9

Experiments for Multistage Amplifying Circuit

Chapter 9 Experiments for Multistage Amplifying Circuit

9.1 Study Objective :

(1) Understanding the principle of amplifiers with various types of coupling.
(2) Understanding the principle of OTL amplifier circuit.
(3) Understanding the principle of OCL amplifier circuit.
(4) Understanding the widely used audio amplification IC's.

9.2 Basic Description :

9.2.1 New Terminology :

(1) OTL AMP: It is the abbreviation of Output Transformer Less AMP, the amplifier in which output transformer is taken away from the output terminal.

(2) OCL AMP: It is the abbreviation of Output Capacitor Less AMP, the amplifier in which output capacitor is taken away from the output terminal.

(3) Frequency response: Means the amplification capabilities that a amplifier carries out over different frequencies. The amplifiers typically suffer from poorer amplification capability at high frequency and low frequency.

(4) Thermal cycle damage: The conducting current of the transistor (semiconductor) will increase along with the rise of temperature. However the increase of the current will cause the rise of temperature, which will result in the cycle of heat and current and will eventually burn down the transistor.

(5) efficiency: It is the ratio of the AC power transformed by a amplifier to the DC power consumed by this amplifier.

$$\% \text{ efficiency} = \eta = \frac{Po(ac)}{Pi(ac)} \times 100\%$$

The amplifier with higher efficiency will save more energy.

9.2.2 Basic Principle :

The three types of coupling widely used in the amplifiers are:

1. RC coupling.
2. Transformer coupling
3. Direct coupling

(1) RC coupling

1) Fig 9-1 (a) shows the load of the preceding stage is resistance Rc1, and the capacitor Cc is used to couple the output signal of the preceding stage to the successive stage.

2) Function of the coupling capacitor Cc: Cc acts as open circuit for DC voltage so that the DC component will be blocked (because Xc = 1/2 π fc and f$\fallingdotseq$0, Xc therefore approaches to ∞),whereas Cc acts as short circuit for AC signal because Xc is higher for AC and Xc is smaller accordingly. The value of Cc is typically in the range of 2~50 μF. Since DC components are isolated by these capacitors, the bias circuits can thus be independent with respect to each other.

3) Advantages:

① As this type of coupling is featured for simplified circuit, lower cost and miniature circuit space, it is the most easy and widely used coupling method.

② Frequency response of this type of coupling is excellent.

③ This coupling is featured for low noise and lower AC hum generated from magnetic induction.

Drawbacks:

① The amplification over low frequency range will be limited by coupling capacitor (since Xc = 1/2 π fc, the very large Xc at low f will result in significantly attenuated signal).

② As resistance load will consume large DC power, this type of coupling will only suitable for low-power amplification or voltage amplification.

③ This type of coupling will suffer from lower efficiency because it is not east to match the impedances of the transistors between preceding stage and successive stage.

(2) Transformer coupling

As shown in Fig 9-3, the transformer can be used to isolate the DC bias of two stages, while this transformer, at the same time, can functions as signal coupling and impedance matching.

1) The basic characteristics of transformer: are shown in Fig 1.

① Turn number is directly proportional to voltage:
$V1/V2 = N1/N2$

② Turn number is inversely proportional to current:
$I2/I1 = N2/N1$

③ Impedance ratio is equal to the square of turn ratio:
$Z1/Z2 = (N1/N2)^2$

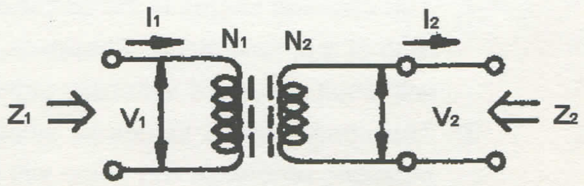


Fig 1

2) Advantages:

① This type of coupling is easy to match the impedance, and can functions as voltage rise or voltage drop.

② This type of coupling is featured for high power and high efficiency.

③ This type of coupling is easy to isolate the interaction of the DC voltages of the successive two stages.

Drawbacks:

① Because of the utilization of output transformer, it will occupy more space than RC coupling.

② Because the output transformer is a inductive device and the capacitance existing between coils, its frequency response is poorer.

③ It more expensive than RC coupling.

(3) Direct coupling

As shown in Fig 9-2, the output of the preceding stage is directly coupled to the input terminal of the successive stage.

1) The coupling of Direct Coupling shall conform to the following two principles:

① The DC bias shall be matched.

② The directions of the currents of preceding and successive stages shall be coincident.

2) The voltage of the power supply shall be stabilized. It is best to select silicon transistor since silicon transistor is featured for lower leakage current and excellent stability, otherwise the chain reaction among the cascade stages will result in the deterioration of the circuit.

3) Advantages:

① Can lower down the loss of coupling circuit.

② Can decrease the phase shift caused by L, L devices.

③ This type of coupling is featured for very wide frequency response, wherein the low frequency can almost extend to zero Hz without the effect of L (X_L) and C (Xc). This circuit can therefore amplify the signals at the spectrum of very low frequency that is close to DC.

Drawbacks:

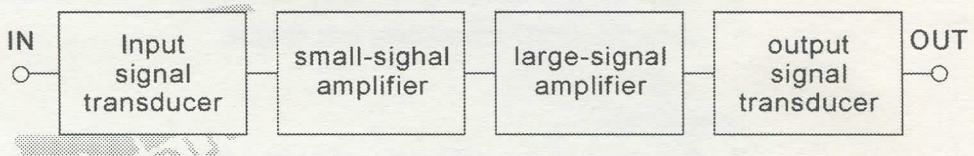
① The cascade stages in the amplifier shall be limited since the variation of Ib of a certain stage, if happens, due to the variation of temperature will result in serious instability of the overall circuit.

② The characteristic values of selected parts shall be as accurate as possible, otherwise the noise will be easily generated and the power will be attenuated.

Amplifier and Gain

(1) Block diagram of amplifier system

1)



① Input signal transducer: transforms the physical signal (voice ...) into electrical signal.

② Small-signal amplifier: provides adequate linear amplification for the input signal, and raise the gain.

③ Large-signal amplifier: Provides power amplification for the output of the small-signal amplifier to drive the output device.

④ Output signal transducer: transforms the signal from large-signal amplifier into the signal that match with the impedance of output device.

2) Large-signal amplifier is also called power or electricity or current amplifier. Discussions for this amplifier typically focus on the efficiency of power, the maximum power capacity of operation, and output impedance matching.

(2) Gain of amplifier: Amplification factor; The ratio of output signal to input signal.

1) Av (voltage gain): the ratio of output voltage to input voltage.

$$Av = Vo/Vi$$

2) Ai (current gain): the ratio of output current to input current.

$$Ai = Io/Ii$$

3) Ap (power gain): the ratio of output power to input voltage.

$$Ap = \frac{Po}{Pi} = \frac{Eo\,Io}{Ei\,Ii} = Av \times Ai$$

(3) Decibel: Decibel is used to express the sensibility of ear in response to volume with a logarithmic measure, and is denoted as db.

1) 0db: corresponds to that the applied voltage is 0.77V while 1mW of power is consumed in a 600Ω of load.

2) $|Ap|_{db} = 10\log_{10}\frac{Po}{Pi}$

3) $|Av|_{db} = 20\log_{10}\frac{Vo}{Vi}$

4) $|Ai|_{db} = 20\log_{10}\frac{Io}{Ii}$

5) dbm: The db value is calculated when 600Ω of resistance is used as reference load and 1mW of power is used as reference level.

(4) Gain and db of cascade system

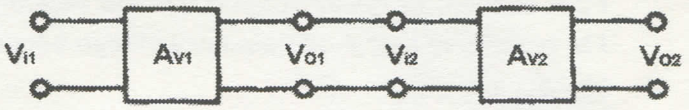


Fig 2 Cascade System

1) Overall gain of cascade system

① $A_{VT}=A_{V1}\times A_{V2}.....$ ④ $|A_{VT}|_{db}=|A_{V1}|_{db}+|A_{V2}|_{db}+.......$

② $A_{IT}=A_{I1}\times A_{I2}.....$ ⑤ $|A_{IT}|_{db}=|A_{I2}|_{db}+|A_{I1}|_{db}+.......$

③ $A_{PT}=A_{P1}\times A_{P2}.....$ ⑥ $|A_{PT}|_{db}=|A_{P2}|_{db}+|A_{P1}|_{db}+.......$

2) If the value of db is positive, it represents that this circuit functions as gain or amplification; if the value of db is negative, it represents that this circuit functions as attenuation.

For example: log1=0 log2=0.3 log2=0.477 log10=1

$$Av = \frac{1}{2} \Rightarrow |Av|_{db} = 20\log \times Av = 20\log\frac{1}{2} = 20\log 1 - 20\log 2$$

$$= 0 - 6 = -6_{db}$$

A_V=0.707=20log 0.707=-3db

Frequency response of amplifier

(1) While the gain of the amplifier is typically used the medium frequency range as reference, the values of gain in low frequency or high frequency will decrease. Low frequency, for example of RC coupling, will be affected by coupling capacitor (because $Xc=1/2\pi fc$, $f\downarrow$, $Xc\uparrow$); the amplification will be affected by the input capacitance and distribution capacitance of the transistors in parallel with the load so that $f\uparrow$, $Xc\downarrow$ and the gain will decrease. This frequency response is illustrated in Fig 3.

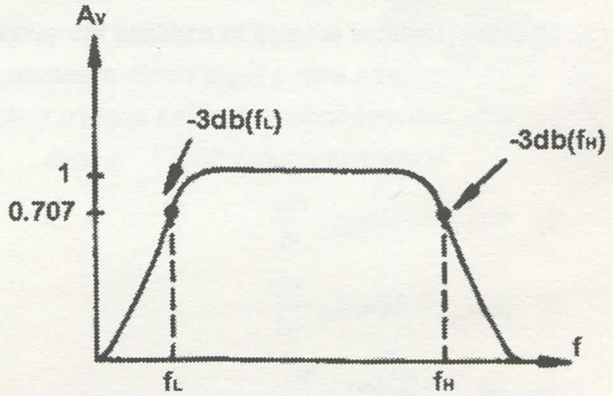
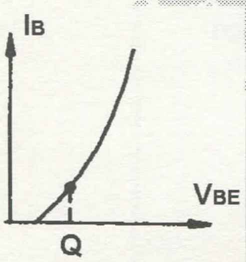


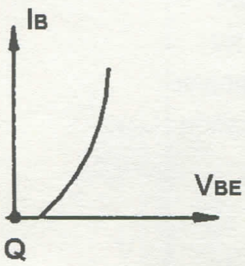
Fig 3

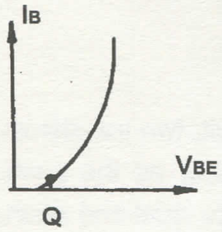
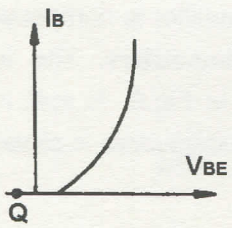
(2) If the gain of medium frequency range is set as 1 (0db), the two points (F_L, F_H) with 0.707 of Av are called half power points.
Fl: is denoted as cut-off frequency of low frequency.
Fh: is denoted as cut-off frequency of high frequency.
Bw (Bandwidth): $F_H - F_L$

Large-signal amplifier

(1) Classification and distortion with respect to the operation of amplifiers
1) Depending on the status of operation bias the power amplifiers can be classified into Class A, Class AB, Class B and Class C. Moreover, in order to enhance the driving capability, the push-pull amplifier has been designed. We hereby provides the comparison among these four types of amplifiers as follows:

Classification of amplifier	Location of quiescent point	Advantages	Drawbacks	Application
Class A  	1. Bias is set at the linear region, and input signal swing is also located at the linear region. 2. Quiescent point is located at the middle point of the load line (output of collector current exists during whole cycle)	1. Amplification can be completed with one transistor 2. Experience the lowest distortion	1. Efficiency is lowest (25%) 2. Can not eliminate harmonic distortion 3. Consumes very large power during quiescent condition. 4. Is hard for large –power amplification	Amplification for small power

Classification of amplifier	Location of quiescent point	Advantages	Drawbacks	Application
Class B 	1. Bias is set at the intersection of linear region and cutoff region ,and signal swing is half located at linear region and half located at cutoff region. 2. Quiescent point is located at cutoff point (output of collector current exists during positive cycle).	1. Even harmonic distortion can be eliminated. 2. Large –power amplification can be achieved. 3. Efficiency is higher (78.5%) 4. There is no power consumption during quiescent condition.	1. Amplification can be achieved only by complementary configuration 2. Exists crossover distortion	Amplification for large power.

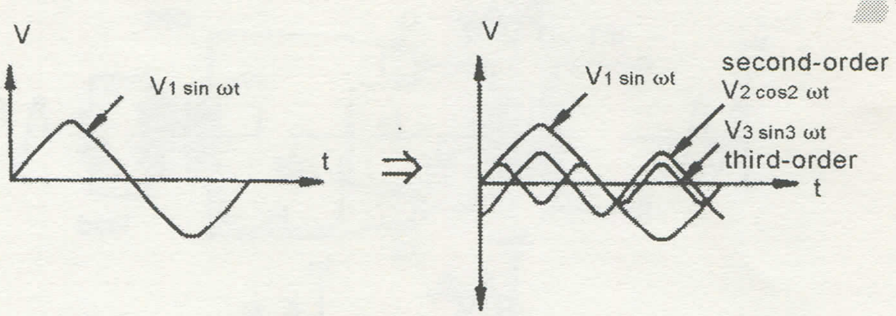
Classification of amplifier	Location of quiescent point	Advantages	Drawbacks	Application
Class AB 	Quiescent point is located between cutoff point and load line.	Can replace Class B as push-pull amplification and can be free from the drawback of crossover distortion.	1. Efficiency is slightly lower than Class B(70%) 2. Small current exists during quiescent condition	Amplification for large power
Class C 	Quiescent point is located below cutoff point .	Efficiency is highest (more than 78.5%)	Distortion is highest.	LC-oscillation transmitter. Harmonic producer

2) Classification of distortions:

Distortions can be classified into non-linear distortion, frequency distortion and delay (phase) distortion.

① Non-linear distortion (also called amplitude distortion):

The operating point is not set at linear region so that the output not only reproduce the original signal but also generate harmonic components. For example, the original signal of 1KHz may generate the harmonic signals such as 2KHz and 3KHz. This distortion is also referred to as harmonic distortion as shown in Fig 4 (a) (b).



(a) Normal waveform (b) Waveform with harmonic components

Fig 4

② Frequency distortion:

The distortion caused by the amplifier that has different amplification factors corresponding to different frequencies.

③ Delay distortion (phase distortion):

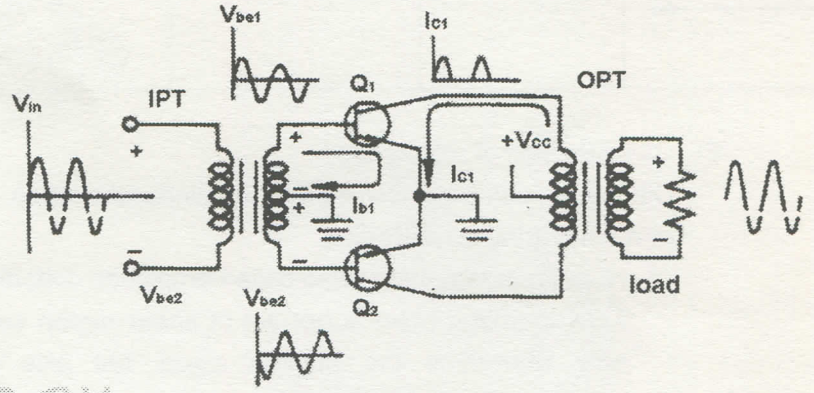
The distortion caused by the amplifier that has different phase-shift angles corresponding to different frequencies.

(2) Push-pull amplification

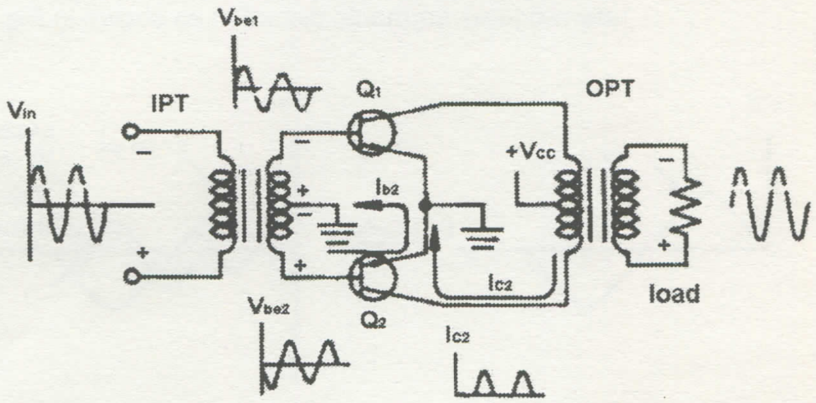
If a larger output power is required in the amplifier circuit, two transistors are typically utilized in the output stage to operate together as the push-pull amplifier. Push-pull amplifiers are further classified into dual-end push-pull amplifier and single-end push-pull amplifier which are respectively described as follows.

1) Dual-end push-pull amplifier

As shown in Fig 5, the basic circuit of push-pull amplifier is composed of input transformer, output transformer and two transistors. The input transformer functions as phase splitter, as shown in Fig 6, to split input signal into two signals that are equal in magnitude but inverse in phase.



(a) Operation status during positive cycle of input signal



(b) Operation status during negative cycle of input signal

Fig 5 Basic circuit of dual-end push-pull amplifier

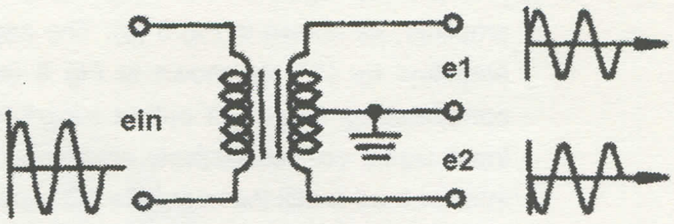


Fig 6

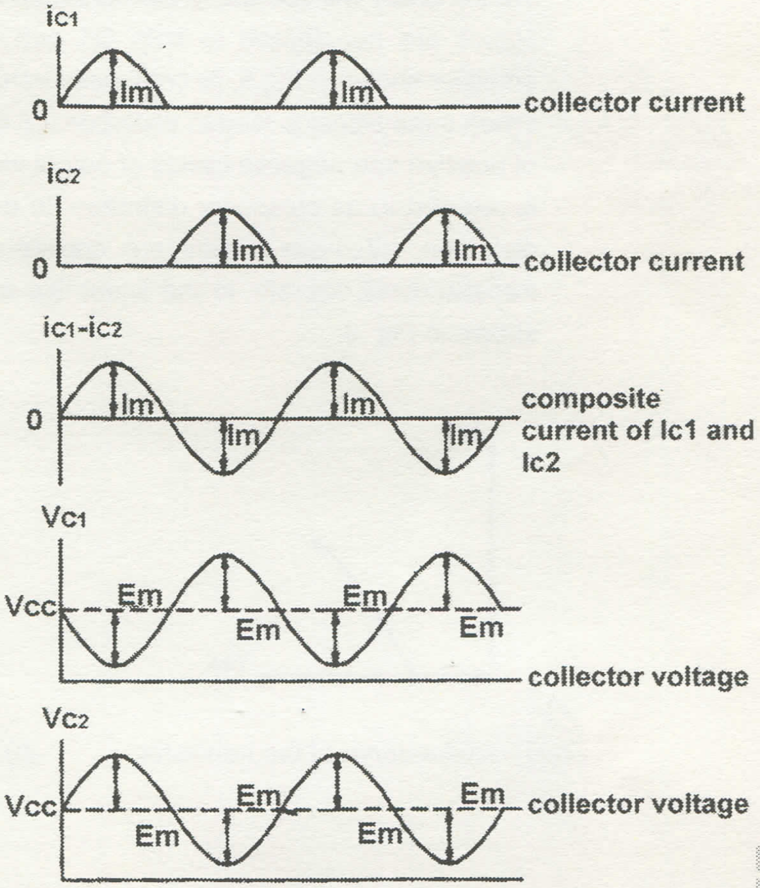
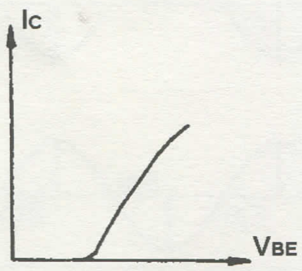
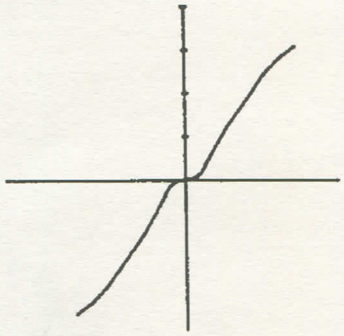


Fig 7 Waveforms of output voltage and current

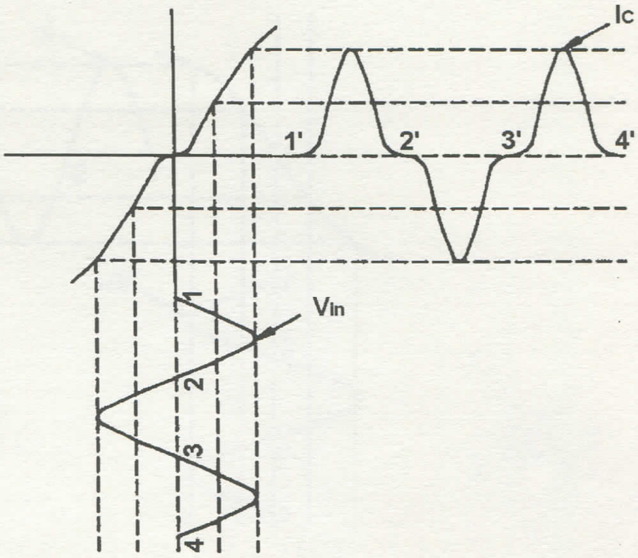
The positive cycle of the input signal is amplified by Q1 of push-pull amplifier, as shown in Fig 5 (a). The negative cycle of the input signal is amplified by Q2, as shown in Fig 5 (b). Ic1 of Q1 and Ic2 of Q2 are combined by means of output transformer. Although two cycles of the input signal are respectively amplified by Q1 and Q2, the signal feeder into the load is still the complete AC signal that is proportional to Vin. Fig 7 shows the waveforms of output current and voltage in the push-pull amplifier. The transfer curve of transistor is shown in Fig 8 (a). If the bias is not applied to the transistor or the applied bias is so small that Ic ≒0, the transistor will operate in the curvature region of the transfer curve. As biases are not applied to both Q1 and Q2 of this dual-end push-pull amplifier shown in Fig 5, its composite transfer curve is shown in Fig 8 (b). When input signal is feeder, distortion will be generated in the intersection of positive and negative cycles of output waveform, wherein this distortion is referred to as crossover distortion. In order to eliminate the crossover distortion, adequate biases are applied to Q1 and Q2 so that these transistors will operate in the linear-like region of the transfer curve, as shown in Fig 9.



(a)Transfer curve of the transistor

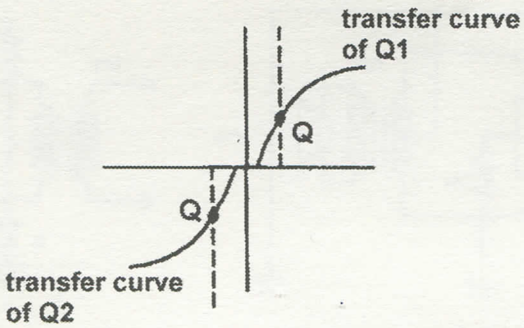


(b) Composite transfer curve that use Q1and Q2 as push-pull

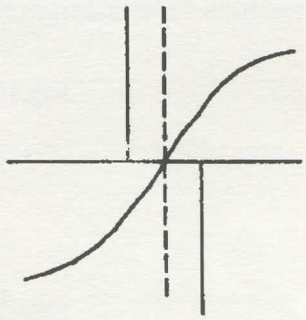


(c) Crossover distortion generated in Ic corresponding to Vin

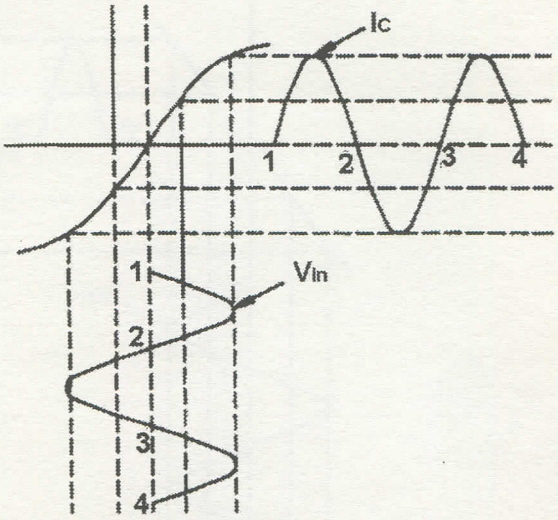
Fig 8 illustration of crossover distortion generated in Class B push-pull amplifier



(a)

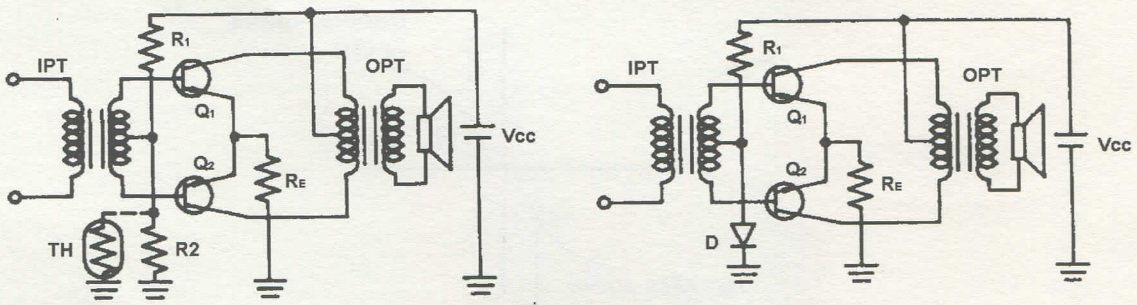


(b) Composite transfer curve that use Q1 and Q2 as push-pull



(b) There is no crossover distortion generated in Ic corresponding to Vi
(Remarks : The Q in the figure means operating point)

Fig.9 illustration of Class AB push-pull amplifier



(a)The required bias is provided by the voltage drop across two terminals of R2 (sometimes TH is incorporated)

(b) The required bias is provided by the voltage drop across the diode

Fig 10 Push-pull Amplifier

① Bias arrangement for dual-end push –pull amplifier

Two widely used methods to provide bias for the transistor are shown in Fig 10. The circuit shown if Fig 10 (a) utilize the voltage drop across two terminals of R2 as the bias for the transistor. A thermistor with negative temperature coefficient is connected in parallel with two terminals of R2 as temperature compensation. If the temperature of Q1 and Q2 rises, Ic will increase with the temperature, which will result in the shift of the operating point. At this time the resistance value of the thermistor will be decreased so that the forward bias of Q1and Q2 will be decreased, and the quiescent current of the transistor, which is constrained, will not be increased with the temperature. The circuit shown in Fig 10 (b) utilize the voltage drop across tow terminals of the diode as the bias for the transistor. Because of the similarity between the diode which is made of PN junction and the transistors Q1, Q2 in which BE's are also made of PN junctions, when temperature rises, Vd ↓ Vbe ↓ Vc ↓ and Ic will not be increased. The negative feedback of current functioning in Re will prevent the transistor from damage due to "thermal cycle" that is caused by the temperature rise and the corresponding increase of Ic.(I ↑ heat ↑ I ↑ heat ↑).

② Advantages and drawbacks of dual-end push-pull amplifier

As dual-end push-pull amplifier utilize two transformers, its frequency response is poorer, distortion is higher, volume is larger, and weight is heavier. However, under smaller power supply Vcc it is easier to gain high-power output. This dual-end push-pull amplifier is therefore widely used in transportable megaphone.

2) Single-end push-pull amplifier

The incorporation of transformers in the dual–end push-pull amplifier results in poor frequency response. In order to improve the drawbacks of dual-end push-pull amplifier, the single-end push-pull amplifier is therefore created. The single-end push–pull amplifiers are further classified into two types described hereinafter.

① OTL amplifier : OTL(Output Transformer Less)amplifier is an amplifier without output transformer. However, a 1000 μ F capacitor will be connected in series between output terminal and load.

② OCL amplifier : OCL (Output Capacitor Less) amplifier further remove output capacitor from the circuit, and this is an amplifier without output capacitor. Output terminal will be directly connected to the load.

OTL circuit is similar to OCL circuit, but with following exceptions :

① OTL only incorporates one set of power supply, but OCL incorporates positive and negative power supplies with equal magnitude. The center-point voltage of OTL is equal to 1/2 Vcc, but is 0V for OCL.

② Although the output transformer is removed from OTL, output capacitor is still incorporated in OTL.
The output capacitor is further removed from OCL.

③ The CE amplifier is typically incorporated in the input stage of OTL; however, differential amplifier is used in OCL.
Because of the similarity between OCL circuit and OTL circuit, only the OTL circuit is introduced herein.

OTL circuits are further classified into the following two types :

① the OTL amplifier that uses transformer as phase splitter,

② complementarily symmetrical OTL,
wherein the complementarily symmetrical OTL is most widely used. We hereby describe this circuit as follows.

Because the NPN and PNP transistors are characterized by their complement wherein the NPN transistor will be conducted if "positive" voltage is applied to its base and the PNP transistor will be conducted if "negative" voltage is applied to its base, the positive and negative cycles of the input signal can be splitter by incorporating one pair of NPN and PNP transistors with same characteristics, instead of the input transformer as the phase splitter.

The basic circuit of complementarily symmetrical singleend push-pull amplifier is shown in Fig 11.

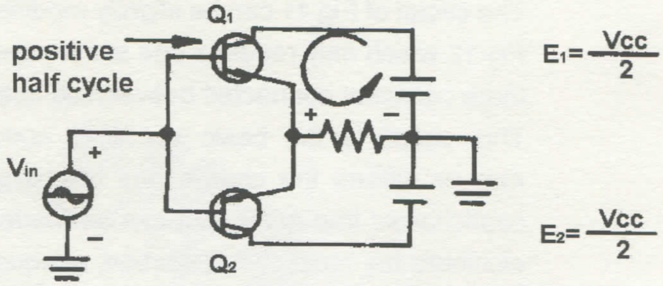
① When the input signal is not feeder, both Q1 and Q2 are cutoff, and there is no current following through the load.

② During the positive half cycle of the input signal, Q1 is forward biased and conducted with current path shown in Fig 11 (a) in which the load gains the positive half cycle. At this time Q2 is cut off.

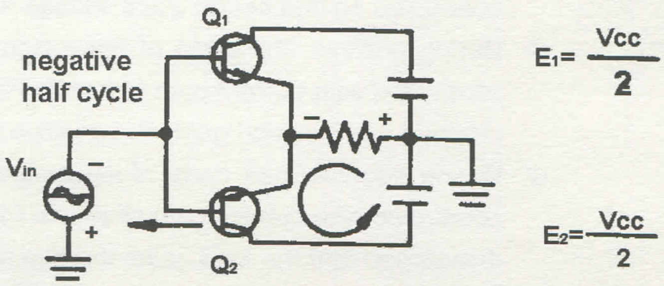
③ During the negative half cycle of the input signal, Q2 is forward biased and conducted with current path shown in Fig 11 (b) in which the load gains the negative half cycle. At this time Q1 is cut off.

④ Since the bias is not applied to Q1 or Q2 of Fig 10, it operates as Class B amplifier which will result in crossover distortion as shown in Fig 8.

⑤ Because the output terminal of this basic circuit is directly connected to the load and dual power supplies are incorporated, it is therefore a OCL circuit.



(a) During positive half cycle of input signal, Q1 is conducted, Q2 is cut off, and the load gains the positive half cycle.



(b) During negative half cycle of input signal, Q2 is conducted, Q1 is cut off, and the load gains the negative half cycle.

Fig 11 Base circuit of OCL

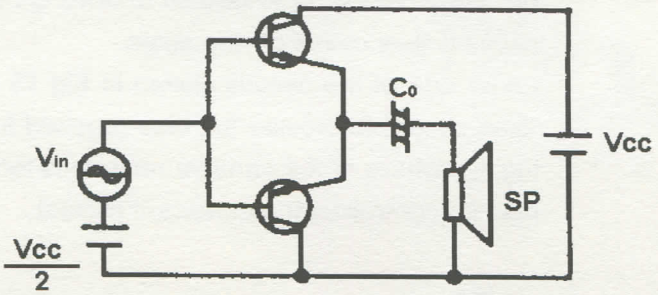


Fig 12 Basic circuit of OTL

The circuit of Fig 11 can be slightly modified as the circuit shown in Fig 12 which only requires one set of power supply, but requires a large capacitor connected between its output terminal and the load, This circuit is the basic circuit of complementary OTL which majorly utilizes the charge and discharge characteristics of the capacitor so that AC output can be feeder to the load. In order to eliminate the crossover distortion, adequate Vbe is applied to the transistor in the practical circuit , as shown in Fig 13.

We hereby describe the operation of Fig 13 as follows:

① Before the feeding of input signal, since Q1 and Q2 are symmetrical and equally biased, both transistors are similarly conducted so that center-point voltage = 1/2 Vcc.

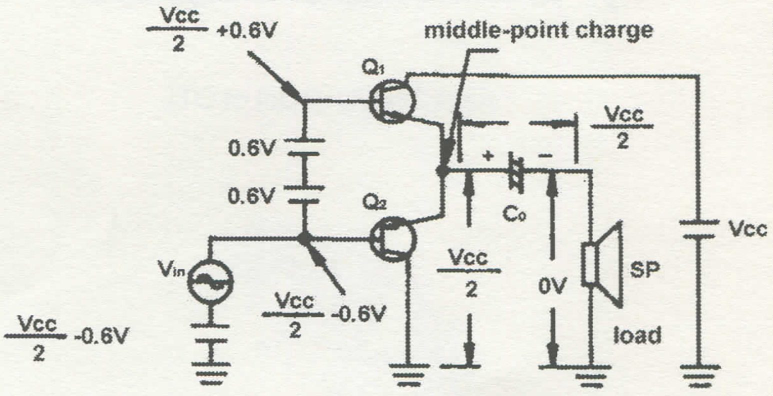
② During positive half cycle of input signal, Q1 will be forward conducted with current path shown in Fig 13 (b) in which Co is charged and the load gains the positive half cycle.

③ During negative half cycle of input signal, Q2 will be forward conducted with current path shown in Fig 13 (c) in which Co is discharged and the load gains the negative half cycle.

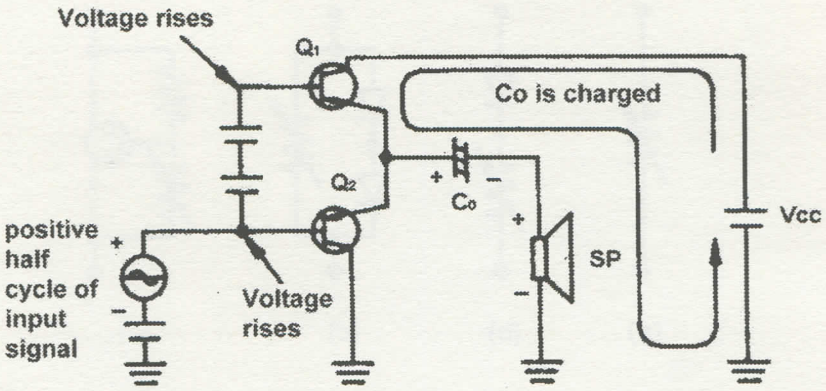
3) Driving stage

Because the output is taken from the emitters of Q1 and Q2 as shown in Fig 13, this circuit functions as the emitter follower featuring for higher current gain along with lower voltage gain. In order to increase the voltage gain, a CE amplifier is incorporated before Q1 and Q2, as shown in Fig 14. Since the output voltage of Q3 shown in Fig 14 is utilized to drive Q1 and Q2, the Q3 related circuit is thus called driving stage.

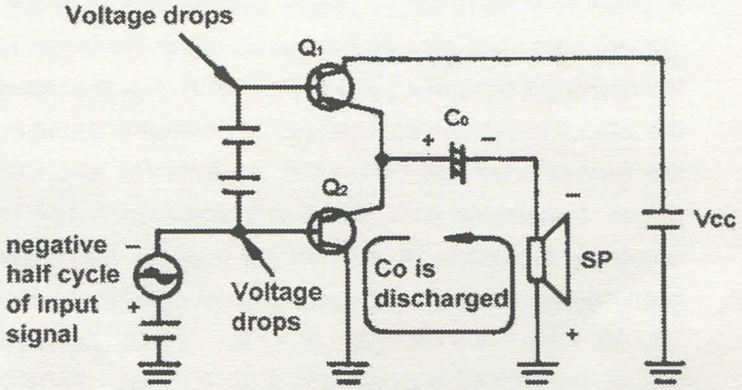
Either one of the circuits shown in Fig 15 can be adopted as the "bias circuit" to provide the bias required for Q1 and Q2 shown in Fig 14, where in the variable resistor is incorporated to adjust the bias for controlling the quiescent current.



(a) While Vin = 0, the voltages at each point.



(b) During positive half cycle of input signal, Q1 is conducted, Co is charged, and the load gains the positive half cycle.



(c) During negative half cycle of input signal, Q2 is conducted, Co is discharged, and the load gains the negative half cycle.

Fig 13 Analysis for driving stage of OTL AMP

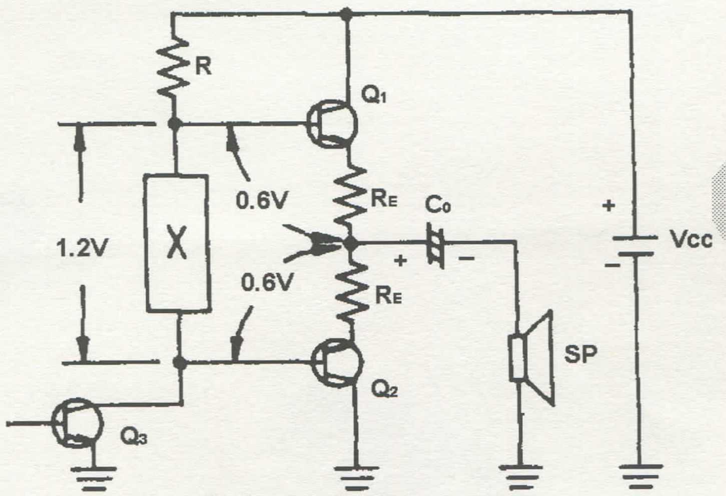


Fig 14 Complementarily symmetrical small-power amplifier

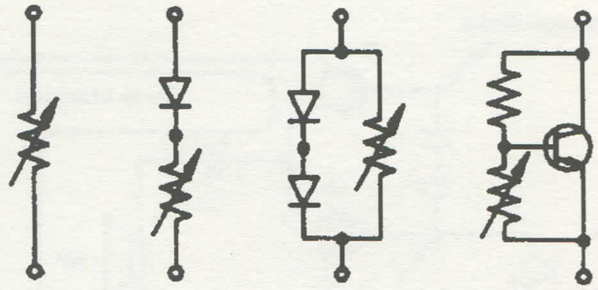


Fig 15 Bias Circuits

4) Large-power output stage

In order to acquire larger power, besided the increase of voltage gain, the current gain shall also be increased since the larger Io will result in larger Po deriving from the equation Po= Io^2 R. For the increase of current gain, the output stage can be changed to darlington configuration. Fig 16 shows the fully-symmetrical OTL AMP, wherein Q4 and Q5 are PNP and NPN power transistors with same characteristics. The resistors Re act as negative feedback of current to prevent the power transistors from burning-down due to the cyclic rise of current -heat (for example, Vbe = Vb - Ve = Vb - Ie × Re ≒ Vb - Ic × Re) When temperature ↑ Ic ↑ , Vbe will be decreased accordingly, and Ib ↓ Ic ↓ , therefore temperature will not rise). Because of the increase of the transistor, the bias Vbe1 + Vbe4 + Vre4 + Vre5 + Vbe5 + Vbe2 will be minimum 2.4V on the basis of Vbe = 0.6V. The bias circuit is therefore modified as the circuit shown in Fig 17 which can provide the functions of biasing as well as temperature compensation.

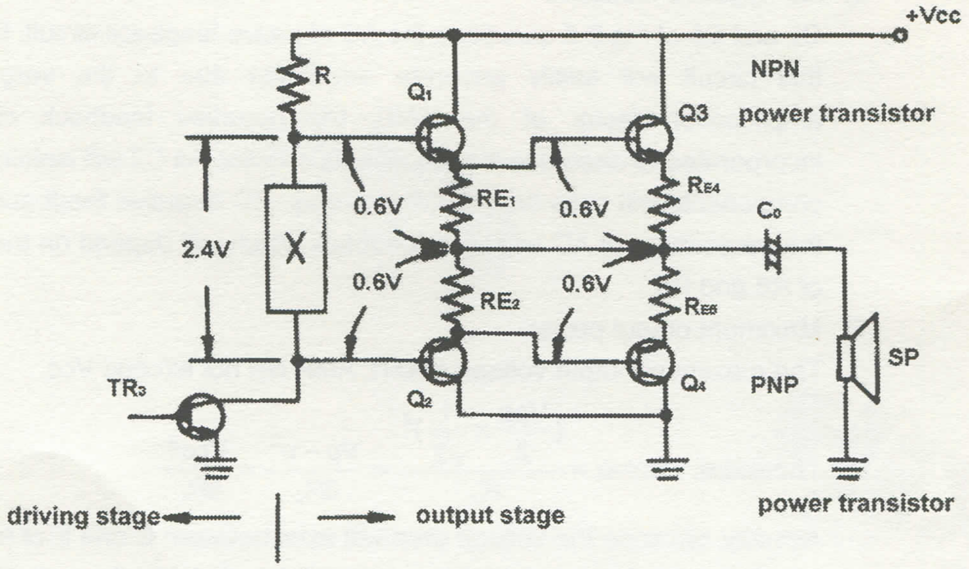


Fig 16 Fully-complementary OTL AMP

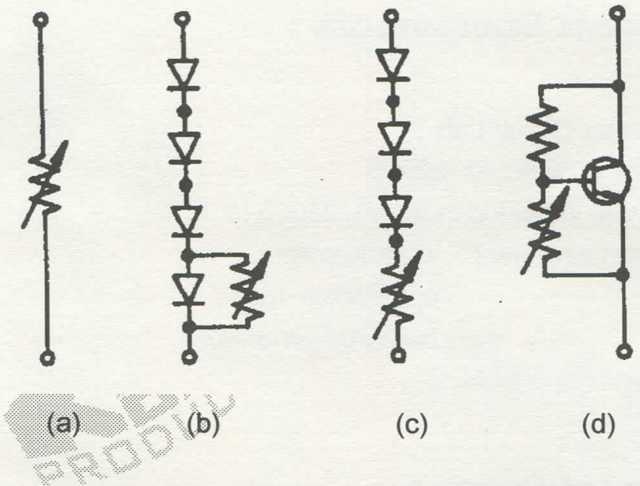


Fig 17 Bias circuit for large power output

5) DC feedback

As shown in Fig 9-5, the feedback resistor VR100K (R6) of OTL AMP is connected to the middle point so as to form the DC negative feedback. If the center-point voltage is shifted, this status will be transmitted to the middle-point and will automatically correct the middle-point voltage to 1/2 Vcc. For example of the OTP AMP shown in Fig 9-5, if the middle-point voltage increases, Vc1 ↑ Vb2 ↑ Vc2 ↓ Vb4 ↓ Ve4 ↓ , and the middle-point voltage will be decreased.

6) AC negative feedback

C2 and R5 of Fig 9-5 constitute the AC negative feedback circuit. Because this circuit will easily generate oscillation due to the verge large amplification factor of the AMP, the negative feedback circuit is incorporated to decrease the amplification factor. As C2 will isolate the DC components will pass the AC components, DC negative feedback is thus the percentage of AC negative feedback which will depend on the values of R6 and R5.

7) Maximum output power

The maximum output voltage of OTL AMP will not exceed Vcc.

Therefore, $Pomax = \frac{(\frac{Vpp}{2} \times \frac{1}{\sqrt{2}})^2}{R_L} = \frac{Vp-p^2}{8R_L} = \frac{Vcc^2}{8R_L}$

Actually, because the voltage drop will exist between C and E of the transistor, the maximum output power will less than the theoretical value.

9.3 Experiment Equipments :

(1) KL-200 Linear Circuit Lab .

(2) Experiment Module : KL-23005 .

(3) Materials : As indicated in the KL-23005 (a, b, c).

(4) Experiment Instrument : 1. Multimeter.

2. Oscilloscope.

3. Signal generator.

(5) Tools : Basic hand tools.

9.4 Experiment Items :

Item one (9-1) : JFET CS Amplifier (self-bias)

9-1-1

9-1-1-1 Experiment Procedures :

(1) Firstly fix the module KL-23005 in the KL-200 Linear Circuit Lab, then locate the block marked 23005-block a.

(2) Insert the short-circuit clip by referring to Fig 9-1 (a) and the short-circuit clip arrangement diagram 23005-block a.

(3) Adjust VR4 and VR3 respectively so that both Vc1 Q1 collector and Vc2 Q2 collector will be 1/2 Vcc.

(4) Connect signal generator and oscilloscope in the input terminal (IN) and connect oscilloscope to the output terminal.

(5) Adjust the signal generator to 1KHz sine wave and gradually increase the output voltage of signal generator so that the output terminal (OUT1) can display maximum non-distorted waveform.

(6) Use the oscilloscope to measure the waveforms of Vb1, Vc1, Vb2 and Vout1, and make records.

(7) Disconnect C3 (47 μ F), then repeat Step (5) and (6).

(8) Randomly adjust VR4 (VR 1M Ω), then view if the waveforms of Vb1, Vc1, Vb2 and Vout1 will be varied.

9-1-1-2 Experiment Result :

Record the experiment result in Table 9-1, then calculate the following values in accordance with the data of this Table. (C3 shall be connected.)

Av1 = Vo1/Vi1 = Vc1/Vb1 =____.

Av2 = Vo2/Vi2 = Vout/Vb2 =____.

Av = Vout/Vi1 =______.

Avs = Vout1/Vin =_____.

Compare the difference between theoretical and actual values by referring to the fomulas of Av.

C3 is connected		C3 is disconnected	
waveform	Vpp	waveform	Vpp
v, V_{IN}, t		v, V_{IN}, t	
v, V_{B1} (V_{i1}), t		v, V_{B1} (V_{i1}), t	
v, V_{C1} (V_{o1}), t		v, V_{C1} (V_{o1}), t	
v, V_{B2} (V_{i2}), t		v, V_{B2} (V_{i2}), t	
v, V_{OUT}, t		v, V_{OUT}, t	

Table 9-1

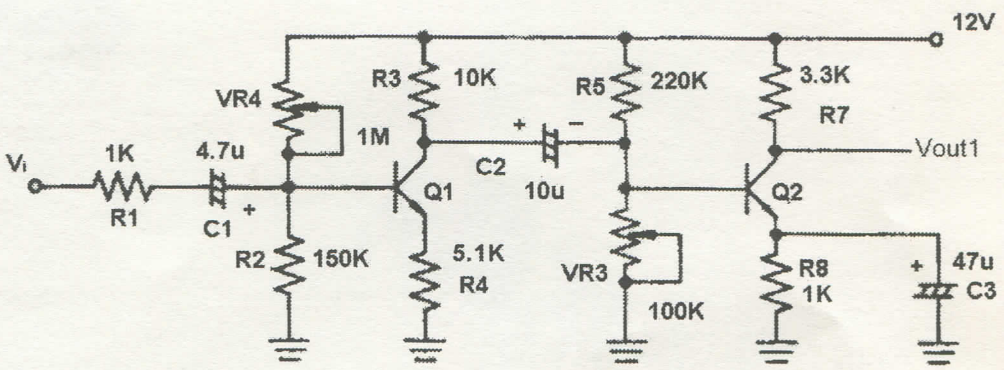


Fig 9-1 (a) RC coupling amplification

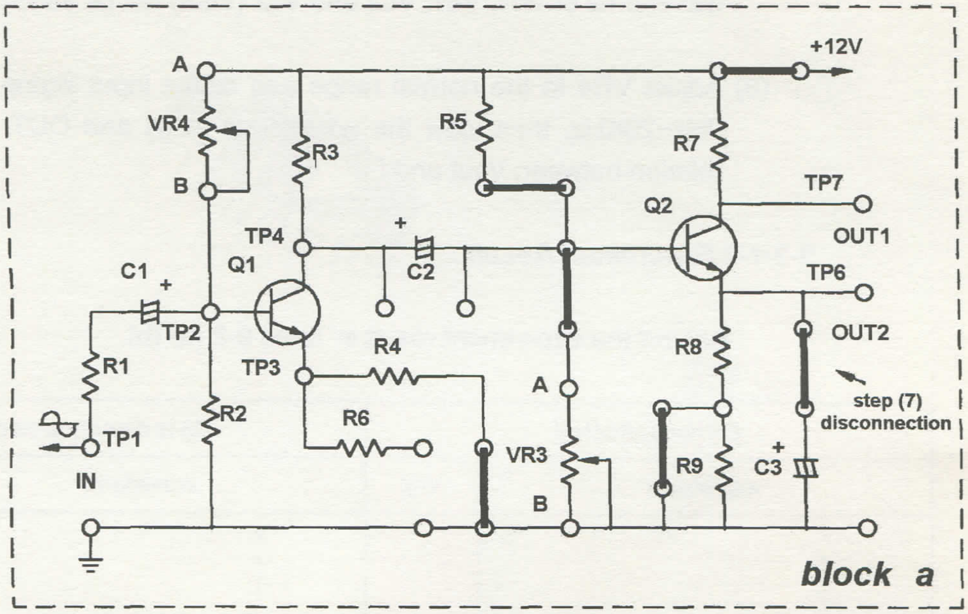


Fig 23005-block a

Item two (9-2) : Direct coupling

9-2-1

9-2-1-1 Experiment Procedures :

(1) Insert the short-circuit clip by referring to Fig 9-2 (a) and the short-circuit clip arrangement diagram 23005-block a.2.
(Please short C3 to discharge it)

(2) Adjust VR4 (VR1MΩ) so that Vc1(Q1) = 1/2 Vcc, then use multimeter to measure (DCV scale) Vb1e1 and Vb2e2, and make records.

(3) Connect signal generator and oscilloscope in the input terminal (IN) and connect oscilloscope to the output terminal (OUT1).

(4) Adjust the signal generator to 1KHz sine wave and gradually increase the output voltage of signal generator so that the oscilloscope can display maximum non-distorted waveform.

(5) Use the oscilloscope to measure the waveforms of Vb1, Vc1, Vb2 and Vc2 (Vout1), and make records.

(6) Disconnect C3 (47 μF), then repeat Step (5).

(7) Connect C3 (47 μF) and randomly adjust VR4 (VR 1MΩ), then view if the waveforms of Vb1, Vc1, Vb2 and Vc2 (Vout) will be varied.

(8) Adjust VR4 to the normal range and adjust input signal frequency from 0Hz~20KHz, then view the waveforms in IN and OUT, and record the relation between Vout and f.

9-2-1-2 Experiment Result :

Record the experiment result in Table 9-2 (a) (b).

C3 is connected		C3 is disconnected	
waveform	Vpp	waveform	Vpp
v / V_{IN} / t		v / V_{IN} / t	
v / V_{B1} (V_{i1}) / t		v / V_{B1} (V_{i1}) / t	
v / V_{c1} (V_{b2}) / t		v / V_{C1} (V_{b2}) / t	
v / V_{OUT} / t		v / V_{OUT} / t	

Table 9-2 (a)

calculate

Calculate the following values in accordance with the data of Table 9-2 (a). (C3 shall be connected.)

Av1 = Vo1/Vi1 = Vc1/Vb1 =____.

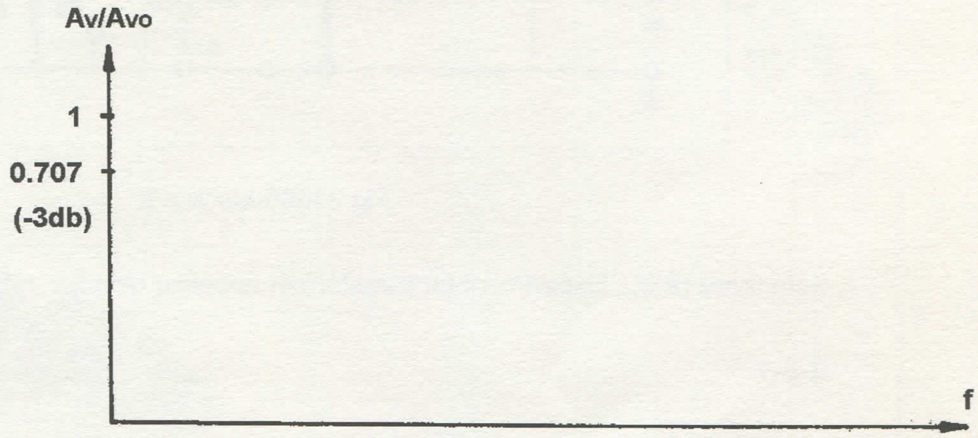
Av2 = Vo2/Vi2 = Vout/Vb2 =____.

Av = Vout/Vi1 =______.

Avs = Vout/Vin =______.

Compare the difference between theoretical and actual values by referring to the fomulas of Av.

Avo: The Av while Vo is maximum.



Frequency response curve

Table 9-2 (b)

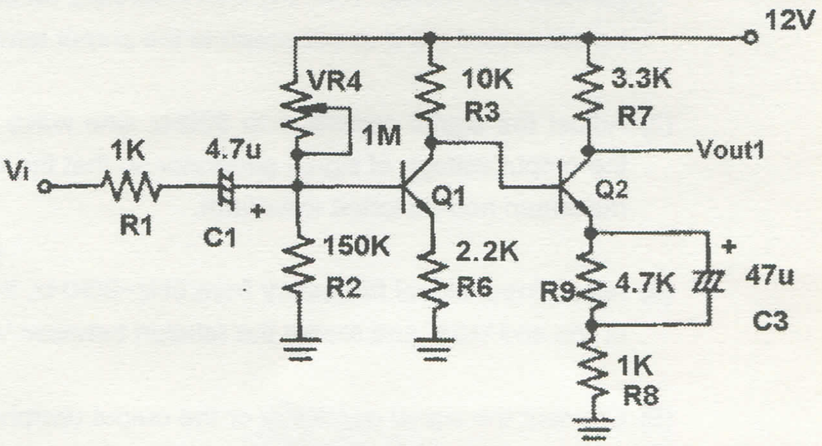


Fig 9-2 (b)

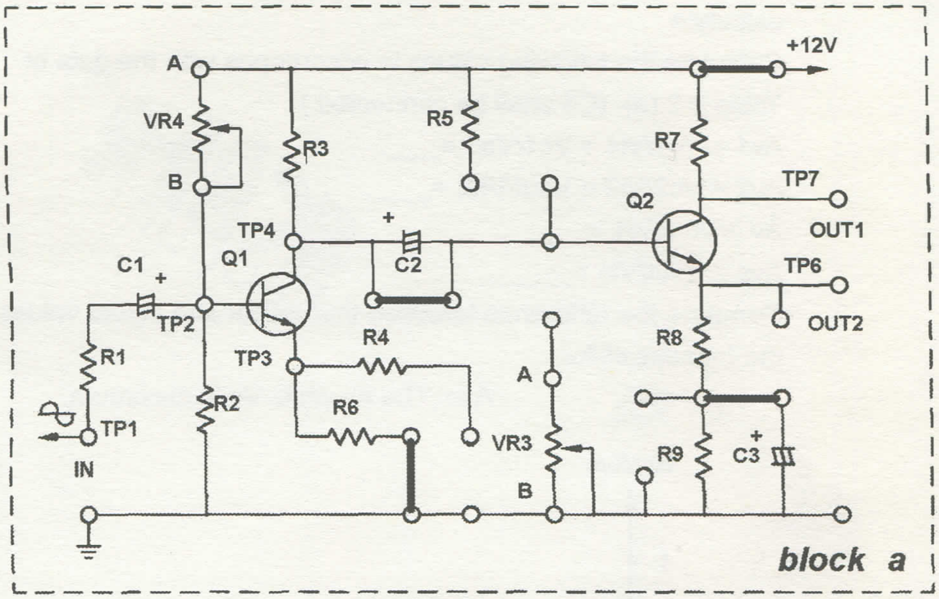


Fig 23005-block a.2

Item three (9-3) : Experiment for transformer coupling circuit

9-3-1

9-3-1-1 Experiment Procedures :

(1) Insert the short-circuit clip by referring to Fig 9-3 and the short-circuit clip arrangement diagram 23005-block b, then connect power supply (+12V).

(2) Connect signal generator and oscilloscope in the input terminal, and connect 8Ω resistor (dummy load is already on board,and do not have to be connected.) and oscilloscope to the output terminal.

(3) Adjust the signal generator to 500Hz sine wave and gradually increase the output voltage of signal generator so that the oscilloscope can display maximum non-distorted waveform.

(4) Adjust input signal frequency from 0Hz~20KHz, then view the waveforms of Vin and Vout, and record the relation between Vout and f.

(5) Connect the signal generator or the output (earphone) jack of walkman in the input terminal again, then view if the voice is still generated in Output terminal.

9-3-1-2 Experiment Result :

Record the experiment result in Table 9-3 (b), and calculate the output power.

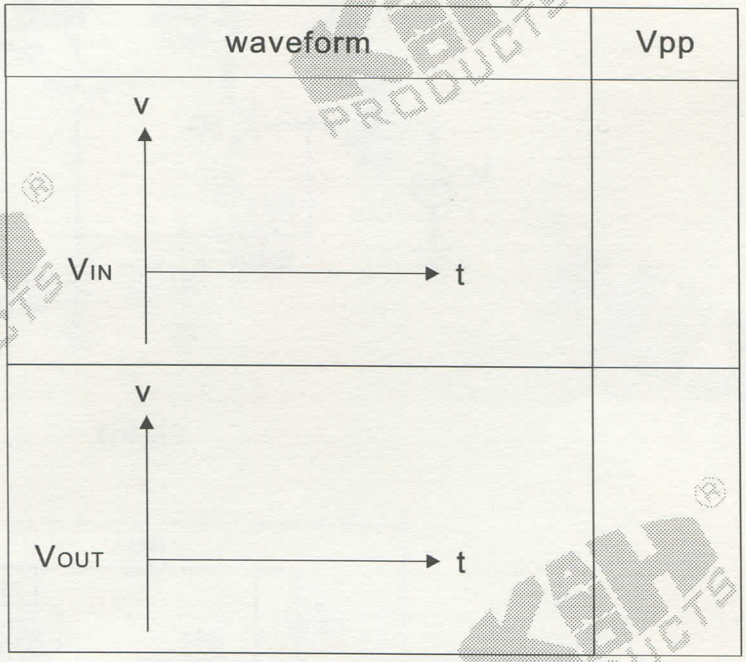


Table 9-3 (a)

Maximum non-distorted output power= $V_{op\text{-}p}^2 / 8R_L$= ______Mw

Avo: The Av while Vo is maximum.

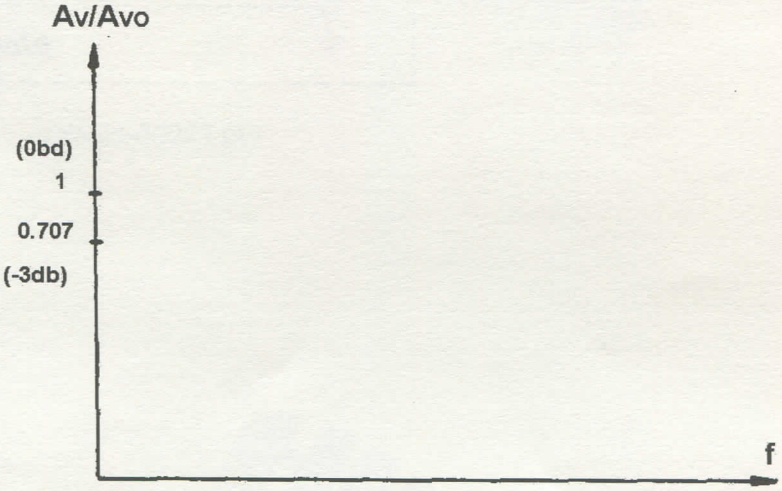


Table 9-3 (b)

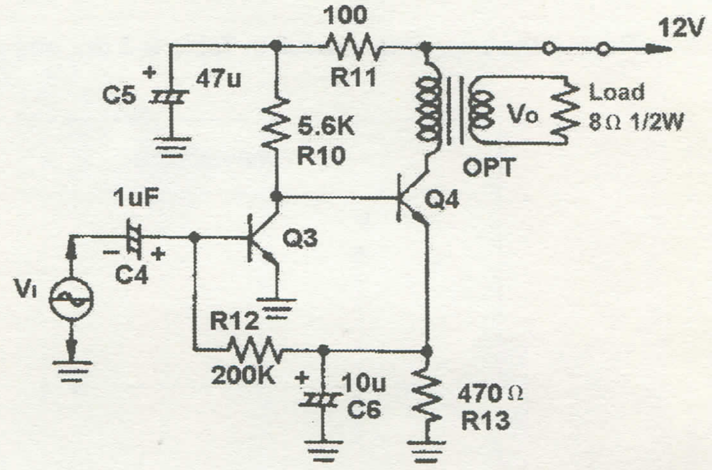


Fig 9-3

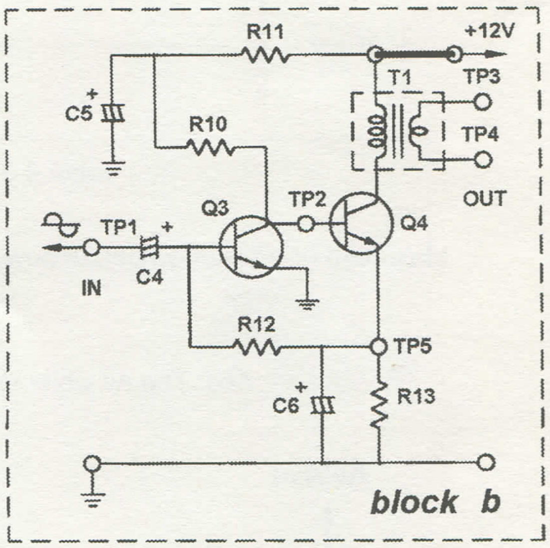


Fig 23005-block b

Item four (9-4) : Experiment for dual-end push-pull amplifier

9-4-1

9-4-1-1 Experiment Procedures :

(1) Insert the short-circuit clip by referring to Fig 9-4 and the short-circuit clip arrangement diagram 23005-block c, then connect power supply +12V (A 8Ω/1W resistor shall be connected to OUT).

(2) Connect the ammeter (A2) (a short-circuit clip can be used in the location of A1 to replace the ammeter at this time) to measure quiescent current. If this current >> 20mA, the push-pull transistors Q6 and Q7 is easily over-heated, and at this time the power supply shall be turned off to check the circuit.(VR1 has to be connected)

(3) Besides the check of possible wrong connection, the voltmeter can be used, while the power supply is connected, to measure Vbe and Vce of each transistor. The status of each transistor can be judged from Vbe and Vce by referring to the following analysis:

① Vbe>0.7V Open circuit between B and E of the transistor

② Vbe≦0.2V Vce = 0V Short circuit between C and E of the transistor

③ Vbe≒0.6V Vce≒0.2V The transistor is saturated.

(4) If it is the status ① or ②, the transistor shall be replaced. If it is the status ③, Vbe (Ib) shall be adjusted by adjusting VR1 (VR 1KΩ) as shown in Fig 9-4.

(5) Connect the ammeter to the A1 location and adjust R15 (SVR 20KΩ) so that Vc1 = 1/2 Vcc, then view the variation indicated in this ammeter.

(6) Adjust VR1 (VR 1KΩ) so that the value of A2 (Ammeter) will be indicated at around 10mA.

(7) Connect signal generator and oscilloscope in the input terminal, and connect oscilloscope to the output terminal.

(8) Adjust the signal generator to 500Hz sine wave and gradually increase the output voltage of signal generator so that the oscilloscope can display maximum non-distorted waveform of this amplifier output.

(9) Use oscilloscope to measure the waveforms of Vb5, Vc5 and Vb6 respectively.

(10) Adjust VR1 (VR 1KΩ) to 0Ω, then view if crossover distortion is generated in the waveform of Vout.

(11) Connection TP8,TP9 to speaker, and randomly adjust the output of signal generator that is applied to the input terminal of this amplifier, then view if the loudness of voice is changed and if Q6 and Q7 are over-heated while the signal with high frequency or large amplitude is applied.

(12) When the signal generator is removed and use finger to touch the input terminal of this amplifier, hum will be generated in the speaker. (Noise will be induced at the input terminal by touching the terminal with finger.)

(13) Connect the earphone output of walkman to the input terminal of this amplifier, then listen to the music.

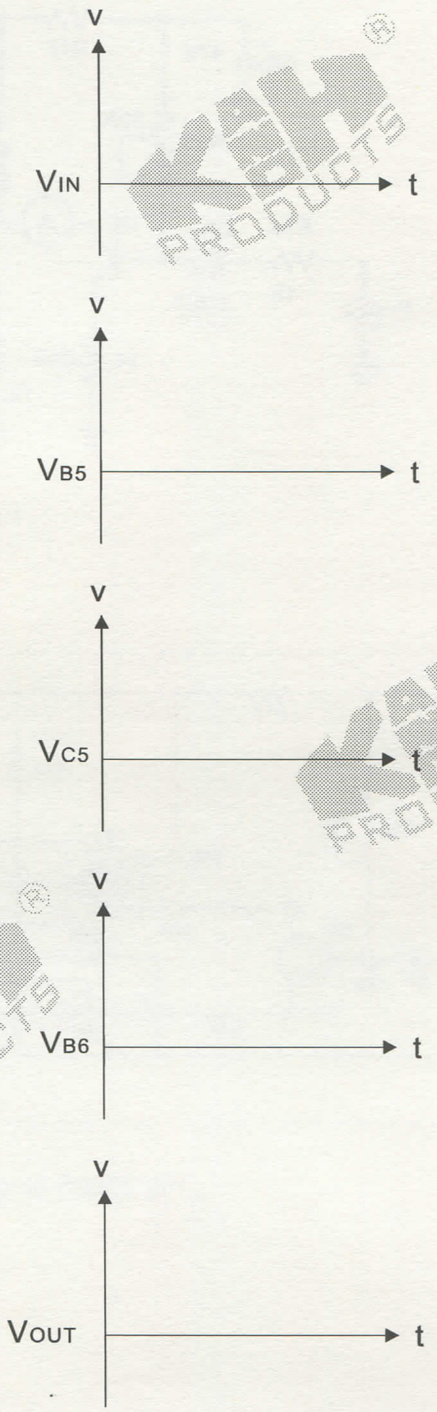
9-4-1-2 Experiment Result :

Record the experiment result in Table 9-4, and calculate the maximum non-distorted output power.

Static Test

Quiescent current(A2)	Vb5e5	Vc5	V b6e6	Vb7e7

Dynamic Test



$$Pout = \frac{V^2out(p-p)}{8R_L} = \_\_\_\_\_\_\_\_. \quad R_L = 8\Omega.$$

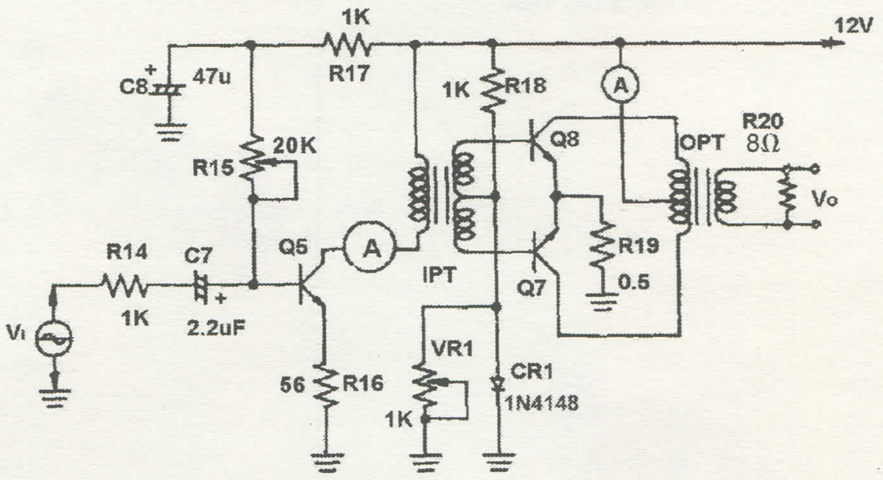


Fig 9 -4

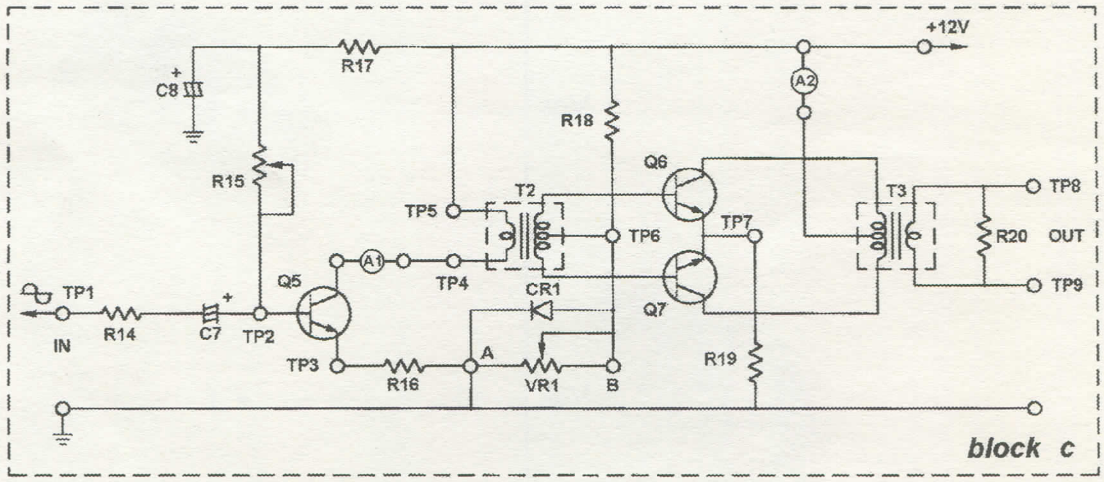


Fig 23005-block c

Item five (9-5) : Experiment for OTL amplifier

9-5-1

9-5-1-1 Experiment Procedures :

(1) Firstly fix the module KL-23006 in the KL-200 Linear Circuit Lab, then locate the block marked 23006-block b.

(2) Insert the short-circuit clip by referring to Fig 9-5 and the short-circuit clip arrangement diagram 23006-block b, then connect A 8Ω/20W resistor as the load

(3) Connect the ammeter to the input terminal for power supply to measure the quiescent current, with polarity shown in Fig 9-5.

(4) Slowly adjust the power supply V+ from 3V to 18V, then view the quiescent current. If the quiescent current exceeds 20mA, adjust R8 (SVR500KΩ) so that the quiescent current can be maintained at around 20mA. If this adjustment is useless, please firstly carry out Step (5).

(5) Adjust VR3 (VR100K) so that the voltage of point A (middle-point voltage) = 1/2 Vcc = 9V (the error shall be within ± 2%).

(6) If the middle-point voltage can not be adjusted to 1/2 Vcc and the quiescent current >> 20mA (the transistors are over-heated), please turn off the power supply. Then, firstly carry out the ohmic test in accordance with the methods for measurement of transistor to check if any transistor is short-circuit.

(7) Connect the voltmeter (DCV) to the power supply for static test. In addition to the middle-point voltage, Vbe and Vce of each transistor shall be respectively measured.

(8) After the middle-point voltage and quiescent current have been normal, connect signal generator and oscilloscope in the input terminal (IN), and connect oscilloscope to the output terminal (OUT). Adjust the signal generator to 1KHz sine wave and gradually increase the output voltage of signal generator so that the oscilloscope can display maximum non-distorted waveform of this amplifier output.

(9) Use oscilloscope to measure the waveforms of Tp2, Tp3, Tp4, Tp6, Tp7 and Tp11.

(10) Adjust SVR500Ω(R8) to minimum, then view if crossover distortion is generated in the waveform of Tp11 (OUT).

(11) Adjust SVR500Ω(R8) to maximum, then view if Q3 and Q4 are over-heated. During normal status Q3 and Q4 shall be slightly over-heated while input signal is applied to this amplifier.

(12) When the middle-point voltage and quiescent current have been adjusted to normal condition, change the connections to 8Ω/20W speaker for output terminal and to other signal source such as CD or walkman ... etc. for input terminal, then listen to the music.

(13) Remove the signal source, then use finger to touch the input terminal, and low-frequency noise shall be heard from the speaker.

9-5-1-2 Experiment Result :

View the waveforms of each test point and Vbe, Vce of each transistor, then record the following items:

① Middle-point voltage (Va)
② Quiescent current (Icc)
③ Vin
④ Waveform of Vout ;

then calculate $Po = V_{op\text{-}p}^2 / 8R_L$, and record in Table 9-5.

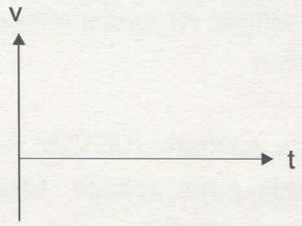
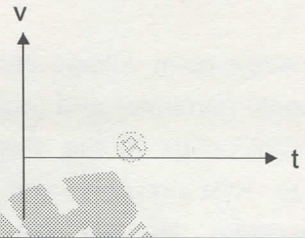
	waveform	Va	Icc	Po
Vin				
Vout				

Table 9-5

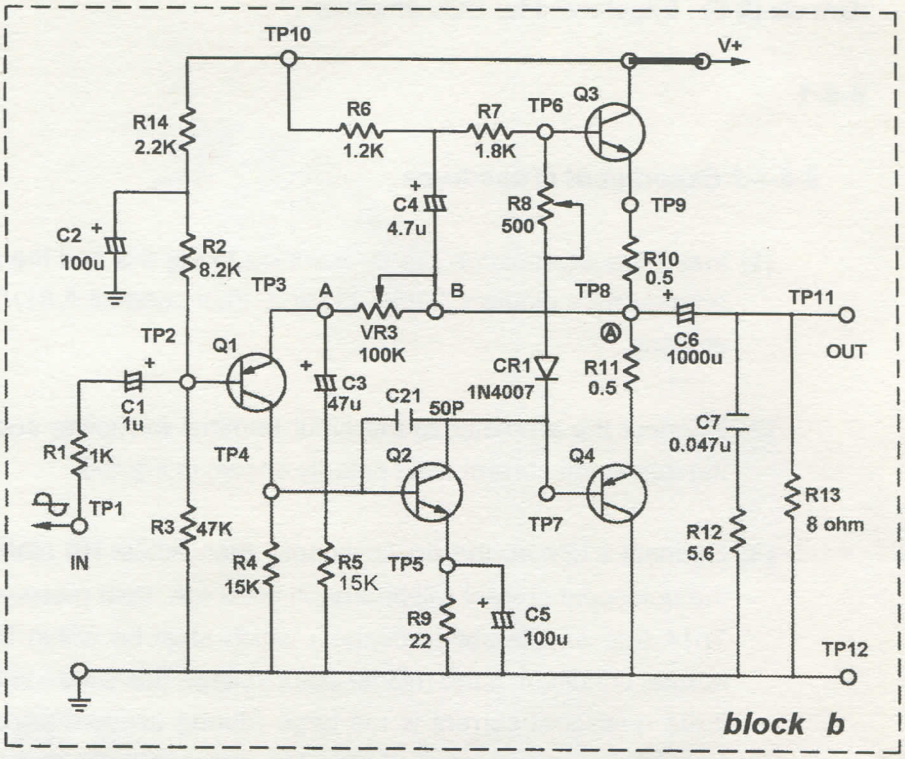


Fig 9-5 (Fig 23006-block b)

Item six (9-6) : Experiment for OCL amplifier

9-6-1

9-6-1-1 Experiment Procedures :

(1) Insert the short-circuit clip by referring to Fig 9-6 and the short-circuit clip arrangement diagram 23007-block a, then connect A 8Ω/20W resistor as the load.

(2) Connect the ammeter to the input terminal for power supply to measure the quiescent current, with polarity shown in Fig 9-6.

(3) Connect ±12V as the power supply, then adjust R9 (SVR 100Ω)so that the quiescent current will approach to 20 mA, then measure the voltage at Tp14 (the middle-point voltage) which shall be within 0V ±0.5V during normal condition. If the middle-point voltage has exceeded ±1V, watch out if the quiescent current is too large (during useless adjustment) and the transistor is over-heated. If yes, The power supply shall be turned off to check the circuit. Referring to the description for principle, the circuit check can be carried through the following steps:① Ohmic test -- Check if there is any short circuit in each transistor. ② Static test -- Connect the power supply, then measure the values of Vbe and Vce of each transistor, wherein these values shall be used to judge the status of each transistor after the power supply has been connected. (Plear refer to the principle description in Chapter 6 -- Transistor Amplifier.)

(4) After the middle-point voltage and quiescent current have been normal, connect signal generator and oscilloscope in the input terminal (IN), and connect oscilloscope to the output terminal (OUT). Adjust the signal generator to 1KHz sine wave and gradually increase the output voltage of signal generator so that the oscilloscope can display maximum non-distorted waveform of this amplifier output.

(5) Use oscilloscope to measure the waveforms of each test point, then view each waveform.

(6) Adjust R9 (SVR100Ω) to minimum, then view if crossover distortion is generated in the waveform of Tp14.

(7) Adjust R9 (SVR100Ω) to maximum, then view if power transistors Q5 and Q6 are over-heated. During normal status Q5 and Q6 shall be slightly over-heated while input signal is applied to this amplifier.

(8) When the middle-point voltage and quiescent current have been adjusted to normal condition, change the connections to 8Ω/20W speaker for output terminal and to other signal source such as CD or walkman ... etc. for input terminal, then listen to the music.

(9) Remove the signal source, then use finger to touch the input terminal, and low-frequency noise shall be heard from the speaker.

9-6-1-2 Experiment Result :

View the waveforms of each test point and Vbe, Vce of each transistor, then record the following items:

① Middle-point voltage (Va)
② Quiescent current (Icc)
③ Vin
④ Waveform of Vout ;

then calculate $Po = Vop\text{-}p^2 / 8Rl$, and record in Table 9-6.

	waveform	Va	Icc	Po
Vin				
Vout				

Table 9-6

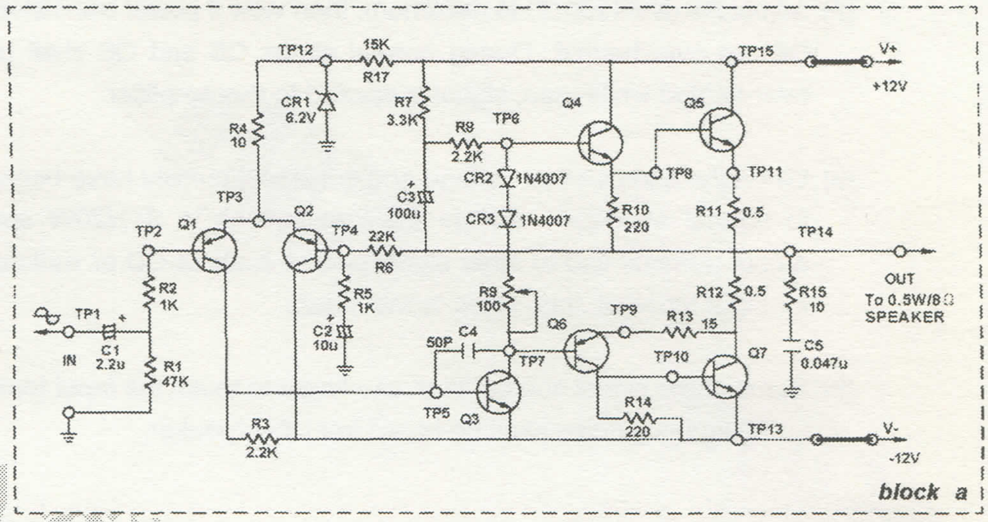


Fig 9-6 (Fig 23007-block a)

Item seven (9-7) : Experiment for OTL audio amplifier IC

9-7-1

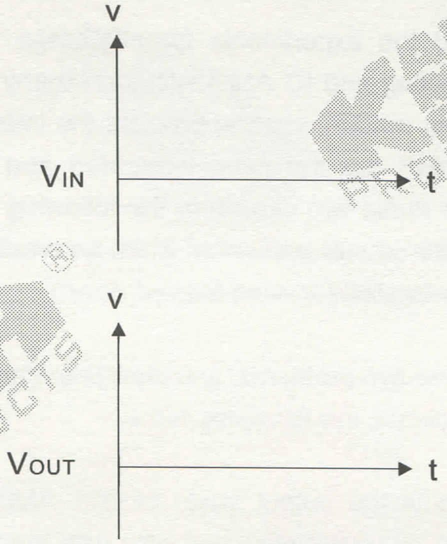
9-7-1-1 Experiment Procedures :

(1) Insert the short-circuit clip by referring to Fig 9-7 (a) and the short-circuit clip arrangement diagram 23006-block a, then connect A 8Ω/0.5W resistor as the load(R16).

(2) Connect signal generator to VR2 , then connect VR2 in the input terminal (INPUT)(Because the IC amplifier is ver large, so the input singal must be lower). Connect oscilloscope to the input terminal (INPUT) and the output terminal (OUTA). Adjust the signal generator to 1KHz sine wave and gradually increase the output voltage of signal generator so that the oscilloscope can display maximum non-distorted waveform of this IC output.

(3) Change the connections to 8Ω/0.5W speaker for output terminal and to other signal source such output of walkman for input terminal, then listen to sound effect.

9-7-1-2 Experiment Result :



$$Av = \frac{Vout}{Vin} =$$

$$Po = \frac{Vo^2p - p}{8R_L} =$$

Table 9-7 (a)

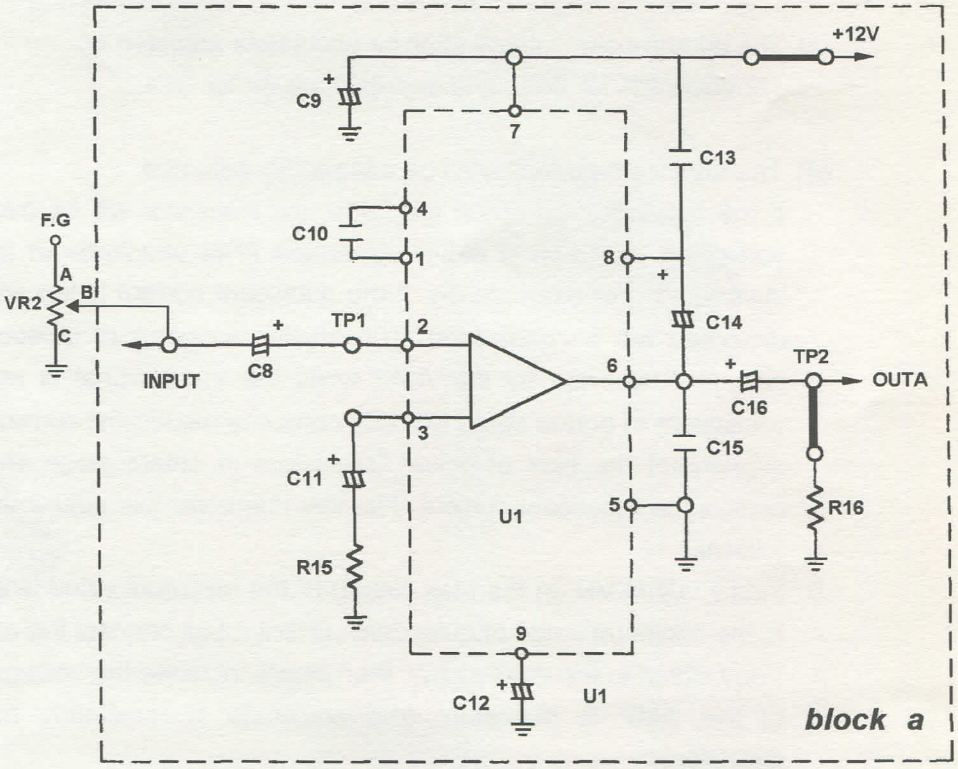


Fig 9-7 (a) (Fig 23006-block a)

9.5 Experiment Discussion:

This unit has discussed the experiments for multistage amplifiers, including the experiments for RC coupling and IC AMP. Although many experiments have been discussed in this unit, the readers shall appreciate the interrelation of the contents. Since OTL and OCL AMP are the most integrated and representative amplifier circuits, we will focus on these two circuits in the following detailed discussion. The following two problems are usually presented when an amplifier is assembled:

① The transistor is over-heated (or even burned down).

② The noise is great.

In order to solve the above two problems, you shall take care of, in addition to the correct assembly of the circuit, the following items:

(1) The transistors used in the output stage of OTL AMP shall select the pair of transistors with same characteristics and also with smaller leakage current. For the OCL AMP, the pairs of transistors with same characteristics shall be used for both output stage and input differential stage.

(2) Shall select the power supply with smaller ripple factor.

(3) The middle-point voltage shall be accurately adjusted to:
1/2 Vcc ± 2% for OTL; and approximate 0V for OCL.

(4) The quiescent current shall be adequately adjusted.
If the quiescent current is too large, the transistor will be over-heated, and the saturation distortion is easily generated (The amplitude of large signal will be clipped off. For example:→); if the quiescent current is too small, the crossover distortion will be generated. The implicit meaning of quiescent current is the current consumed by the AMP while the input signal is not applied. As the transistors of output stage typically consume the largest current, in the process of adjustment the bias of power transistors in output stage shall be adjusted to control the quiescent current. The key points for this adjustment is described as follows:

① Firstly adjust VR (in the bias circuit) to the minimum value which will correspond to the minimum value of quiescent current (shall connect the ammeter to view).

② Feed signal to the input signal, then slowly increase the voltage so that the output of this AMP is maximum (the amplitude is maximum, but with crossover distortion).

③ Slowly adjust VR to larger value (which will correspond to the larger quiescent current) and watch out for the variation of waveform, until the crossover distortion is just eliminated. If the peak is sightly clipped off, please lower down the voltage of input signal, or slightly increase the voltage of the power supply. The quiescent current that will eliminate the crossover distortion but still consumes very small current can be adjusted through the above procedures. Please refer to Table 1 foor the typical range of quiescent current.

Maximum collector power consumption of transistor (Pcmax)	1W~3W	3W~10W	10W~30W	30W~100W
Adequate quiescent current	1mA~5mA	3mA~5mA	5mA~10mA	10mA~30mA

Table 1

The transistors are easier to be burned down in OCL circuit comparing with OTL circuit. Moreover, because the speaker is easily damaged if the middle-point voltage is shifted from 0V during the abnormal status of the circuit, the speaker protector or fuse is typically incorporated in the output terminal of the OCL AMP to prevent the speaker from damage when the middle-point voltage is abnormal. Since the Co is used in OTL AMP to isolate the DC component, it is not necessary to incorporate the speaker protector. As Co is removed from the OCL AMP, this AMP is featured for superior frequency response. In order to decrease the percentage of IC burning-down, OTL configuration is widely incorporated in the internal circuit of IC AMP. The inverse coupling circuit including R14 and C2, as shown in the OTL AMP of Fig 9-5, functions to eliminate the ripple so that low-frequency oscillation will not be generated. The C4, referred to as reactance-rise capacitor, is used to rise the AC impedance of R7 in the circuit so that the amplitude in the positive half cycle will not be attenuated due to R7.

9.6 Repairs for Simulated Faults

Carry out the following repairs by referring to the test results of instruments along with the operating principle, but the electric iron is not allowed to be used. List the faulty parts, and briefly describe your steps for repairs.

9-1 : RC coupling amplifier as shown in Fig 9-1 (a).

1. Fault phenomenon:
   ① The DC bias of Q1 is abnormal, and the amplification of first stage is faulty.
   ② The DC bias of Q1 is abnormal, and the amplification of first stage is faulty.
2. Fault parts:
3. Steps for repairs:

9-2 : Direct coupling amplifier as shown in Fig 9-2 (a)

1. Fault phenomenon:
   ① The DC biases of Q1 and Q2 are abnormal.
   ② The DC biases of Q1 and Q2 are abnormal.
2. Fault parts:
3. Steps for repairs:

9-3 : Transformer coupling as shown in Fig 9-3.

1. Fault phenomenon: Amplification is faulty.
2. Fault parts:
3. Steps for repairs:

9-4 : Dual-end push-pull amplifier as shown in Fig 9-4.

1. Fault phenomenon:
   ① Amplification is faulty.
   ② There is no signal output.
2. Fault parts:
3. Steps for repairs:

9-5 : OTL AMP as shown in Fig 9-5.

1. Fault phenomenon:
   ① Crossover distortion is very serious.
   ② Middle-point voltage is abnormal.
   ③ Middle-point voltage is abnormal.
2. Fault parts:
3. Steps for repairs:

9-6 : OCL AMP as shown in Fig 9-6.

1. Fault phenomenon:
   ① Amplification is faulty.
   ② Middle-point voltage is faulty.
   ③ Distortion is very serious, and the quiescent current is too small.
2. Fault parts:
3. Steps for repairs:

9.7 Problems :

(1) Selection :

( ) 1. In order to acquire the best frequency response, which type of amplifier shall be selected?

1. Direct coupling.
2. RC coupling.
3. Transformer coupling.

( ) 2. The most widely used coupling type for amplifier is:

1. Direct coupling.
2. RC coupling.
3. Transformer coupling.

( ) 3. Which one will not affect the low-frequency response of the amplifier?

1. Junction capacitance of the transistor.
2. Coupling transistor.
3. Emitter by-pass capacitor.

( ) 4. For a three-stage amplifier, if the voltage gains Av for each stage are 50, 100 and 200 respectively, what is the overall voltage gain of this amplifier?

1. 100db.
2. 80db.
3. 120db.

( ) 5. Which amplifier has the minimum distortion?

1. Class A.
2. Class B.
3. Class C.
4. Class AB.

( ) 6. Which amplifier has the maximum efficiency?

1. Class A.
2. Class B.
3. Class C.
4. Class AB.

( ) 7. All linear amplifiers adopt:

1. Class A.
2. Class B.
3. Class C.

( ) 8. For an output transformer with turn ratio 10:1, if a 8Ω speaker is connected in the secondary side, the impedance (Zo of the transistor) in the primary side will be:

1. 8 Ω
2. 8KΩ
3. 800Ω

( ) 9. The push-pull amplifier usually adopts:

1. Class A.
2. Class B.
3. Class C.

( ) 10. If it is required to eliminate the crossover distortion for the push-pull amplifier, we shall adopt:

1. Class A amplifier.
2. Class AB amplifier.
3. Class A amplifier.

( ) 11. The amplifier that operates in the non-linear region will generate:

1. Frequency distortion.
2. Amplitude distortion.
3. Phase distortion.

( ) 12. The middle-point voltage of OCL AMP shall be:

1. 0V.
2. 1/2 Vcc.
3. Vcc.

( ) 13. The OTL amplifier:

1. does not incorporate output transformer.
2. does not incorporate output capacitor.
3. incorporates dual power supplies.

( ) 14. The R14 and C2 in Fig 9-5 is referred to as:

1. inverse coupling circuit.
2. voltage divider circuit.
3. charge circuit.

( ) 15. The C4 of Fig 9-5 is referred to as:

1. filter capacitor.
2. by-pass capacitor.
3. reactance-rise capacitor.

(2) Practice :

1. The tone control circuit is shown in Fig (a). Please complete the assembly in accordance with the circuit diagram , and carry out the following experiment:

   ① While low-frequency (50Hz) sine wave signal is feeder to the input terminal and the oscilloscope is connected to measure Vo, adjust bass VR and treble VR, then view which one will result in better effect.

② While high frequency (higher than 2KHz) sine wave signal is feeder to the input terminal, adjust bass VR and treble VR, then view which one will result in better effect. Alternatively, while the 500Hz square wave is feed to the input terminal, adjust bass VR and treble VR, then view the variation status of square wave. If the strength of treble and bass can be identified from the variation of this square wave?

③ After the test has been completed, connect the output terminal of this tone control circuit to the input terminal of OTL or OCL to complete a simple AMP.

④ Connect the crystal pick-up or other signal source to the input terminal of this tone control circuit, then connect a speaker to the output terminal of OTL or OCL, and test the sound effect.

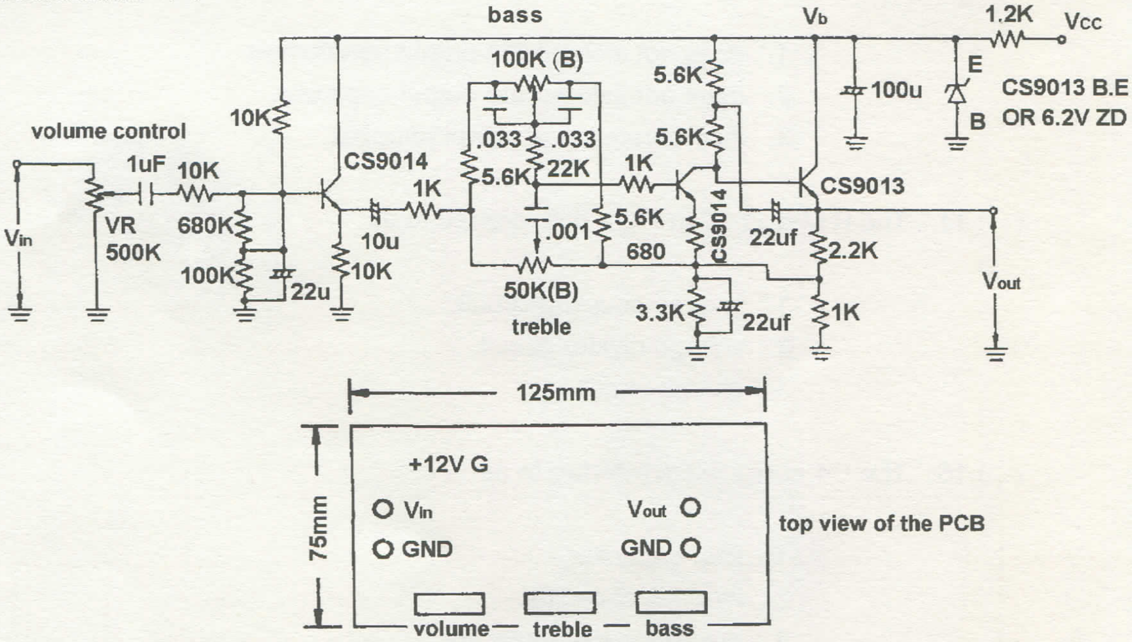


Fig (a)

Operation Contents and Instruction	Used Machines, Tools and Others
1. Adjust the bias of TR3 by adjusting the resistor 100K so that Vre of TR3 will be equal to 1/2 Vb. 2. Adjust Re of TR2 so that the voltage Vre2 will approach to 1/2 Vb and Ic2 of TR2 ≒ Ic1/5=500 μA	1. Oscilloscope. 2. power supply. 3. signal generator.

2. The speaker protection circuit is shown in Fig (b). Please complete the assembly in accordance with the circuit diagram, and carry out the following experiment:
   ① If the voltage applied in IN is abnormal, view if the relay is still turned on.
   ② View the magnitude of abnormal voltage while the relay keeps turning-on.

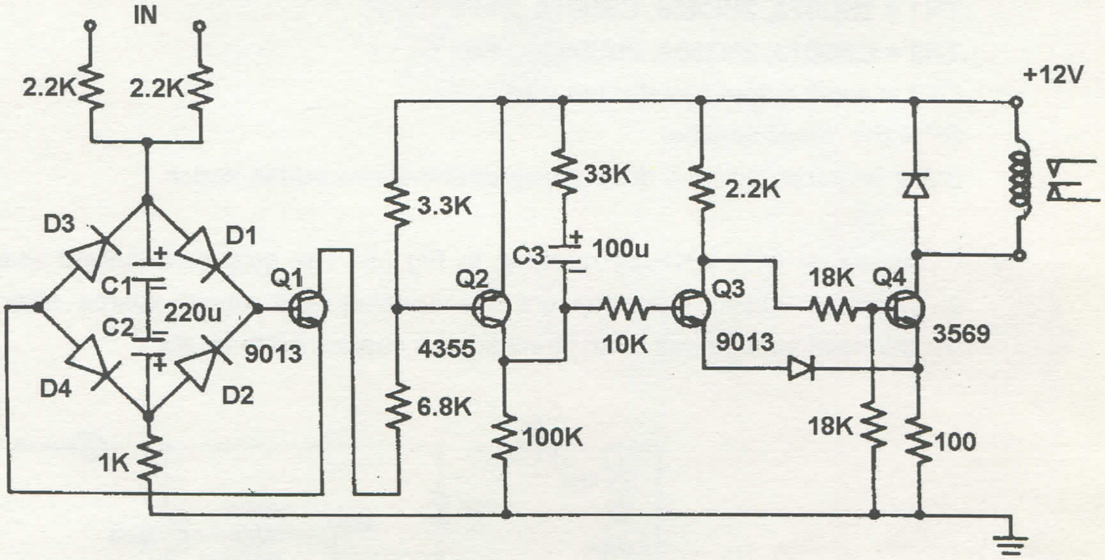


Fig (b) Speaker Protector

3. By referring to Fig (c), use the following materials to complete an intercom circuit.

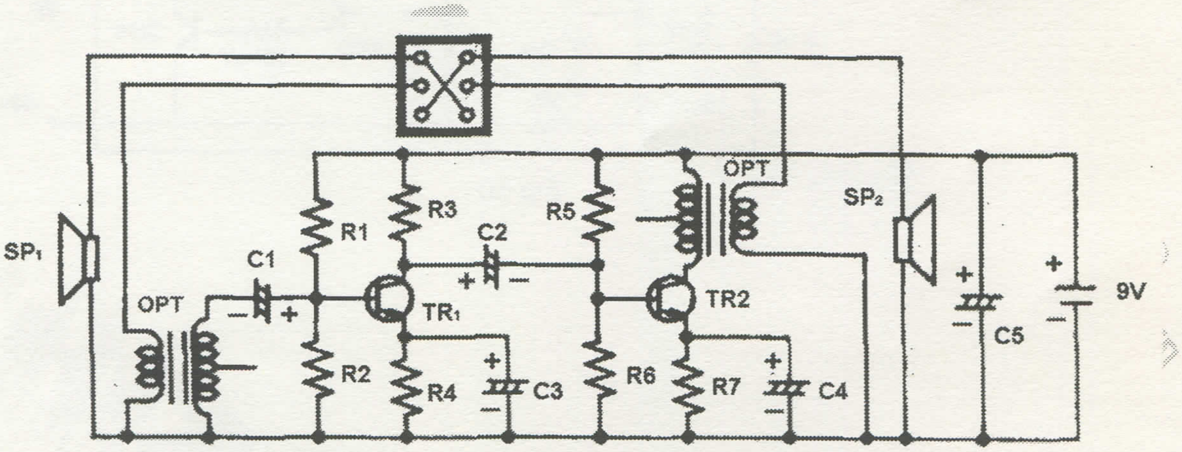


Fig (c)

Materials:

R1 = 33K R2 = 10K R3 = 4.7K

R4 = 1K R5 = 5.6K R6 = 4.7K

R7 = 100Ω C1 = 4.7 μF C2 = 4.7 μF

C3 = 10 μF C4 = 33 μF C5 = 33 μF

TR1 = 2SC373, 2SC458, CS9014 ... etc.

TR2 = CS9013, 2N3569, 2N3053 ... etc.

OPT = small output transformer (red).

SP = 8Ω small speaker.

SW = intercom switch = double-pole double-throw button switch.

4. Complete an OCL AMP by referring to Fig (d). The quiescent current shall be adjusted to 30mA, then connect the speaker and signal source after the middle-point voltage has been checked and conformed to be 0V.

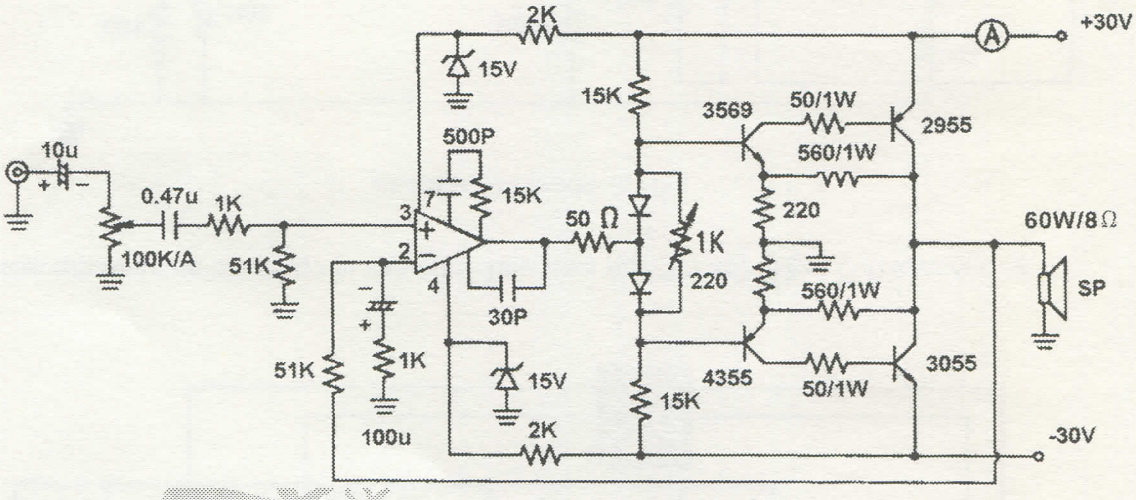


Fig (d)