rightarrow R = 4.15/2.96 = 1.42\ k$

$\tau = C \times R_{eq}$; $R_{eq} = 10 \| 4 + 1.92 = 2.86 + 1.92 = 4.78\ k$



$v(c) = -2e^{-t/\tau}$

@ t_1, $V_c = -.5 \Rightarrow .5 = 2e^{-t_1/\tau}$

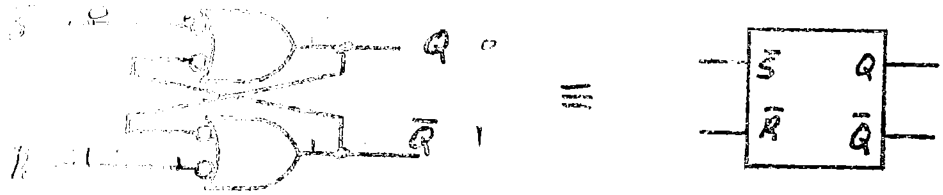
$\ln .25 = -t_1/\tau \Rightarrow \tau = \frac{-t_1}{\ln .25} = t_1 \ln 4 = (10^{-5}) \times 1.38$

$\therefore (4.78 \times 10^{4}) C = 1.38 \times 10^{-5}$

$\Rightarrow C = \frac{1.38}{.478} \times 10^{-9} = 2.9\ nF$

6

3. Two 2-input positive NANDs as shown on page 160 of Strauss are used to form an R-S flip-flop as shown. (drawn as low-level NORs).

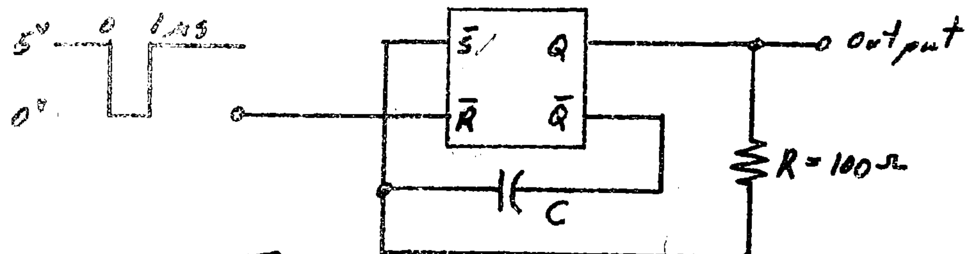


The circuit shown below might be called a "pulse stretcher". Note that a low level input on $\bar{R}$ causes $\bar{Q}$ to become high.

a) Explain the approximate operation of the circuit.

b) What value of C should be used if the output pulse length is to be 10 microseconds. (To simplify, assume switching occurs at 1.35 Volts on the curve of page 160, that $V_{ce,sat}$ = 0.3 Volt, and that V_{diode}=0.6 Volt.)

c) What is the maximum value of R which will allow the circuit to work properly?



2

$\bar{R}$	$\bar{S}$	R	S	Q	$\bar{Q}$
0	1	1	0	1	0
1	0	0	1	0	1
0	0	1	1	1	1
1	1	0	0	x	x

~~HIGH~~ LOW $\bar{R}$ (ASSUMED LOW $\bar{S}$) ⇒ HI $\bar{Q}$
$\bar{Q}$ FED THRU RC NETWORK TO OUTPUT, AND YIELDS HI LEVEL $\bar{S}$, IF $\bar{R}$ HAS BECOME LOW, Q THUS BECOMES, AND STAYS HIGH, FEEDING $\bar{S}$ THRU R,
(?)??