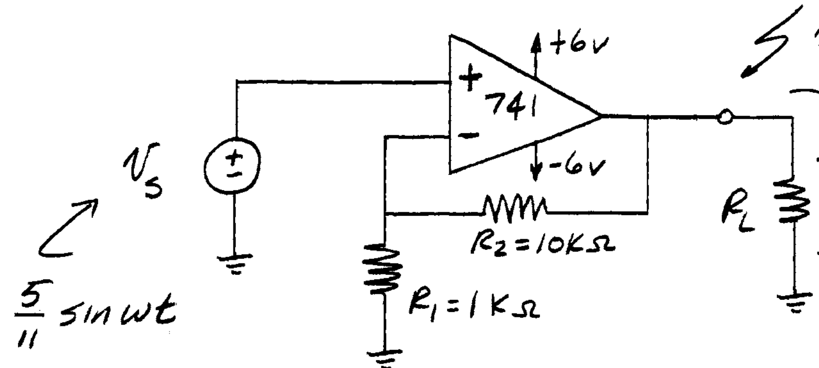
LAB XI : DORM ENTERTAINMENT SYSTEM

A) CURRENT LIMITATIONS OF AN OP-AMP

- IN ORDER TO PREVENT INTERNAL DAMAGE TO AN OP-AMP DUE TO SMALL RESISTIVE LOADS, A CURRENT LIMITER IS BUILT INTO ALMOST EVERY OP-AMP. FOR THE 741 OP-AMP, THIS LIMIT IS APPROXIMATELY ± 25 mA.

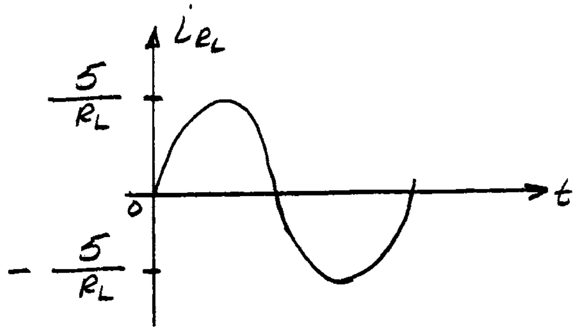
- FOR EXAMPLE - NON-INVERTING AMPLIFIER

WITH ±6V POWER SUPPLY V_O CAN SWING ≈ ±5V

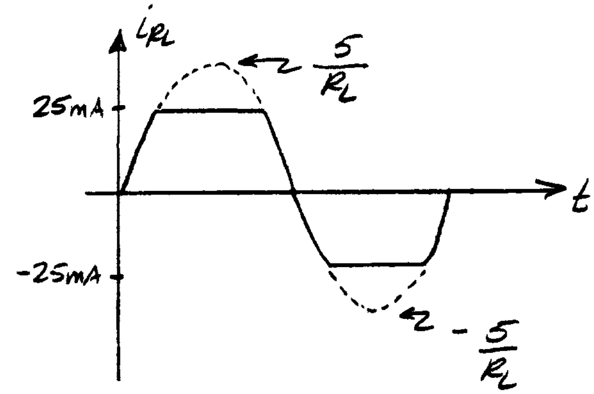


$$V_O = \left(1 + \frac{R_2}{R_1}\right)V_S = 11 V_S = 5 \sin \omega t$$

FOR $R_L > 200\Omega \left(= \frac{5V}{25mA}\right)$

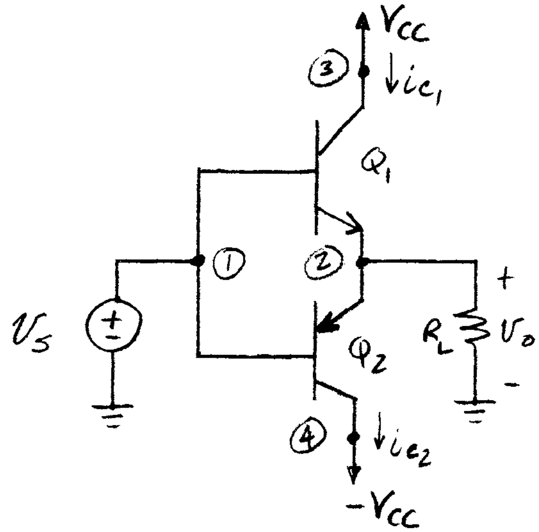


FOR $R_L < 200\Omega \left(= \frac{5V}{25mA}\right)$



∴ WE CAN'T USE THIS WITH AN 8Ω OR 4Ω SPEAKER.

B) Complementary Pair Power Booster - Class B



Note: When the base-emitter of Q_1 is forward-biased, the emitter-base of Q_2 is reverse-biased and vice-versa.

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COMPLEMENTARY PAIR
VS 1 0  SIN (0 6 1K)
RL 2 0 8
Vcc+ 3 0 6
Vcc- 4 0 -6
Q1 3 1 2 TIP31
Q2 4 1 2 TIP32
.model TIP31   NPN(Is=2.447p Xti=3 Eg=1.11 Vaf=100 Bf=208.2 Ise=70.69p
+               Ne=1.565 Ikf=.9743 Nk=.6134 Xtb=1.5 Br=12.59 Isc=11.68n
+               Nc=1.835 Ikr=3.86 Rc=.4685 Cjc=142p Mjc=.4353 Vjc=.75 Fc=.5
+               Cje=188.5p Mje=.4878 Vje=.75 Tr=194.2n Tf=19.85n Itf=164.1
+               Xtf=5.945 Vtf=10 Rb=.1)
.model TIP32   PNP(Is=51.23f Xti=3 Eg=1.11 Vaf=100 Bf=434.1 Ise=51.23f Ne=1.22
+               Ikf=.3883 Nk=.5544 Xtb=2.2 Br=55.47 Isc=51.23f Nc=1.205
+               Ikr=10.87 Rc=.3443 Cjc=136.9p Mjc=.3155 Vjc=.75 Fc=.5
+               Cje=179.9p Mje=.4294 Vje=.75 Tr=20.25n Tf=13.05n Itf=6.85
+               Xtf=1.573 Vtf=10 Rb=.1)
.DC VS -6 6 6M
.TRAN 10U 2M 0 10U
.PROBE
.END
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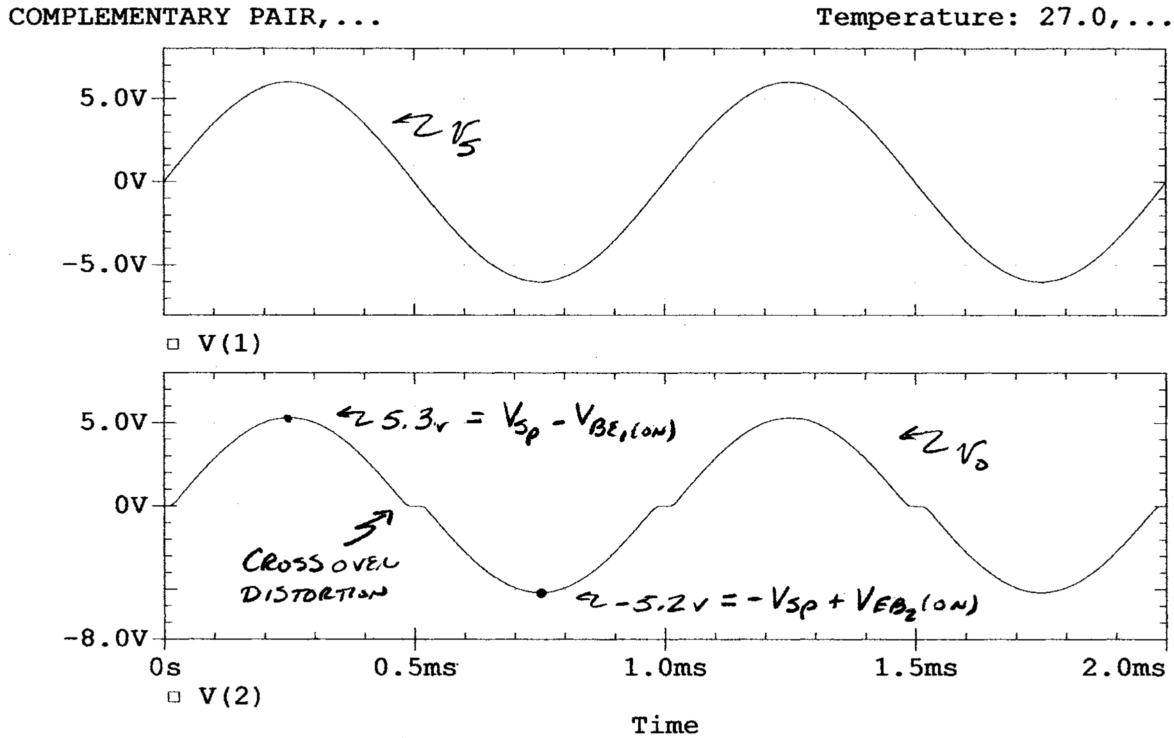
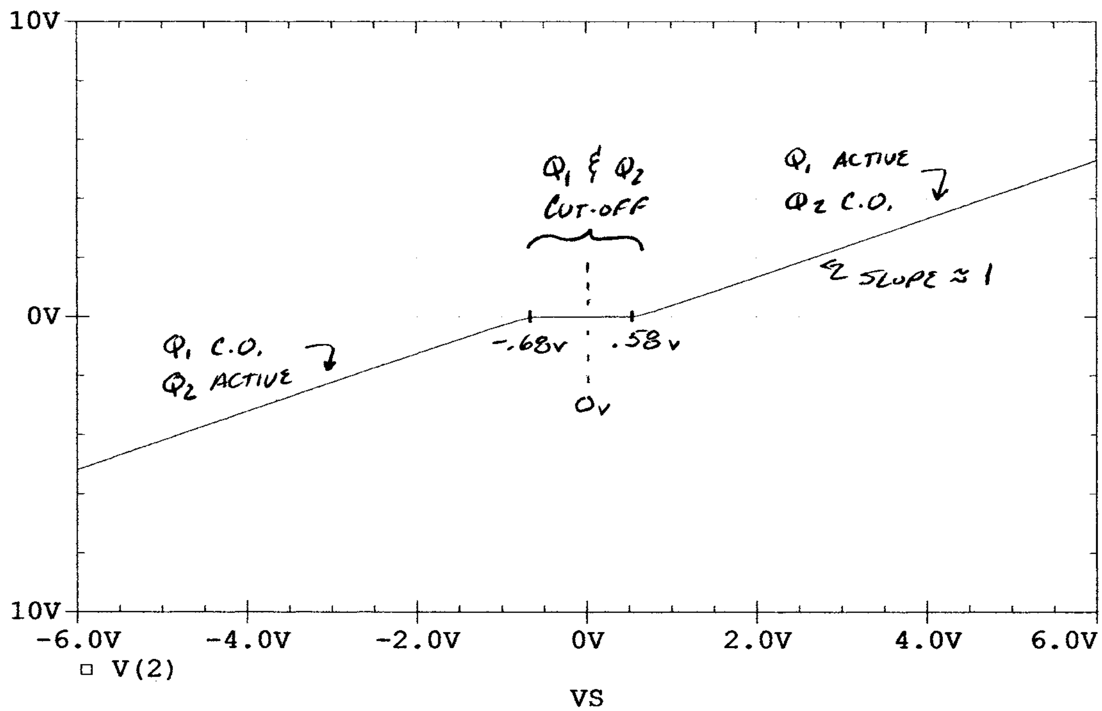
From the SPICE output:

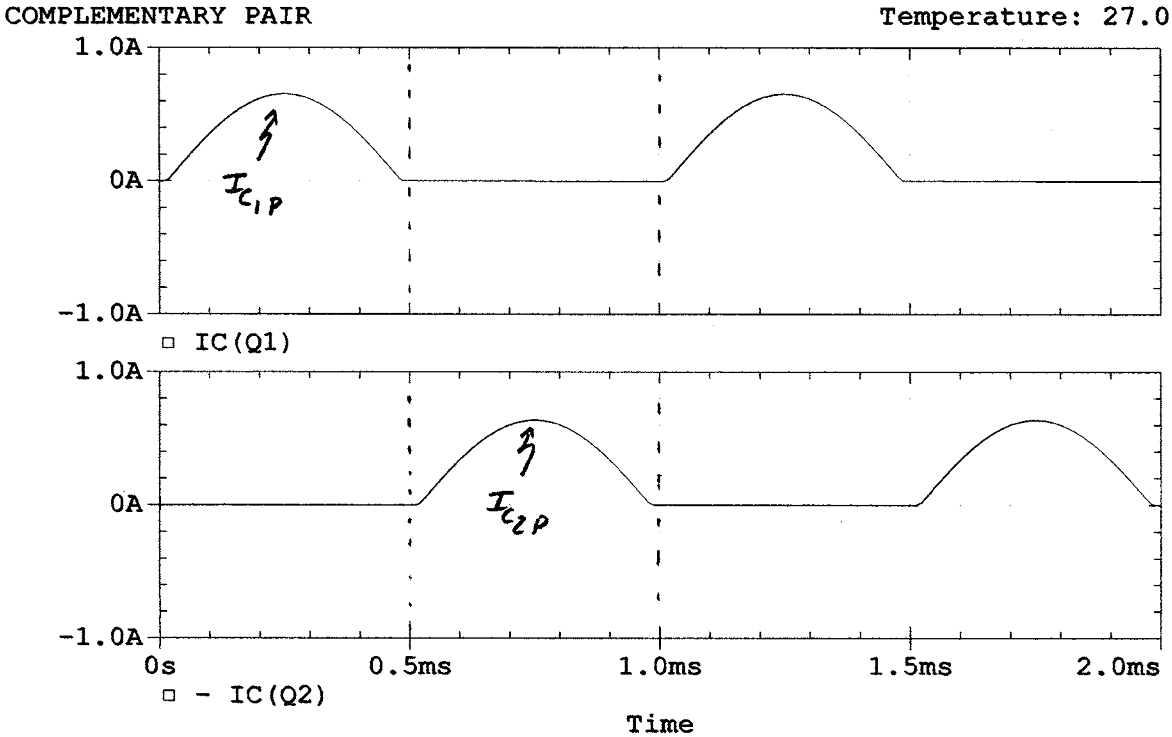
1) For $-V_{EB_2(on)} \leq V_S \leq V_{BE_1(on)}$, $V_O = 0$ (Q_1 & Q_2 cut-off)

2) For $V_S \geq V_{BE_1(on)}$, $V_O = -V_{BE_1(on)} + V_S$ (Q_1 active & Q_2 cut-off)

3) For $V_S \leq -V_{EB_2(on)}$, $V_O = V_{EB_2(on)} + V_S$ (Q_1 cut-off & Q_2 active)


COMPLEMENTARY PAIR,...
Temperature: 27.0,...
5.0V
0V
-5.0V
V(1)
V_S
5.0V
0V
-8.0V
0s
0.5ms
1.0ms
1.5ms
2.0ms
V(2)
Time
5.3v = V_Sp - V_BE1(ON)
V_o
CROSSOVER DISTORTION
-5.2v = -V_Sp + V_EB2(ON)


10V
0V
10V
-6.0V
-4.0V
-2.0V
0V
2.0V
4.0V
6.0V
V(2)
VS
Q1 & Q2 CUT-OFF
Q1 ACTIVE
Q2 C.O.
SLOPE ≈ 1
Q1 C.O.
Q2 ACTIVE
-.68v
.58v
0v



4) For $V_o > 0$, $i_L = i_{E_1} \cong i_{C_1}$

$$i_{C_1(AVE)} \triangleq I_{C_1} = \frac{1}{T}\int_0^T i_{C_1}(t)\,dt \cong \frac{1}{T}\left[\int_0^{T/2} I_{C_1P}\sin(\omega t)\,dt + \int_{T/2}^{T} 0\,dt\right]$$

$$= \frac{1}{T}\int_0^{T/2} I_{C_1P}\sin\left(\frac{2\pi}{T}t\right)dt = \frac{1}{T} I_{C_1P}\left[\frac{-T}{2\pi}\cos\left(\frac{2\pi}{T}t\right)\Big|_0^{T/2}\right]$$

$$= -\frac{1}{T} I_{C_1P}\frac{T}{2\pi}\left[\cos\left(\frac{2\pi}{T}\frac{T}{2}\right) - \cos(0)\right] = -\frac{I_{C_1P}}{2\pi}\left[-1 - 1\right]$$

$$= \frac{I_{C_1P}}{\pi}$$

5) For $V_o < 0$, $i_L = i_{E_2} \cong i_{C_2}$

$$i_{C_2(AVE)} \triangleq I_{C_2} \cong \frac{I_{C_2P}}{\pi}$$

6) AVE. POWER SUPPLIED $\triangleq P_{IN} \cong \frac{1}{T}\int_0^T (V_{CC}\, i_{C_1} + V_{CC}\, i_{C_2})\, dt$

$$= V_{CC}\left[\frac{1}{T}\int_0^T i_{C_1}\, dt + \frac{1}{T}\int_0^T i_{C_2}\, dt\right] = V_{CC}\left[\frac{I_{C1P}}{\pi} + \frac{I_{C2P}}{\pi}\right]$$

$$= \boxed{\frac{V_{CC}}{\pi}\left[I_{C_1P} + I_{C_2P}\right]}$$

7) $I_{C_1P} \cong \frac{V_{OP}}{R_L} = \frac{V_{SP} - V_{BE_1(ON)}}{R_L}$

$$I_{C2P} \cong -\frac{V_{OP}}{R_L} = -\left[\frac{-V_{SP} + V_{EB_2(ON)}}{R_L}\right] = \frac{V_{SP} - V_{EB_2(ON)}}{R_L}$$

$$\therefore P_{IN} = \frac{V_{CC}}{\pi}\left[\frac{V_{SP} - V_{BE_1(ON)}}{R_L} + \frac{V_{SP} - V_{EB_2(ON)}}{R_L}\right]$$

$$= \frac{V_{CC}}{\pi R_L}\left[2V_{SP} - V_{BE_1(ON)} - V_{EB_2(ON)}\right]$$

8) AVE POWER OUT $\triangleq P_{OUT} = \frac{1}{T}\int_0^T (V_o \cdot i_L)\, dt$

$$\triangleq V_{O(RMS)} \cdot i_{L(RMS)} = \frac{V_{O(RMS)}^2}{R_L}$$

$$\therefore P_{OUT} \cong \frac{\left(\frac{V_{O(P-P)}}{2\sqrt{2}}\right)^2}{R_L} = \frac{\left[\left(V_{SP} - V_{BE_1(ON)}\right) - \left(-V_{SP} + V_{EB_2(ON)}\right)\right]^2}{8R_L}$$

$$= \frac{\left[2V_{SP} - V_{BE_1(ON)} - V_{EB_2(ON)}\right]^2}{8R_L}$$

9) % EFFICIENCY $\triangleq \eta = \frac{P_{OUT}}{P_{IN}} \times 100\%$

$$\eta = \frac{\left[2V_{SP} - V_{BE_1(ON)} - V_{EB_2(ON)}\right]^2}{8R_L} \cdot \frac{\pi R_L}{V_{CC}\left[2V_{SP} - V_{BE_1(ON)} - V_{EB_2(ON)}\right]} \times 100\%$$

$$\therefore \boxed{\eta = \frac{2V_{Sp} - V_{BE_1(on)} - V_{EB_2(on)}}{V_{CC}} \frac{\pi}{8} \times 100\%}$$

– FOR OUR SPICE SIMULATION

$$\eta = \frac{2(6) - 0.7 - 0.8}{6} \frac{\pi}{8} \times 100\% = 68.7\%$$

– MAXIMUM THEORETICAL η

IF $2V_{Sp} >> V_{BE_1(on)}$ OR $V_{EB_2(on)}$ THEN

$$\eta = \frac{2\,V_{CC}}{V_{CC}} \frac{\pi}{8} \times 100\% = 78.5\%$$

– STANDBY POWER

IF $v_S = 0$, $V_O = 0$, $i_{C_1} = i_{C_2} = 0$, THUS $P_{IN} = 0$

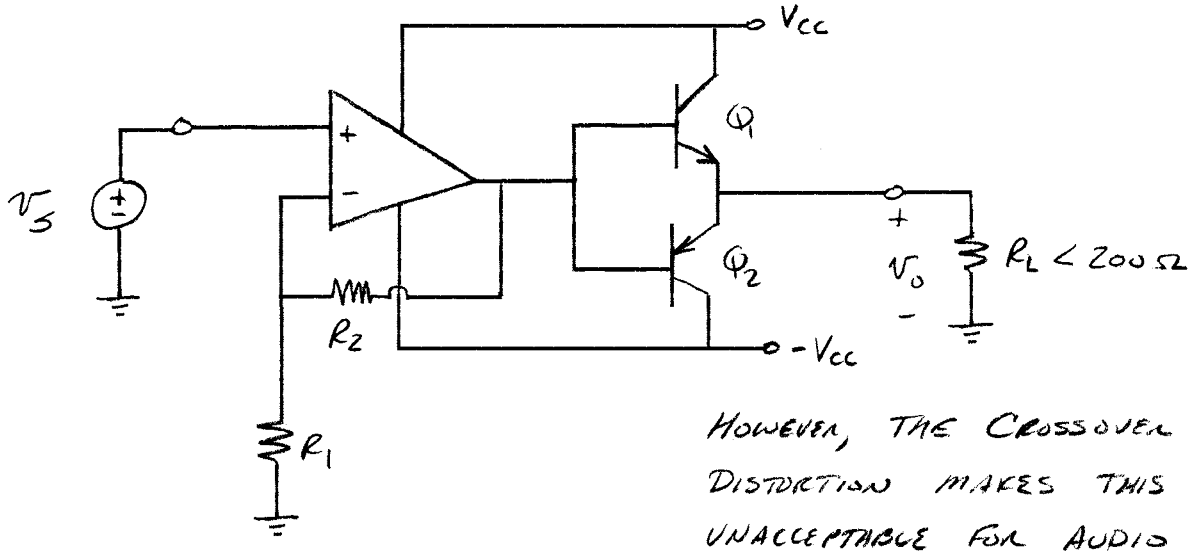
– OTHER EFFICIENCIES

IF $V_{Sp} = \frac{1}{2} V_{CC}$ THEN

$$\eta = \frac{2(3) - 0.7 - 0.8}{6} \frac{\pi}{8} \times 100\% = 29.4\%$$

NOTE: η VARIES WITH THE INPUT PEAK VALUE. HOWEVER, MAXIMUM η IS AT MAXIMUM INPUT.

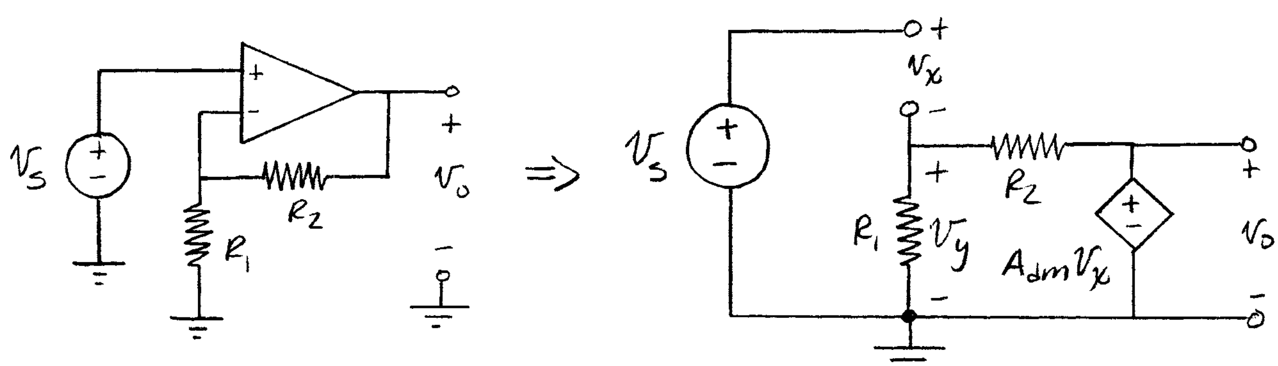
C) Power Boosting



However, the crossover distortion makes this unacceptable for audio circuits.

D) Crossover Reduction

1) For a non-inverting amplifier



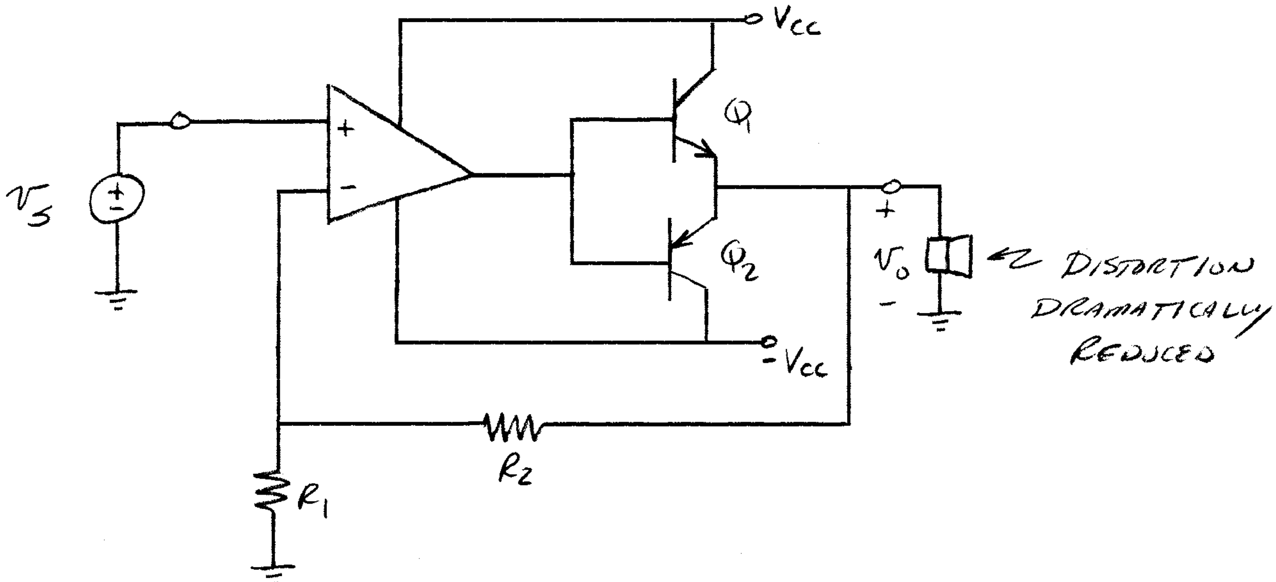
i) $v_y = v_o \dfrac{R_1}{R_1 + R_2}$

ii) $v_s = v_x + v_y = \dfrac{v_o}{A_{dm}} + v_o \dfrac{R_1}{R_1 + R_2}$

$$= v_o \left(\frac{1}{A_{dm}} + \frac{R_1}{R_1 + R_2} \right)$$

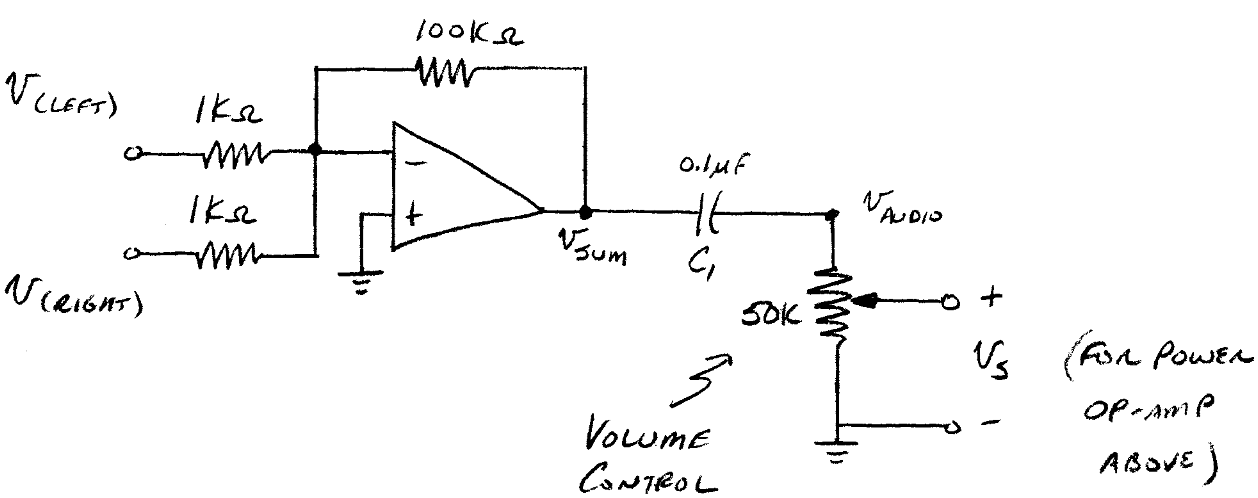
iii) $\therefore \dfrac{v_o}{v_s} = \dfrac{1}{\dfrac{1}{A_{dm}} + \dfrac{R_1}{R_1 + R_2}} = \dfrac{R_1 + R_2}{R_1} \dfrac{1}{\dfrac{1}{A_{dm}} \dfrac{R_1 + R_2}{R_1} + 1}$

IF A_{dm} IS LARGE, $\frac{v_o}{v_s} \cong \frac{R_1+R_2}{R_1}$. HOWEVER IF A_{dm} IS LARGE AND NON-LINEAR, $\frac{v_o}{v_s}$ IS STILL $\frac{R_1+R_2}{R_1}$.



E) STEREO-TO-MONAURAL CONVERTER

– WE ARE GOING TO PLAY BOTH CHANNELS OF A PORTABLE PLAYER IN ONE SPEAKER (LOW BUDGET ENTERTAINMENT SYSTEM).



$$V_{AUDIO} = V_{SUM} \frac{50K}{50K + \frac{1}{j\omega\, 100(10^{-9})}}$$

$$= V_{SUM} \frac{j\omega \cdot 100(10^{-9}) \cdot 50K}{j\omega \cdot 100(10^{-9}) \cdot 50K + 1}$$

$$= V_{SUM} \frac{j\frac{\omega}{200}}{j\frac{\omega}{200} + 1} = V_{SUM} \frac{j\frac{\omega}{2\pi(32)}}{j\frac{\omega}{2\pi(32)} + 1}$$

FOR $\omega \gg 200$ OR $f \gg 32$

$$V_{AUDIO} \cong V_{SUM} = -100\left(V_{(LEFT)} + V_{(RIGHT)}\right)$$

AND
$$V_S = V_{AUDIO} \frac{\alpha(50K)}{\alpha(50K) + (1-\alpha)(50K)}$$

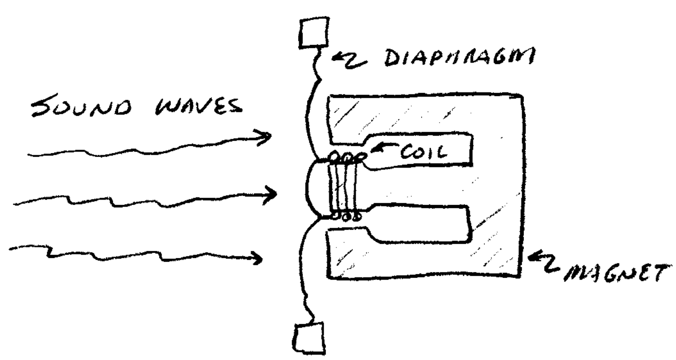
$$= V_{AUDIO} \frac{\alpha(50K)}{50K(\alpha + 1 - \alpha)} = \alpha V_{AUDIO}$$

WHERE $0 \le \alpha \le 1$

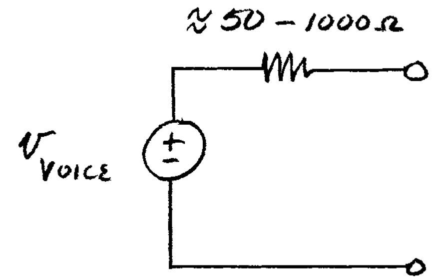
– THUS C_1 PASSES AUDIO FREQUENCIES BUT BLOCKS DC. THE REASON WE NEED TO DO THIS IS THAT A SMALL DC LEVEL FROM THE PLAYER WILL SEE A LARGE GAIN. THIS DC GAIN WILL PUSH THE CONE OF OUR SPEAKER IN ONE DIRECTION LIMITING THE AUDIO OUTPUT.

F) Microphone Amplifiers

- The microphones commonly used in recorders are magnetic (or dynamic) microphones. The name comes from the fact that the microphone has a moving part, a coil. The coil winding that is wound around the pole piece of a magnet is able to move up and down the pole. It is attached to a flexible diaphragm and is caused to move by sound waves striking the diaphragm. As it moves, it passes through the magnetic field set up between the poles of the magnet. Since the diaphragm will move at an audio rate, the voltage induced into the coil when it moves will also vary at an audio rate.



— MODEL



WHERE $V_{VOICE} \approx 100 \mu V$

— WE NEED A HIGH GAIN AMPLIFIER TO AMPLIFY V_{VOICE} FROM μV TO VOLTS.

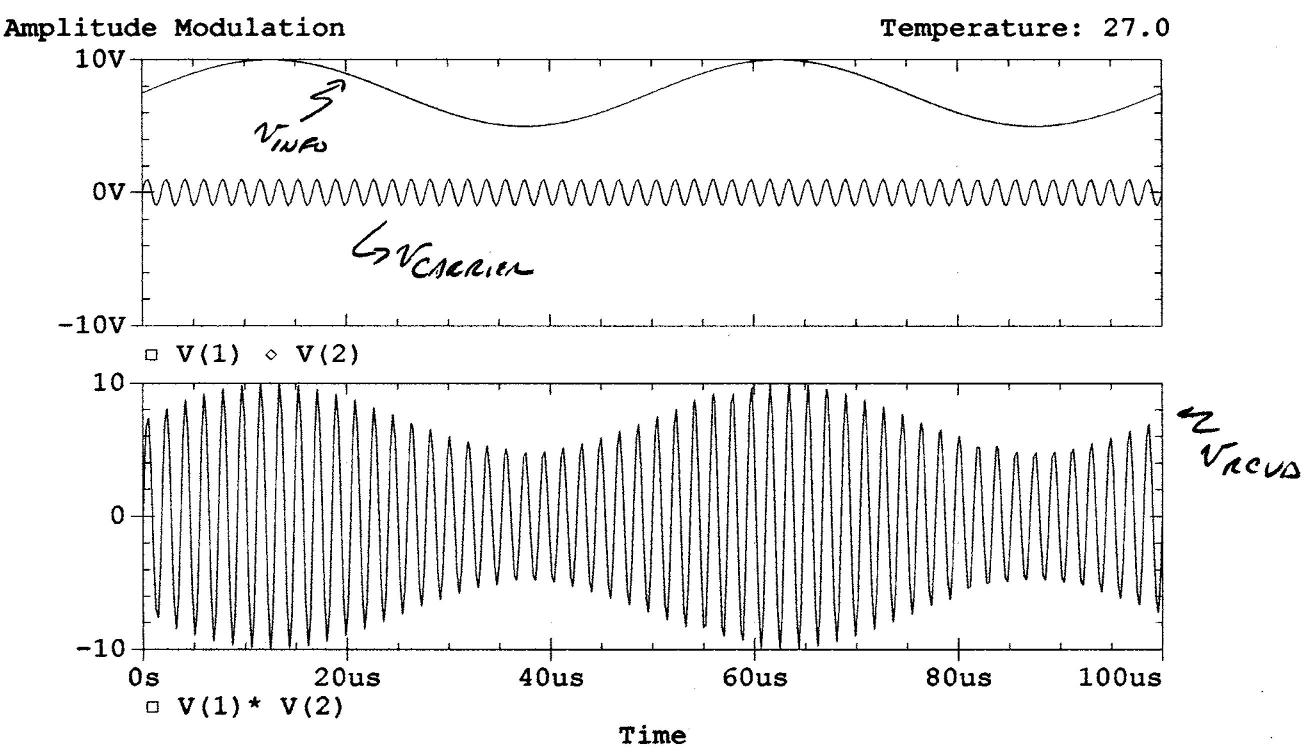
G) AM RADIO

— IN BROADCAST SYSTEMS, INFORMATION IS TRANSMITTED THROUGH SPACE. ANTENNAS CONVERT AC INTO ELECTRO-MAGNETIC WAVES. THE WAVE THEN PROPAGATES THROUGH SPACE AND IS RECEIVED AND RECONVERTED BY AN APPROPRIATE RECEIVER. UNFORTUNATELY AUDIO FREQUENCIES CANNOT BE EFFICIENTLY RADIATED BY AN ANTENNA. ANTENNAS TEND TO OPERATE EFFICIENTLY ONLY WHEN THE ANTENNA DIMENSIONS ARE COMPARABLE TO $\frac{1}{4}$ THE WAVELENGTH OF THE TRANSMITTED SIGNAL. THE WAVELENGTH IN FREE SPACE IS $\lambda = C/f$ WHERE C IS THE SPEED OF LIGHT AND f IS THE FREQUENCY IN HZ.

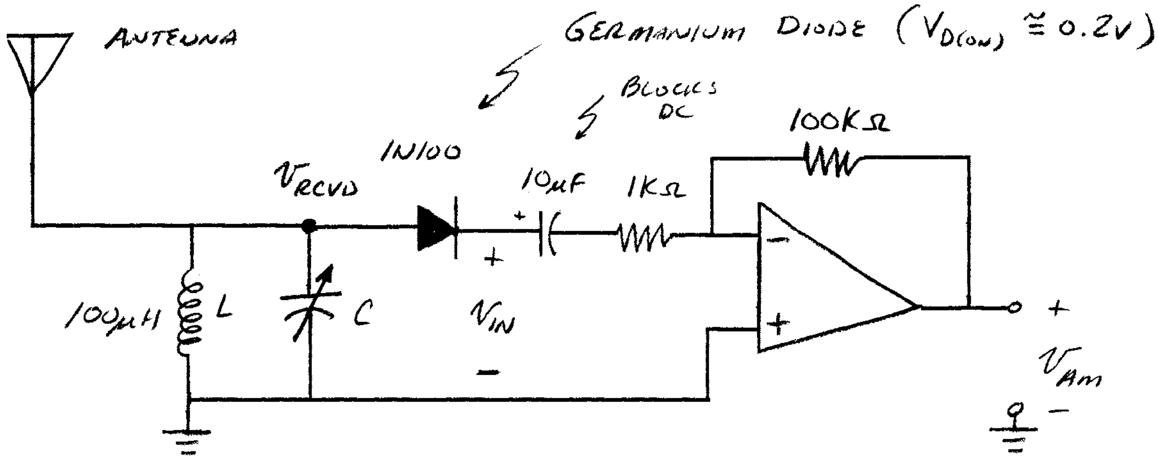
– THE WAVEFORM SHOWN BELOW IS REPRESENTATIVE OF THE SIGNAL TRANSMITTED BY AN AM RADIO STATION (AM540). IT CONSISTS OF A CARRIER SIGNAL f_C AT 540 KHZ AND AN INFORMATION SIGNAL MULTIPLIED TOGETHER, I.E.

$$V_{INFO} \cdot V_{CARRIER} = [V_{INFO}(t)][\sin(2\pi \cdot 540k)t] = V_{RCVD}(t)$$

FOR THE PLOT SHOWN, $V_{INFO} = 7 + 2.5\sin(2\pi \cdot 20k \cdot t)$. THE $2.5\sin(2\pi \cdot 20k \cdot t)$ REPRESENTS THE HIGHEST FREQUENCY AUDIO SIGNAL THAT WE CAN HEAR.



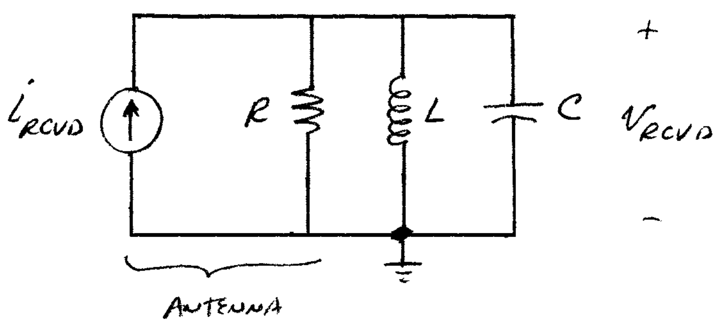
1) SIMPLE DIODE RECEIVER



WHERE:

OPTIMUM LENGTH OF ANTENNA $= \frac{1}{4}\lambda = \frac{1}{4}\frac{c}{f} = \frac{234(10^6)}{f}$ FEET

— AT $f_o = \frac{1}{2\pi\sqrt{LC}}$, $j\omega L = j\frac{L}{\sqrt{LC}} = j\sqrt{\frac{L}{C}}$,



AND $-j\frac{1}{\omega C} = -j\frac{\sqrt{LC}}{C}$

$= -j\sqrt{\frac{L}{C}}$

THUS $V_{RCVD} = i_{RCVD} R$

— V_{IN} IS THE POSITIVE PORTION OF $V(1) * V(2)$ ON p12.

— FOR f_o = AM 870 = .870 MHz, C = 334pF AND THE ANTENNA LENGTH ≅ 268 FEET. MOST AM RADIOS HAVE A LOOP ANTENNA TO ACHIEVE THIS.

- THE 10μF CAPACITOR ALONG WITH THE 1KΩ RESISTOR BLOCKS DC BUT PASSES OUR AUDIO SIGNAL AND THE CARRIER FREQUENCY, I.E.

$$-j\frac{1}{\omega C} + R = -j\frac{1}{\omega(10\mu)} + 1K = -j\cdot\frac{100K}{\omega} + 1K$$

$$= -j\frac{100K}{2\pi f} + 1K \text{ \& } \frac{100K}{2\pi f} \ll 1K \text{ FOR } f \gg 15.9 HZ$$

- A HIGH GAIN IS NEEDED BECAUSE THE AUDIO SIGNAL MAY BE VERY SMALL (μV).

- WE WILL SEE IN LATER COURSES THAT MOST OP-AMPS WILL PASS THE AUDIO RANGE OF FREQUENCIES FOR GAINS UP TO A MAGNITUDE OF 100.

- LIKEWISE, THE GAIN AT FREQUENCIES STARTING IN THE LOW MHZ RANGE IS MUCH LESS THAN THE GAIN AT THE AUDIO RANGE OF FREQUENCIES.

- THUS ONLY OUR AUDIO SIGNAL IS PASSED AT v_{AM}.