POWER

Power is basically the rate of doing work, or the rate of producing or consuming energy. The unit that power is measured in is the WATT. One watt of power results when one volt produces a current of one ampere. This relationship is expressed as P=I X E. Power developed is equal to the current flow through a device times the voltage dropped by the device. Two other formulas used to indicate power are $P=I^2$ X R and $P=E^2/R$.

An example of power is as follows: Figure 1 shows a waterwheel that is attached to a generator, which is connected to a battery.

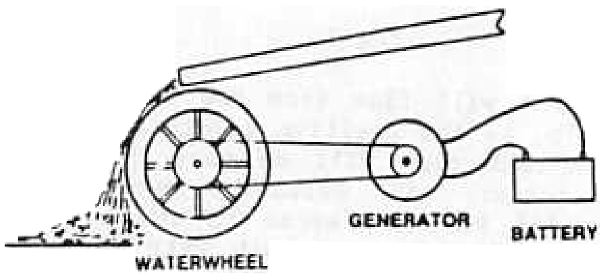

Fig 1.

There is a certain amount of potential energy in the water as it drops in elevation. Flowing across the waterwheel, the water gives up part of its power or energy to the wheel which in turn uses the energy to turn the generator. Power has been transferred from the potential energy of the water to the generator. As the generator turns, it produces current flow which will be used to charge the battery. The mechanical energy of the waterwheel has now been converted to electrical energy and stored in the battery. Some of the power applied to the waterwheel will be used to overcome the friction of the bearings in the wheel and generator. This energy is converted to heat. Some energy is lost due to the resistance of the wires connecting the generator to the battery and is also given up as heat. This heat is wasted energy that serves no useful purpose. Once the battery has been charged, a certain amount of power has been stored in the battery. Figure 2 indicates the battery is now connected to a light bulb.

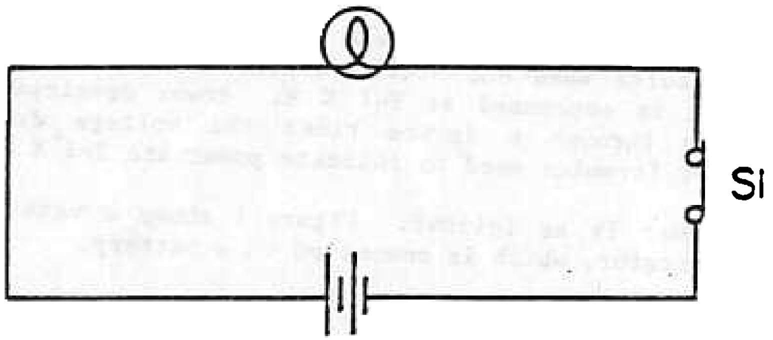

Fig 2.

When S1 is closed, current will flow from the negative terminal of the battery, through the bulb, to the positive terminal. With only the light bulb in the circuit, current flow will be very high and, if the bulb doesn't burn up, the battery will discharge very rapidly. The power stored in the battery will be transferred to the wires and lightbulb. With maximum current flow the wire and bulb will give off maximum heat which in this application will be wasted energy. The light given off by the bulb will be the useful work. Figure 3 shows a resistor has been added to the circuit.

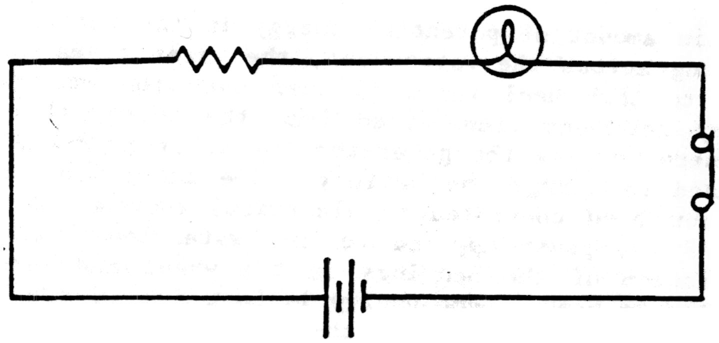

Fig 3.

Now, when the switch is closed, current will flow, the battery will discharge, and the power in the battery will be transferred to the lightbulb, but at a much slower rate.

We can see that energy or power cannot be created or destroyed but can be controlled and put to a useful purpose. Power is required to accomplish work and in this lesson we will be talking about power used to drive a speaker.

POWER AMPLIFIERS

Power amplifiers are designed to furnish signal energy to a load rather than signal voltage as with the small-signal amplifiers discussed in the preceding lessons. The load fed by a power amplifier may convert the signal energy to a physical movement as in the case of a loudspeaker.

Figure 4 is a very common type of speaker

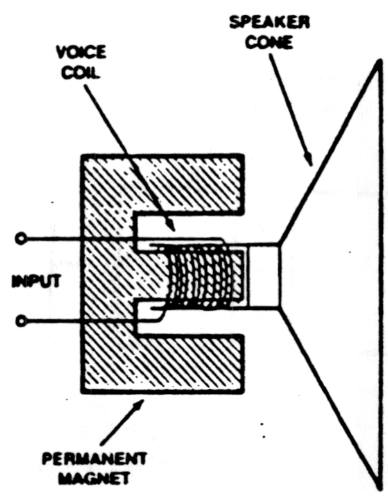

Fig 4.

In this type, a strong magnetic field is produced between the poles of a fixed permanent magnet. A small voice coil is suspended in the airgap and is attached to the speaker cone. When varying currents are applied to the voice coil, the interaction between the fixed field and the moving field causes the voice coil to move back and forth. This motion also causes the speaker cone to move back and forth, resulting in the alternating compression and expansion of the air in the form of sound energy. This conversion of electrical energy to mechanical energy requires a good amount of current which in this case we will call power.

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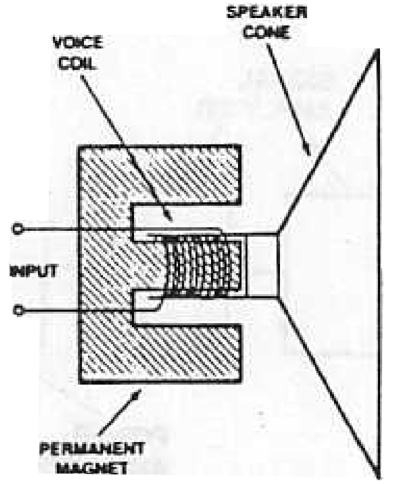

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In small-signal amplifiers, an impedance match is usually not important and in many cases, the load resistance is two or three times higher than the output resistance of the preceding stage. The reason for this is that a maximum transfer of power is not desired or needed because signal-voltage amplification is the primary goal. In power amplification, impedance matching is more closely adhered to in order to provide maximum signal-power transfer. When maximum power transfer is required, transformers will be used as coupling devices since their primaries and secondaries can be wound to provide various impedances. The following examples show how impedance mismatches can effect power transfer.

Low values of resistance will be employed to illustrate the application of Ohms law. Figure 6 shows a generator (G) with an internal resistance of 8Ω, which is represented as a series resistor (Rg), as shown at A of figure 6. The generator has an output of 48V. The load resistor (RL) is 8Ω and is in series with Rg. The total resistance is 16Ω. Thus, 3A of current flows through the network. The power consumed by the load resistance is 72W. This is clearly evident from simple Ohm's law calculations, as follows.

$$\text{Current (I) through network} = \frac{E}{R} = \frac{E}{Rg + RL} = \frac{48}{16} = 3A$$

Voltage (E) across RL = I x RL = 3 X 8 = 24V

Power dissipated in RL = ERL X I = 72W

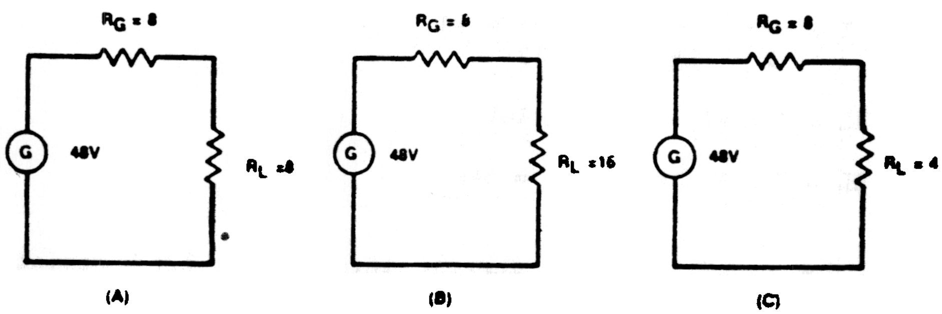


Fig 6.

As long as the generator voltage remains at 48V and its internal resistance is 8Ω, no other value of load resistance will furnish as much power as one having an 8Ω value. When the load resistance has a value either higher or lower, less power will be developed in it. In B of fig 6, the load resistance has been changed to 16Ω to illustrate how the power in the load decreases when its resistance is other than 8Ω. With the 16Ω load resistance, the power in the load drops to 64W, as indicated by the following calculation:

$$I = \frac{E}{R} = \frac{E}{Rg + RL} = \frac{48}{24} = 2A$$

E across RL = I X RL = 2 X 16 = 32v

Power in RL = ERL X I = 32 x 2 = 64W

It will be noticed that, in this instance, the voltage across the load resistor has increased and, if output voltage was desired instead of output power, the increase in the value of the load resistance would be preferable. Since, however, we are concerned with the power available across the load resistor, the power delivered from the generator to the load is of primary importance.

The opposite condition from B is shown at C, where the load resistance has now been reduced to 4Ω. By Ohm's law calculation, the power dissipation in the load resistor is again below the 72W obtained when the internal resistance of the generator matches the load resistance. This is indicated by the following calculation:

$$I = \frac{E}{R} = \frac{E}{Rg + RL} = \frac{48}{12} = 4A$$

E across RL = I X RL = 4 X 4 = 16V

Power in RL = ERL X I = 16 X 4 = 64W

It should be noted that the current through the load resistor at C of figure 6 is larger than when the load resistor matches the internal resistor of the generator, as shown in A. The lower value of load resistor a C, however, results in a lower voltage drop and a corresponding decrease in power output. As the value of the load resistor is changed, below or above that which constitutes a match with the internal resistance of the generator, the resultant power in the load resistor will always maximum when the impedances are matched.

In the preceding discussion on impedance matching the generator and load resistor that were used for illustration could have been the output impedance of a voltage amplifier and the input impedance of a power amplifier.

CLASSES OF OPERATION

Power amplifiers can be operated Class A, AB, or B.

In designing a power amplifier circuit there are three objectives: (1) minimum distortion of the signal, (2) maximum power output, and (3) maximum power source efficiency. All three objectives cannot be met simultaneously, there must be some compromise. For example, maximum power output usually has to be sacrificed for minimum distortion.

In a previous lesson it was pointed out that Class A operation provided the best reproduction of an input signal, (good fidelity), but was the least efficient of all classes of operation. Class B operation was more efficient than Class A but resulted in large amounts of signal distortion. Class AB falls somewhere between Class A and Class B as far as distortion and efficiency are concerned.

CLASS A POWER AMPLIFIERS

For audio power amplification, the only class of operation that should be used with one transistor is Class A. A single transistor can be used when low output power will do and a constant current drain from the power source can be tolerated. Figure 7 is an example of a SINGLE STAGE, CLASS A POWER AMPLIFIER.

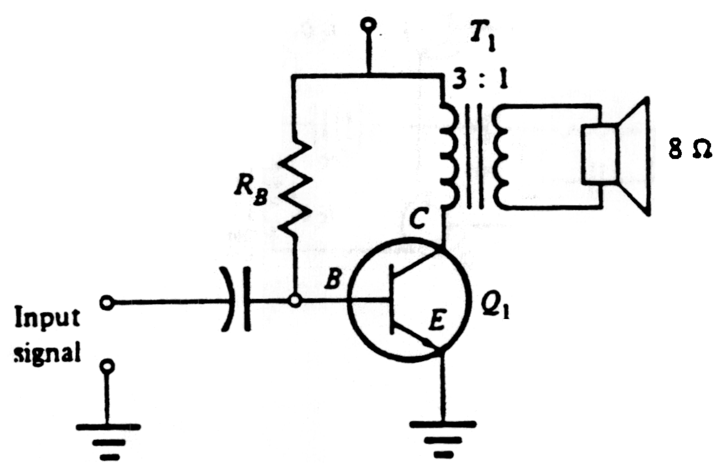


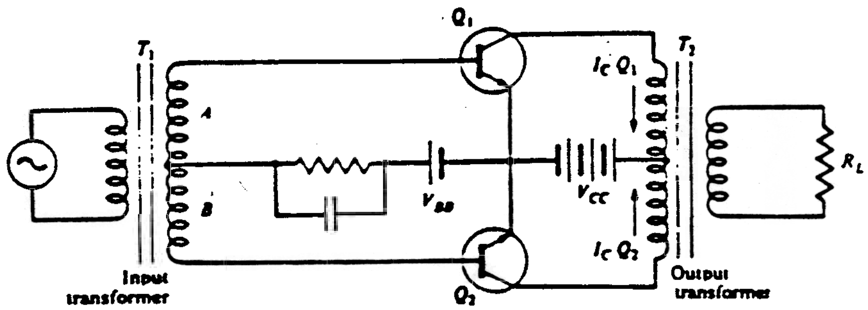
Fig 7.

Notice that the main difference between this circuit and those already covered in previous lessons is that the load resistor has been replaced with the primary of a transformer. The operation is basically the same as discussed in previous lessons. An input signal applied to the base will cause variations in the forward biased emitter/base junction resulting in variations in collector current. The primary of the transformer offers very little resistance to collector current so an adequate amount of power is developed to drive the output speaker. One use of this arrangement would be in a small portable radio where high driving currents are not required. Here, cost, weight, size, and fidelity would be determining factors.

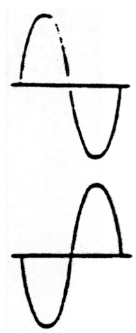
CLASS A PUSH-PULL OPERATION

Operation of transistor power amplifiers in a push-pull circuit is a means of developing more power output than can be obtained from a single transistor. Refer to figure 8(A). Two identical transistors are wired with their bases driven with signals from the opposite ends of a center-tapped input transformer, T1. The collectors of the transistors are fed to the opposite ends of a center-tapped output transformer. The use of identical transistors and center-tapped transformers results in a balanced circuit.

The signal applied to the primary of T1, the input transformer, produces a voltage across each half of the tapped secondary that is at any moment opposite in polarity (180 out of phase), but equal in amplitude. See figure 8(B).



A



B

Fig 8.

The two input signals 180 out of phase, are applied to the base of Q1 and Q2. They are then amplified, appear as the collector currents of Q1 and Q2 and flow through the primary of T2. The two collector signals, 180 out of phase, are combined in the output transformer where the phase of one signal is inverted so that it adds with the other. The combined signal is coupled to the secondary winding of the output transformer where it appears across the load, RL.

The combination of the output signals of Q1 and Q2 in the output transformer can be explained more easily if we assume a no signal collector current of 2A for each transistor. With no signal present the collector currents of Q1 and Q2 flow through the primary of T2 in opposite directions. The magnetic fields thus created are equal in strength but opposite in polarity; thus they cancel each other. This results in no induced voltage appearing in the secondary of T2, with no output voltage across RL and no magnetic lines of force in the transformer core.

When a signal appears across the secondary of the input transformer T1, we assume that, for the first 90 degrees of the input cycle, the forward bias for Q1 is increased and the forward bias of Q2 is decreased. See figure 9.

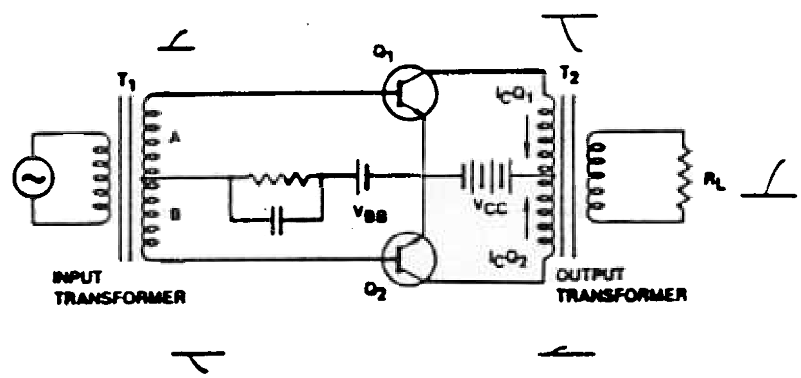


Fig 9

Assume, then, that for Q1, Ic will increase from a value of 2A to 3A, while the Ic of Q2 will drop from 2A to 1A. The magnetic fields, no longer being equal will not cancel. The rise in Ic of Q1 will produce a stronger magnetic field resulting in an output across RL. The drop in the Ic of Q2 will reduce the cancellation of a portion of the magnetic field created by Ic of Q1, resulting in a greater increase in the magnetic field and thus further increasing the induced voltage output appearing across RL.

For the next quarter of the input cycle the input signal reduces to zero and the collector current of both transistors return to 2A and no output is produced. See figure 10.

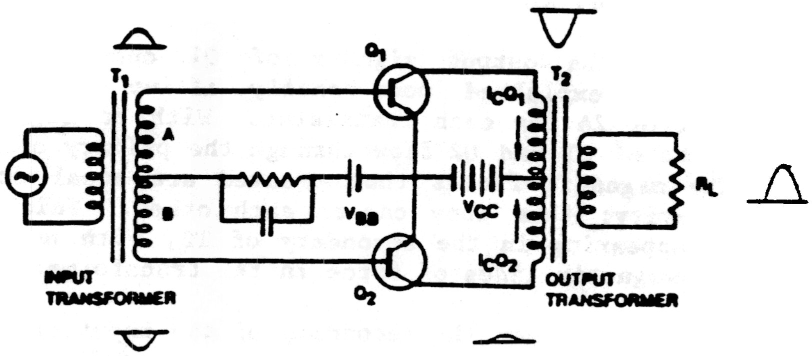


Fig 10

The next quarter of the input cycle brings the signal to 270 and causes the collector current of Q1 to drop from 2A to 1A and the collector current of Q2 to increase from 2A to 3A. See figure 11.

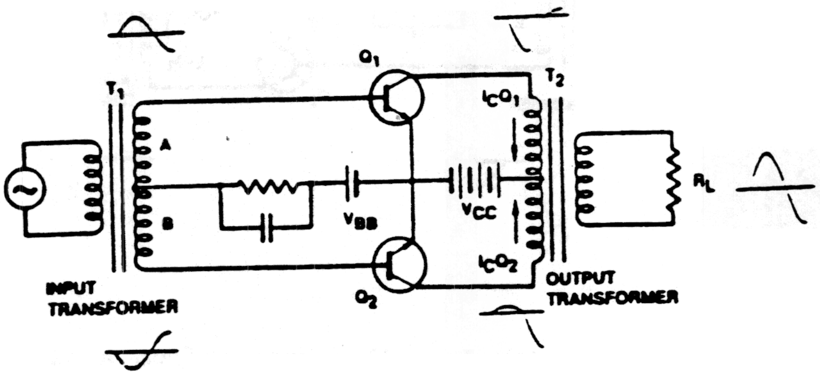


Fig 11

The magnetic fields, no longer being equal, do not cancel. The rise in Ic of Q2 produces a stronger magnetic field, resulting in an output across RL. The drop in Ic of Q1 reduces the cancellation of a portion of the magnetic field created by the Ic of Q2, resulting in a greater increase in the magnetic field and thus further increasing the induced voltage output across RL. The voltage across R1 is now of the opposite polarity.

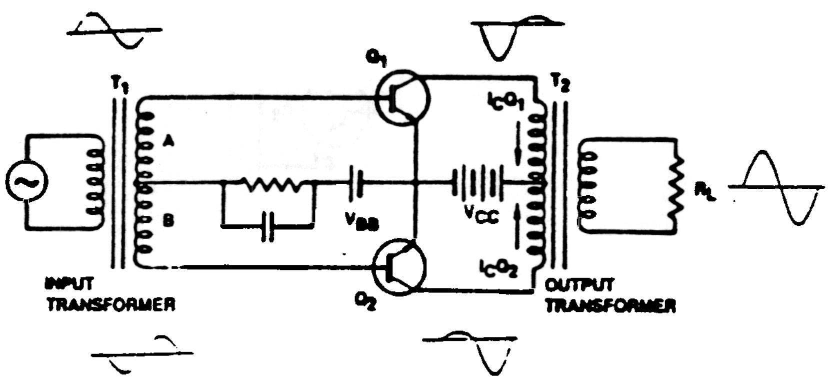


Fig 12.

In figure 12 the input has completed one cycle. The output signal will now contain enough driving current to operate an output device.

The use of the push-pull circuit results in benefits not obtained when using the same transistors in a single-ended operation. The current drawn from the power source will be constant because as IcQ1 rises, IcQ2 lowers a like amount, and as IcQ1 lowers, IcQ2 rises a like amount. The result is a constant load on the power source enabling it to maintain a constant output voltage. Disadvantages of Class A push-pull operation would be; (1) distortion due to mismatches of circuit components, thus requiring reasonably close tolerance components, (2) Class A puts a constant drain on the power source reducing the efficiency of the circuit.

CLASS B PUSH-PULL

While Class A push-pull circuits have a low distortion level, their efficiency is no better than 50%, as discussed in an earlier lesson. As a result Class B is employed in push-pull circuits so that efficiencies of close to 75% can be obtained. When Class B is used in push-pull, the high distortion level experienced in single-ended Class B is reduced to acceptable levels. A Class B push-pull amplifier configuration is shown in figure 13.

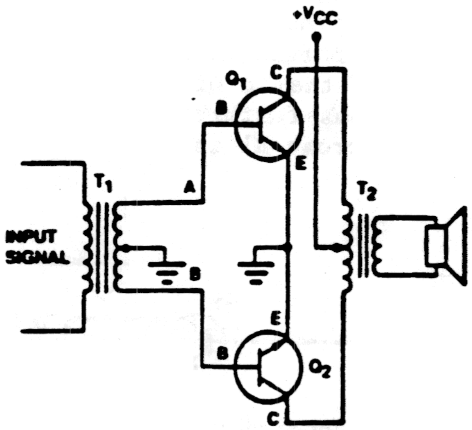


Fig 13.

The circuit is generally the same as that just discussed for Class A push-pull, except that there is NO forward bias. The circuit is biased at cutoff.

When no signal is present, the current drain from the power source is zero, both Q1 and Q2 are cutoff. When a signal is applied to the primary of T1 a negative going signal will be felt by the base of Q1, driving it deeper into cutoff. The base of Q2 is driven positive, causing it to come out of cutoff and produce collector current flow. The collector current flows through the primary of T2 and the signal is coupled to the load, R1. During this half of the cycle, Q1 has not operated at all. See figure 14.

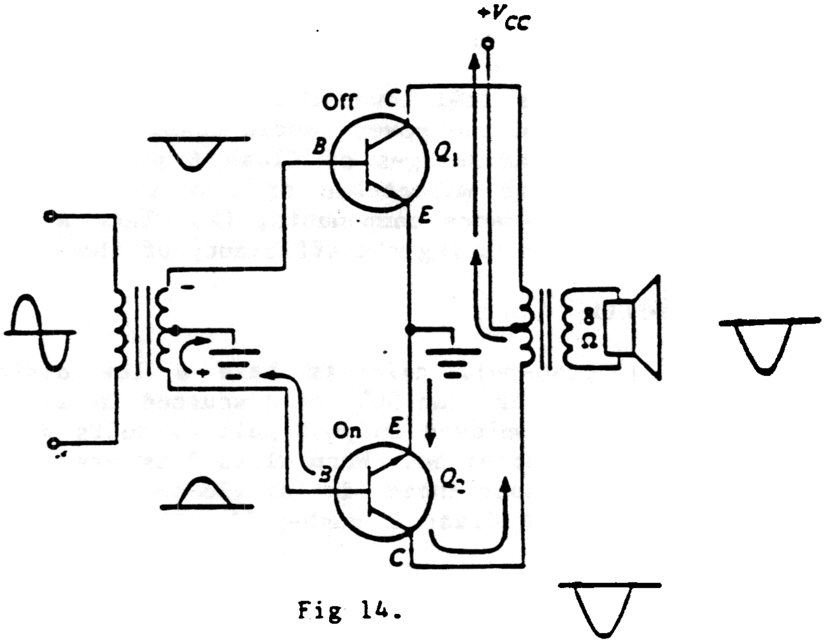


Fig 14.

-During the second half of the cycle, the polarity of T1 reverses and the base of Q1 is driven positive, causing Q1 to conduct, while the base of Q2 is driven further into cutoff. The collector current of Q1 flows through T2 which inverts the phase and delivers the second half of the cycle to the load, R1. See figure 15.

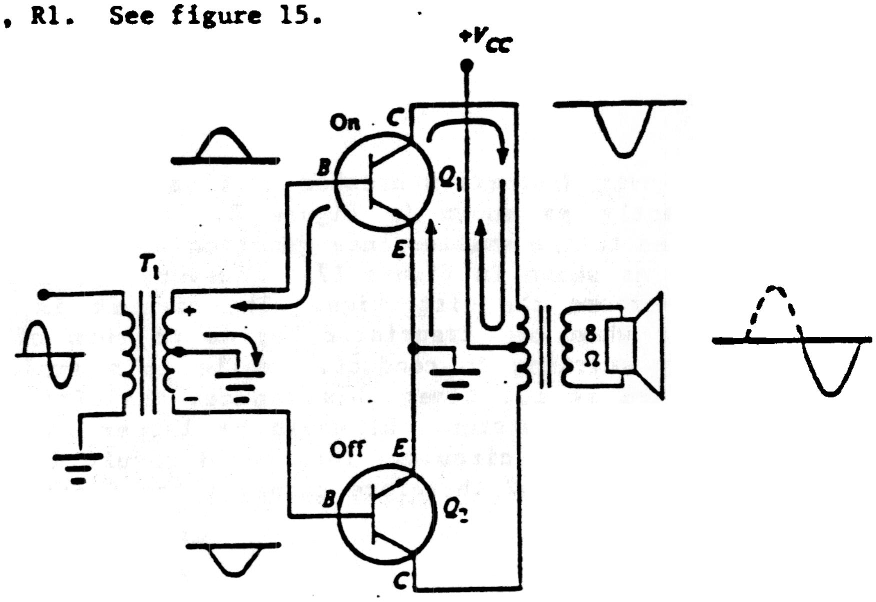


Fig 15

The collector current is not distortion free but in fact distorts at the point at which one transistor cutoff and the other begins to conduct. The result is CROSSOVER DISTORTION. See figure 16.

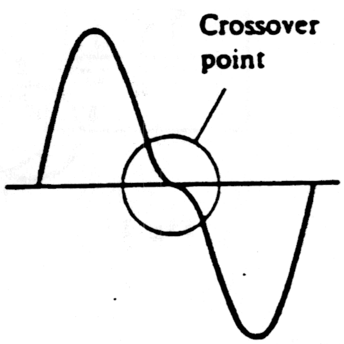


Fig 16.

Unlike Class A push-pull, Class B operation makes great demands on the ability of its power source, VCC, to maintain a constant output voltage under a varying load. With no input signal, the Class B push-pull stage draws no current and then rises to maximum upon application of full signal. The major benefit of Class B push-pull operation as compared to Class A is the increased efficiency, in the order of 75%, at the sacrifice of low distortion levels.

CLASS AB PUSH-PULL

Because of the cross-over distortion created by Class B operation, it is not always used exactly as shown in figure 8. Some small amount of forward bias is applied to the emitter/base junction so that in appearance the circuit would be as shown in figure 17. However, the amount of bias is only enough to overcome the distortion. The circuit is biased just above cutoff so that when one transistor begins to turn off the other transistor is already starting to conduct. While this small amount of forward bias is applied at all times this reduces the efficiency but it also drastically reduces distortion. R1 would be larger in this circuit than in the Class A push-pull circuit. This would result in less forward bias being applied to Q1 and Q2 therefore changing the Class of Operation from Class A to Class AB.

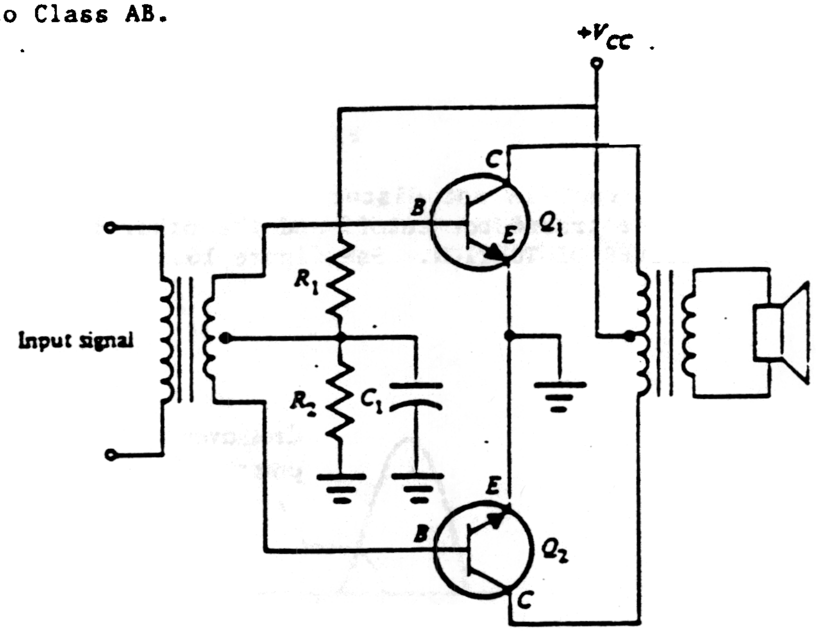


Fig 17.

DRIVER AMPLIFIERS

Many power amplifiers require large input signals in order to produce their rated output currents. Because of this, the stage that feeds the power amplifier is frequently also a power amplifier but operated at a lower power level. In most instances, this stage, called the driver, is a low or medium-powered Class A amplifier. Driver amplifiers can be either transformer coupled or capacitor coupled to the power amplifier.

COMPLEMENTARY SYMMETRY AMPLIFIERS

The input transformer and the output transformer of the Class AB power amplifier can be eliminated by replacing Q1 and Q2 with opposite-polarity transistors. Figure 18 shows an example of this amplifier connection. It is called the Complementary Symmetry Amplifier. The action of this circuit is very similar to that of a push-pull amplifier. Positive dc voltage is developed at the emitter/base junctions to bring the transistors into Class AB operation. In the static mode both transistors are biased on very slightly and a very small trickle current is flowing through them.

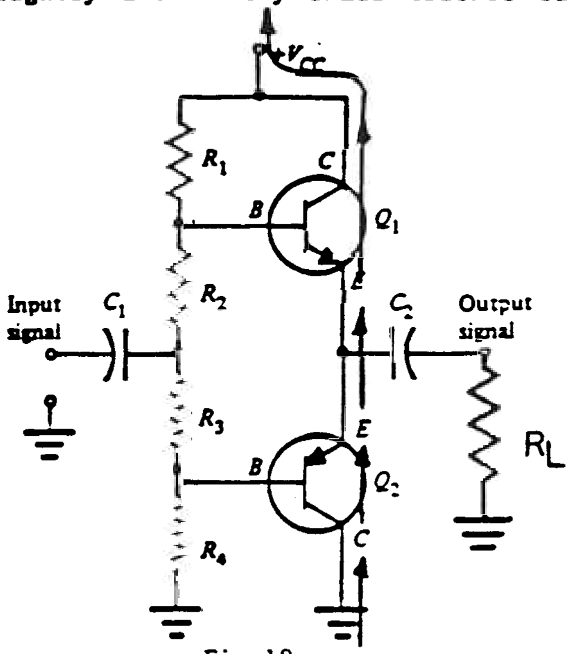


Fig 18.

See figure 19. A positive going signal applied to the circuit will be felt at the base of both Q1 and Q2. This positive going signal will increase the forward bias of Q1 causing it to conduct harder. At the same time the positive going signal will be applied to the base of Q2 which reverse biases it and turns it off. With Q1 conducting and Q2 cutoff, current will not flow up from ground, charge C2, negative on the right, positive on the left, through Q1 to the power source.

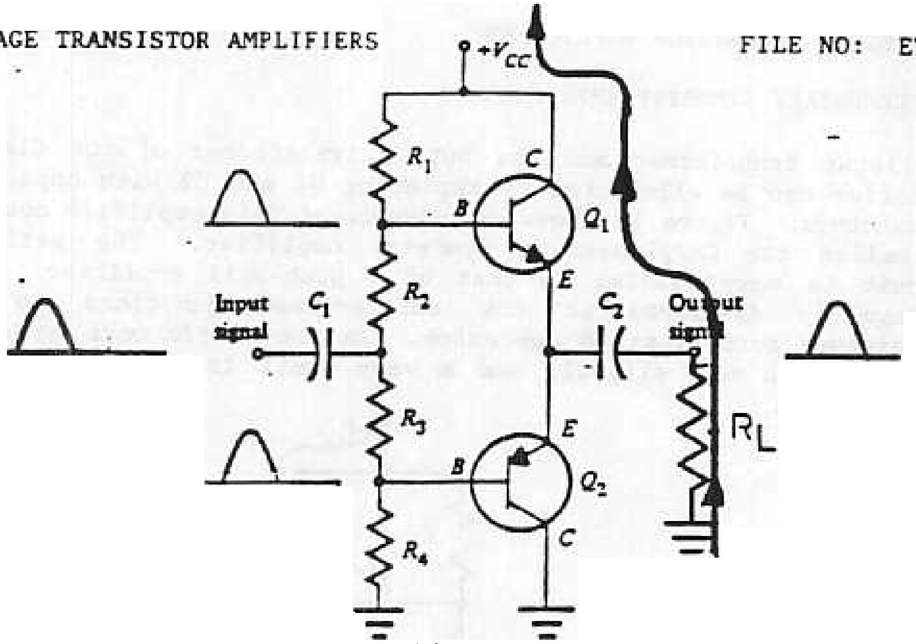


Fig 19.

See figure 20. Before the input signal was applied, both transistors were conducting. Current was just barely flowing, due to the low forward bias, up from ground, through Q2 to Q1, through Q1 to the power source. Since both transistors were conducting equally, they both had the same resistance. If VCC was 12V and both transistors were displaying the same resistance then both would drop the same voltage. Both emitters, being tied together, would read 6V.

With the input signal applied and Q2 cutoff C2 will charge to a higher voltage. Electrons being forced off the left plate of C2 make both emitters become more positive. A signal developed at the emitters will now be a positive going signal which is coupled through C2 at this time. The positive half of the output signal is developed across RL.

As the input signal goes negative Q1 now cuts off and Q2 begins to conduct. With Q1 cutoff the positive charge on C2 is now the applied voltage for Q2. C2 will now start to discharge. Electrons leave the right side of the capacitor, move down through RL to ground, come up from ground and through Q2 to the left side of C2. As C2 discharges down through Rl, it develops the negative half cycle of the signal.

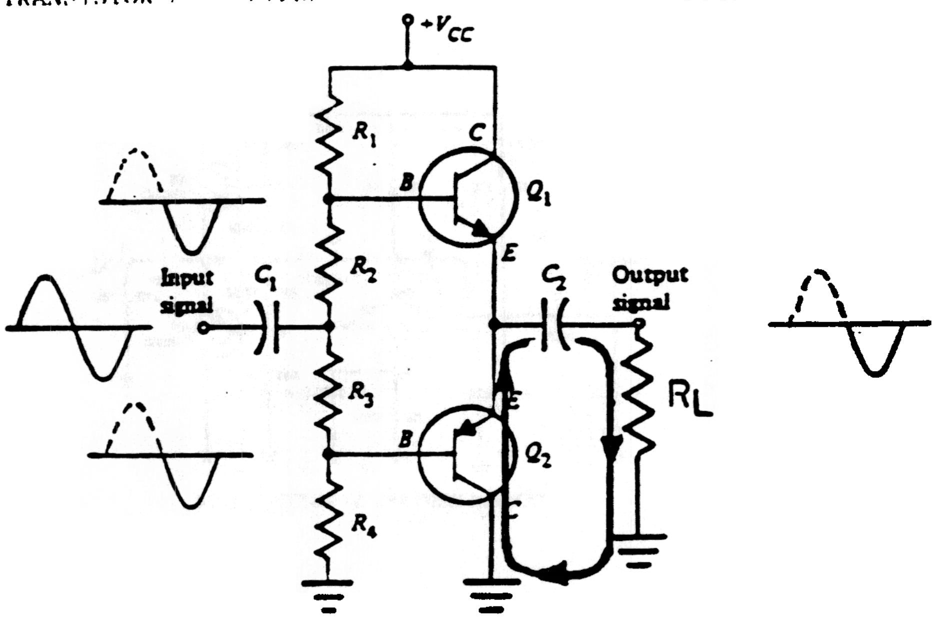


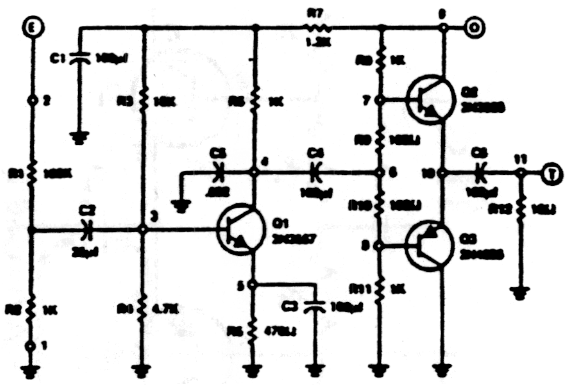
Fig 20.

The polarity of the input signal was responsible for turning the two transistors on and off. It will be remembered that this is the responsibility of the input transformer in the push-pull amplifier connection.

The output transformer of the Class AB amplifier is eliminated by the Complementary Symmetry Amplifier. The output from the amplifier is taken from the emitters. The transistors are connected in the Common Collector configuration. Since the Common Collector amplifier develops low output impedance, the output of this amplifier can be connected to a speaker. For this configuration to operate properly the components must be closely matched.

MULTISTAGE TRANSISTOR POWER AMPLIFIER CIRCUIT (PC 34).

Figure 21 is a schematic of the circuit you will work on during the practical exercise. It is PC 34 and is called the Complementary Symmetry Amplifier.



COMPLEMENTARY SYMMETRY PC 34

Fig 21.

Notice that the circuit is basically two circuits, or stages. Q1 and its associated components is the Driver stage, and Q2, Q3 is a Complementary Pair configuration.

The Driver stage will be used to provide sufficient driving currents required by the Complementary Pair. R1 and R2 make up a voltage divider that will develop the input signal for the circuit. They are not a part of the amplifier circuit and have nothing to do with current operation other than to determine the size of the input signal. R3 and R4 form a voltage divider which sets the bias for Q1 as well as aiding in the bias stabilization of the Driver circuit. R5 is the load resistor that will develop the output signal. Notice its small size in respect to the circuits already discussed. It's small size will allow for heavy transistor current. R6 is the emitter resistor used for biasing and stabilization. C3 is an emitter by-pass capacitor which prevents degeneration resulting from R6. C1 prevents any signal developed between R5 and R7 from being felt back on the base of Q1. C2 is the input coupling capacitor. C4 will couple the output signal of the Driver stage to the Complementary amplifier. C5, being very small in size, will be reactive to high frequency signals and will pass to ground any noise or high frequency oscillations that might develop in the Driver stage.

Notice that Q1 is connected in the common emitter configuration. The signal at TP4 will be 180 degrees out of phase with the input signal. Q1 will be biased so that it operates Class A, resulting in good reproduction of the input signal. The gain of the Driver stage is 25.

The positive alternation of the input signal will result in increased forward bias of Q1. The increase in forward bias results in heavier transistor base and collector currents. As more collector current flows through R5, more voltage is dropped by R5 resulting in a decrease of collector voltage and the development of the negative alternation. The negative input alternation will reduce the forward bias of Q1, decreasing base and collector currents. Less current through R5 results in its dropping less voltage causing collector voltage to swing more positive, and develops the positive alternation of the output signal.

Q1's collector signal is coupled through C4. The collector currents of Q1, (Driver Stage), result in high base currents in the Complementary Symmetry Amplifier. These high base currents will result in high emitter currents which would be used to drive an output device.

The Complementary Symmetry Pair consist of Q2, Q3 and their associated components. R8, R9, R10, AND R11 form a voltage divider that will develop the bias voltage for Q2 and Q3. Q2, (NPN), and Q3, (PNP), are opposite type transistors hence the name Complementary Pair. Although they are opposite type transistors, their operating characteristics are the same. C6 is the output coupling capacitor. R12 is a low value resistor that will be used as the load. An actual load in a circuit could be a speaker, motor, or another amplifier requiring high currents.

Both Q2 and Q3 are individually, connected in the Common Collector configuration. Characteristics of this configuration are high input impedance, low output impedance, high current gain, voltage (signal), gain of less than one, and no phase inversion. The high input impedance and low output impedance will allow its use between the driver, (high output impedance), and the load, (low input impedance). When connected as shown in Figure 21, Q2 and Q3 will be considered one stage whose configuration is push-pull.

The base voltage divider develops a low value of bias and both Q2 and Q3 will be biased for Class AB operation. Both transistors are biased just above cutoff. They could be biased Class A which would result in less efficiency, or Class B which would greatly improve efficiency but would also create distortion of the output signal by developing Cross over Distortion.

With Q2 and Q3 biased AB, and no input signal being applied, both transistors will conduct very lightly. Collector current will flow up from ground through Q3 to Q2, through Q2 to the power supply. Since both transistors are closely matched they will drop equal amounts of voltage. The voltage at TP10 would then be one-half the applied voltage, 7.5V if the applied voltage is 15V. C6 will charge to this value.

When a signal is applied to the circuit, Q2 and Q3 will alternately conduct and cutoff. With the positive alternation being coupled from the Driver Stage to TP6, TP7, and TP8, this positive alternation will be felt at the base of both Q2 and Q3. A positive signal at the base of Q2 will cause it to conduct harder. At the same time, a positive signal is felt at the base of Q3. Since Q3 was biased just above cutoff, the positive signal applied to the N type base will decrease the bias on Q3 and drive it into cutoff. With an increase in forward bias of Q2 it will conduct harder. With Q3 cutoff, current for Q2 must now flow from ground, up through R12, charging C6 to a higher value, (accumulating more electrons on the right side and forcing electrons off the left side), through Q2 to the power supply. If the input signal increased by 1V, the signal on the emitter of Q2, (TP10), would increase by something slightly less than 1V. Assume TP10 increased from 7.5V to 8.4V, (.9V increase). The current flow up through R12 will develop the positive alternation of the output signal and can be observed at TP11.

When the signal at TP6 swings negative, this change will also be felt at the bases of Q2 and Q3. The decrease in positive voltage will now drive Q2 into cutoff. The negative going voltage will now be felt as an increase in forward bias by Q3 and it will start to conduct. With Q2 cutoff, the charge on C6 will be felt by Q3 as its supply voltage (VCC). The emitter of Q3 will be more positive than the base or collector so all the requirements are met to forward bias Q3. C6 will now start to discharge. Electrons will leave the right side of C6, flow down through R12 to ground, up from ground through Q3 to the left side of C6. The current flowing down through R12 will now develop the negative alternation of the output.

Since current flows two directions through R12, bottom to top with Q3 cutoff and top to bottom with Q2 cutoff, the signal developed at the output is a true AC signal.

TROUBLESHOOTING

Before beginning to troubleshoot the card, it is very important to record the normal DC readings of the card as well as knowing what signals appear at various points in the circuit. The first step in troubleshooting the card would be to use the oscilloscope to check input and output signals. The input signal to the amplifier is at TP3. TP 4 is the output of the Driver Stage and should be an amplified and inverted signal.

TP6 is the input to the Complementary Pair. Since both Q2 and Q3 are Common Collector amplifiers, there should be no signal gain or amplification of the signal present at TP6 observed at TP10. The normal procedure would be to check the output, (TP11), input, (TP2), and midpoint, (TP4). If there is a good signal at TP4 and none at TP11, the defective stage would be the Q2, Q3 stage. The Complementary Pair is considered on stage. A good signal at TP3 and none at TP4 indicates the Driver Stage, (Q1), defective.

Once the malfunction has been isolated to a stage, DC checks and resistance checks should be used to isolate the faulty component. Keep in mind that the circuit is still a combination of voltage dividers. This fact should help when comparing known good readings to abnormal readings. Another thought to keep in mind is that when a component is opened or shorted it will change the impedance characteristics of the circuit which can result in what appear to be abnormal signals. When signals throughout the entire circuit are distorted, it is often impossible to correctly indicate the faulty stage by observing signals only. In this instance, it becomes necessary to take voltage readings around all the transistors to get into the proper area. If the problem is in either Q2 or Q3, the DC reading at TP10 will give a good indication as to which half of the Complementary Pair is malfunctioning. If TP10 is more positive than normal, the malfunction is likely to be in the Q3 area. If TP10 is lower than normal, the problem will be in or around Q2.

MULTISTAGE TRANSISTOR AMPLIFIERS FILE NO: ET09AL

SUMMARY:

During this conference a definition of power was presented and its effects were displayed. Impedence matching and its effects were discussed. The operation of a speaker and how it converts electrical energy to soundwaves was explained. Different types of power amplifiers were covered. Various types of push-pull amplifiers and their characteristics were discussed.

The operation of a multistage circuit (PC34) was covered and the following points were stressed: purpose of components, static mode, dynamic mode, and troubleshooting.