Online Radio & Electronics Course

Reading 26

Ron Bertrand VK2DQ
http://www.radioelectronicschool.com

AMPLIFIERS

DEGREES

The basic purposes of an amplifier is to do just that, to amplify (a signal). However, the way different types of amplifiers do this can vary greatly, and an amplifier can do other tasks besides amplifying. Generally when we speak of amplifiers we mean increase the power of a signal. We are starting to get into the building blocks that make up part of a radio system.

Signals that we actually amplify in radio and communications are very often not sine waves, though many times they are. For our discussion we will consider that we are amplifying a sinewave(s) of alternating voltage or current.

When discussing alternating signals it is usual to speak of a full cycle as being equivalent to 360 degrees. Fractions of a full cycle can then be more easily described. As an illustration, if a full 360 degrees sine wave of alternating current is sent to a rectifier, only 180 degrees of current will appear at the output. A halfwave rectifier or diode could be said to have an operating angle of 180 degrees. Similarly, different types of amplifier will provide at their output only a portion of the amplified input signal. An amplifier with an operating angle of 180 degrees will behave similar to a halfwave rectifier except that the output is amplified.

This is usually the hardest concept about amplifiers to grasp. It is bad to make the assumption: "what goes into an amplifier is the same as what comes out, only bigger". True in many cases, audio amplifiers for example, we want exactly what goes in to come out. We just want it to be louder or amplified. However, in radio circuits there are all sorts of other considerations. One of the main ones is efficiency of the amplifier, and a number of techniques are used to improve the efficiency. Typically, audio (sound) amplifiers have a very low efficiency, probably at best 30%.

We have covered the actual principle of amplification in the last two readings. A smaller voltage or current is used to control a much larger voltage or current. Most of the time this is done using one of the **active devices**, BJT, JFET, Triode etc. Now we cannot get power for nothing. The power supplied to the amplifier comes from the power supply, so if an amplifier has an efficiency of only 25%, that means for 25 watts of useable signal output we have to provide it with 100 Watts of power from the power supply. So efficiency, particularly at radio frequencies where the power tends to be high (perhaps 100,000 watts for a TV station), becomes important. Efficiency is not just important in terms of say running down batteries in portable equipment, but also heat. If a power supply is only 25% efficient, then 75% of the power is being converted into heat and this heat brings with it all sorts of other problems, particularly with semiconductors, and keeping them cool.

A little more on efficiency. An active device (in practice several active devices in a multistage amplifier) say a BJT, is forward biased which is normal. Even with no input

signal there is still emitter-collector current. So even though we are not doing any amplifying, the active device is consuming power from the power supply.

So accept just for now, that not all amplifiers actually amplify the entire input signal fed to them. Like the example given above, if an amplifier only amplified half of one cycle it would have an operating angle of 360/2 = 180 degrees. It may seem that if an amplifier does not have an operating angle of 360 degrees then what we put in (the input signal) will not be what we get out, and this is true. An amplifier that does not have an operating angle of 360 degrees distorts, or is non-linear. Sometimes this does not matter, other times it does.

Amplifiers fall into four basic categories called Classes, and you need to remember all (though I can never remember a question on Class AB). It is important you remember the classes and their efficiency, and the basic principles, and in a couple of cases you will need to identify a circuit. This does not mean you need to know the complete circuit operation.

CLASSES OF AMPLIFIER AND THEIR OPERATING ANGLES

Class A   360 degrees
Class B   180 degrees
Class AB   270 degrees
Class C   90-120 degrees

At the outset you should see that a Class A amplifier with an operating angles of 360 degrees amplifies all of the input signal - this is the basic definition of a linear amplifier, though more formally "without distortion" should be added. However, Class A operation is the least efficient. We will discuss efficiency later. Class A is used for small signal applications because of its poor efficiency, but nevertheless it is a quality amplifier. However we can do tricks with the others as well, to make linear amplification possible. In some cases we don't care if we have linear amplification.

A LOOK AT HOW THE CLASSES DIFFER

Take an active device such as an electron tube. If the control grid is made negative enough the anode current will fall to zero. This point is called **cutoff**. Decreasing the negative bias applied to the control grid increases the anode current linearly, until at zero bias the anode current is almost at maximum. Making the control grid positive will increase anode current slightly, but the electron tube quickly saturates.

(Saturation is when an active device is conducting its maximum current).

A fixed DC voltage applied to the control grid (bias) determines the class of operation. That's so important I will say it again - bias determines the class of operation. For Class A operation, the electron tube (or any active device) is biased at the centre of the linear portion (straight-line section) of the operating curve. Class B is biased at, or near, cutoff. In Class C operation the bias is about twice cutoff, though it can be higher. For Class AB, bias is about halfway between cutoff and the centre of the linear portion of the operating curve.

Radio hobbyists and professionals frequently use the term "linear amplifier" as a synonym for "power amplifier". Such usage is incorrect as power amplifiers can be linear or non-linear, depending on their application. For audio, Class A operation is the only single

ended amplifier that provides linear amplification. (Single ended means only one active device employed). Linear amplifiers do not distort the amplitude of the signal being amplified (within specified practical limits at least). It is possible to use Class AB and B as linear radio frequency (RF) amplifiers for amplitude modulated signals, since the output power is proportional to the input power. The missing cycle can be restored in the tank circuit (flywheel effect). Amplitude modulated signals are those which contain intelligence (or information) in their amplitude.

Since a Class B amplifier has an operating angle of 180 degrees, it is possible by using a pair of active devices, and to arrange for each device to amplify half of the sine wave, to combine the two amplified halves in the output to achieve linear amplification. Such an arrangement is called a class B push-pull and is most useful for audio amplifiers and RF amplifiers.

Class B is non-linear and has an operating angle 180 degrees. However, we can arrange two such amplifiers to look after each half of the input, and combine them after amplification in the output, to obtain the full signal with *linear* amplification

Why bother? Well we discussed that Class B was biased at or near cutoff, so with no input signal (the signal to be amplified), little or no current flows in the anode, collector or drain circuit - no power taken from the supply when no amplification is taking place means higher efficiency

AMPLIFIER EFFICIENCY

CLASS **A**   25-30%
Use:
Audio - low distortion
RF: Very inefficient

CLASS **B**   30-35%
Use:
Audio Power (push-pull)
RF power - all modes (modes are to be discussed)

CLASS **AB**   50-60%
Use:
RF Power Amplifiers all AM modes

CLASS **C**   60-80%
Use:
RF power - FM

We have not covered transmission modes. Most will be familiar with AM and FM radio stations. AM is amplitude modulation, the information, music, intelligence, is in the amplitude of the signal. FM is frequency modulation, the information, music; intelligence is in the frequency of the wave. Remember, a sine wave has two characteristics - think back to your basic sine wave. These characteristics are amplitude and frequency. Either can be modified to carry information (modulated), the amplitude or the frequency, and we can disregard the other without losing any information.

CLASS A – OPERATING CURVE

The characteristic curve diagram of figure 1 is that of an electron tube Class A amplifier. It could just as easily be for a FET or BJT. In an electron tube a negative bias is applied to the grid. In the diagram I have labelled the grid bias (above zero) as shown. The actual value in volts of the grid bias is of no significance, as it will vary from device to device. The graph is a plot of grid bias versus plate (anode) current. It is important to understand this graph. Forget the waveforms for a moment and just concentrate on the line on the graph, which is a plot of grid bias verses plate current. The plate (anode) current is on the vertical axis while the negative grid volts are on the horizontal axis. You can see on the graph that there is a point where the grid bias is so negative that no plate current will flow, and this point is labelled **cutoff**. Further along the curve is a spot marked operating point. This operating point is the amount of bias required for Class A operation. Note that the characteristic curve is really a curve, for if I had extended the curve a bit further upward it would have quickly flattened out, this is called saturation. Importantly, notice that a portion of the characteristic curve is a straight line. If the active device (here an electron tube) is operated on the straight line portion of its characteristic curve, then variations to the bias by the input signal superimposed on it will cause proportional variations in the larger anode current. Operating an amplifier on the linear portion (straight-line portion) means the amplifier will be linear and faithfully reproduce the output signal the same as the input signal. If I seem to be highlighting a lot it is because this must really be understood.
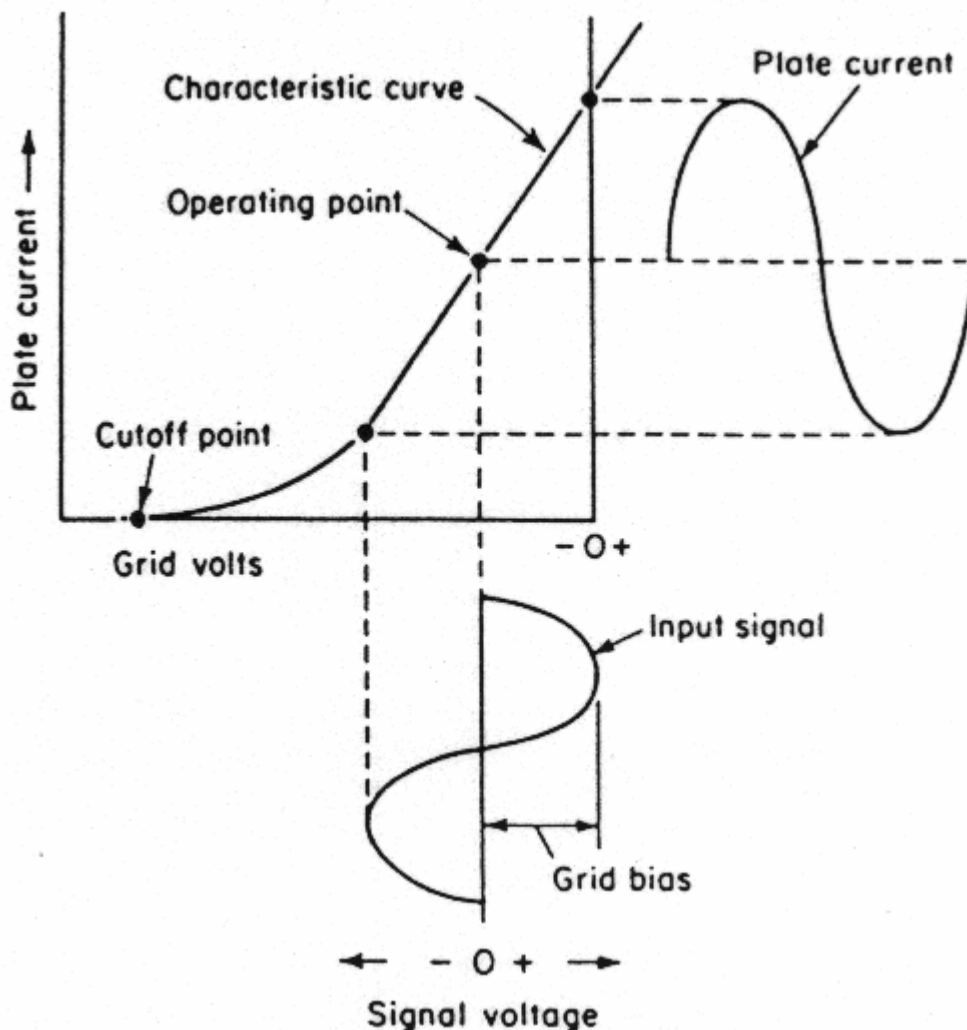

Figure 1 – Operating Curve for Class A Amplifier.

If the input signal drives the bias point into cutoff or saturation then the amplifier will produce distortion, and the output anode current will not be an exact representation of the input signal.

As an example, audio amplifiers (low power ones) often operate in Class A. Think of your TV or stereo system. If you turn the volume control up too high, the music will be louder but it will begin to sound distorted.

The volume control adjusts the level of input signal into the audio amplifier. When you turn it up too high you overdrive the amplifier causing it to go into the cutoff and saturation regions of the curve, and you hear it as distortion.

So figure 1 above demonstrates Class A operation. The active devices are operated on the linear portion of the operating curve. Since all of the input signal is amplified in a Class A amplifier, it is said to have an operating angle of 360 degrees.

CLASS B - OPERATING CURVE

Have a look at the operating curve of a Class B amplifier in figure 2. Notice the operating point is at, or near, cutoff.
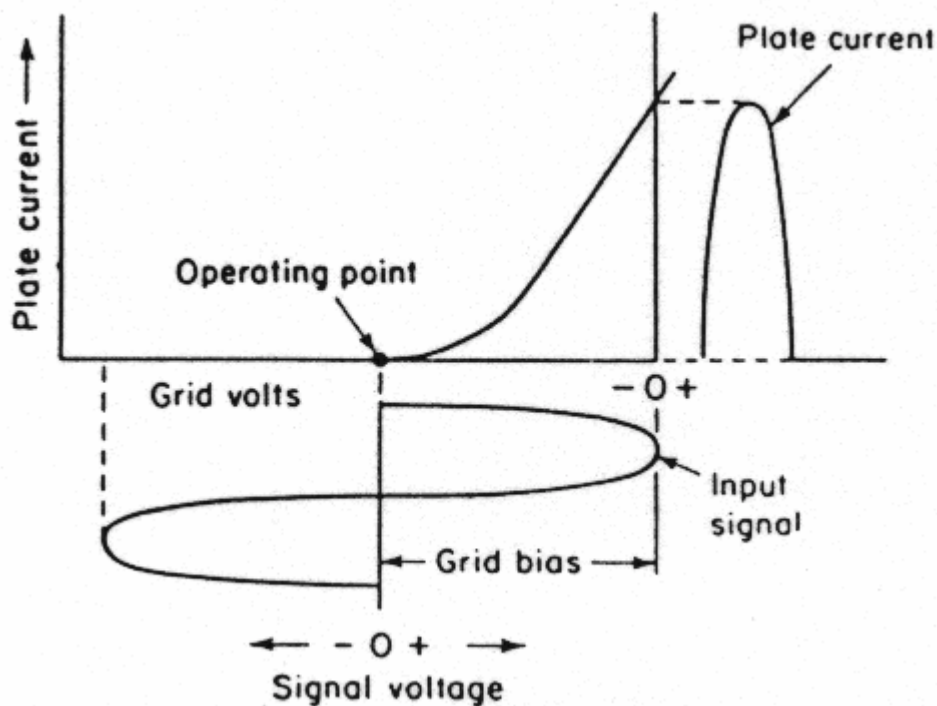

Figure 2 – Operating Curve for Class B Amplifier.

Cutoff is when the grid voltage is so negative that it prevents any electrons from flowing from cathode to anode. If the input signal is negative going, it takes the electron tube beyond cutoff and no anode (plate) current flows. However, if the input signal goes positive it will take the electron tube out of cutoff (to the right on the horizontal axis) and current will flow in the output and be amplified. As you can see by the diagram, only one half cycle of the input signal is amplified. A Class B amplifier is therefore *not* a linear amplifier. However, unlike a Class A, with no input signal there is no anode current in a Class B, so it is a more efficient amplifier. A Class B amplifier has an operating angle of 180 degrees. A combination of two Class B amplifiers configured correctly, one to amplify one half cycle and the other the other half cycle, can be used to produce linear amplification.

CLASS C - OPERATING CURVE

Have a look at the operating curve of a Class C amplifier in figure 3. Notice the operating point is beyond cutoff, at or near cutoff.
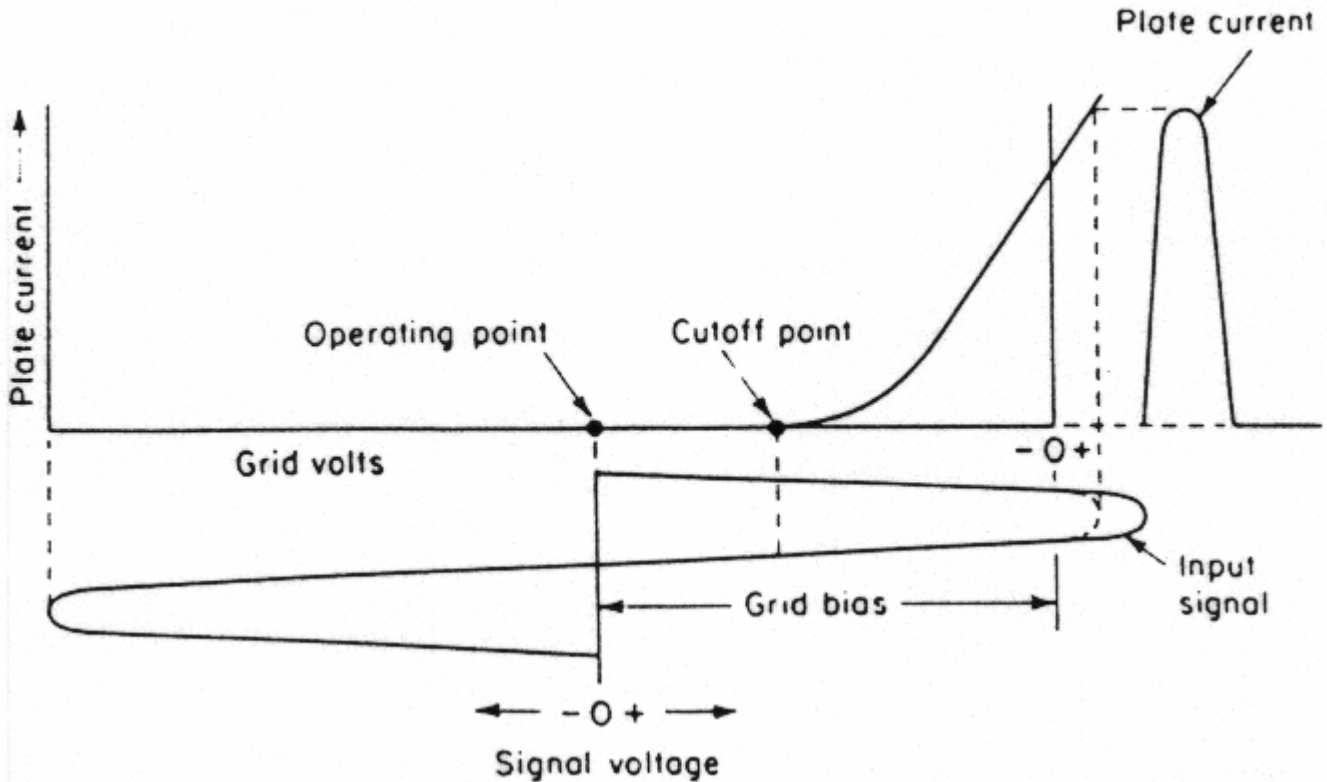

Figure 3 – Operating Curve for Class C Amplifier.

Not even one half cycle of input signal is amplified (180 deg). About 90 to 120 degrees of the input signal is amplified. A Class C amplifier causes massive distortion to the amplitude of the input signal. Don't be confused by the size of the input signal and the output signal (plate current) shown on any of these curves, their physical size on the curves does not represent their power levels. On all the curves, plate current is much larger and at a much high voltage than the input signal.

If there is information in the amplitude of the input signal it will be severely distorted. However, if there is information in the frequency of the input signal, there is no distortion, as the frequency of the signal that goes in, is the same as that which comes out. So if we have coded some information into the frequency (frequency modulation), the Class C amplifier is the only way to go, as it is the most efficient amplifier of all. A Class C amplifier can only be used at radio frequencies (RF).

We can restore the full cycle in the output of a Class C amplifier by using a tuned circuit in the plate of the electron tube. Such a circuit is called a tank circuit, and it will restore the other half cycle by utilising the flywheel effect.

CLASS AB

I will just mention that there is another Class of amplifier called Class AB - it is not in the syllabus. It is an improvement of the Class B. For linear amplification, two active devices like a Class B amplifier, are required. One problem with the Class B is that the operating curve is not quite straight for a little bit near cutoff. Even if you use two Class B amplifiers,

one for each half cycle, you get some distortion when one amplifier turns off (after one half cycle) and the other Class B amplifier turns on. This is due to the non-linear part of the operating curve near cutoff. The distortion that results is called crossover distortion. The Class AB is a minor modification of the Class B to overcome this problem.

ACTIVE DEVICES

I have used graphs of an electron tube to illustrate the operation of Class A, B and C, as I think it is easier to visualise. Any active device can be used for all of the classes of amplifier. For a FET we would have to speak of gate bias instead of grid bias, and drain current instead of plate current. The polarity of the bias voltage will be different depending on the type of active device used. Polarities are not important for this reading, I just used them because I was explaining the operation of the curves using an electron tube.

You may be presented with a circuit diagram of different amplifiers in the exam and basically have to identify them. The exam is multiple-choice, so you are presented with a circuit (schematic) diagram and asked to pick one of four choices of what it is. I have seen dozens of actual exam papers so I will show you a couple of schematics of amplifiers and give you the clues to identification. I may cover some of the operation only for the purpose of reinforcing some earlier material - a type of revision.

PUSH-PULL AMPLIFIERS

We spoke of a Class B amplifier as having an operating angle of 180 degrees. To obtain linear amplification we could use two Class B amplifiers, one to look after and amplify each half cycle. This type of amplifier is called a **push-pull**. Class A amplifiers can also be used in push-pull. The diagrams below are labelled Class A push-pull but they are virtually the same. If you do see a diagram like this it won't be ambiguous, the examiner will be testing you to see if you know what a push-pull configuration looks like. The bias would be set to about 0.66 of cutoff for Class A operation. For Class B operation (the most likely use) the bias is about 0.95 of cutoff.

Following is a brief description of the operation that will give you a bit more of an idea of what push-pull is, rather than just circuit identification.

Refer to the vacuum (electron) tube circuit of figure 4 and assuming class A operation (established by the Cathode resistor). With no signal applied to the grids, equal anode current will flow through V1 and V2 since the bias is the same to both tubes.

Both tubes are biased to the centre of the linear portion of their operating curves (Class A). Assume that I1 and I2 each register an anode current of 50 mA, then I3 will be I1 + I2 = 100 mA. Now suppose an input signal is applied via T1, which makes the top of the secondary 5 volts positive with respect to the centre tap and the bottom five volts negative with respect to the centre tap.
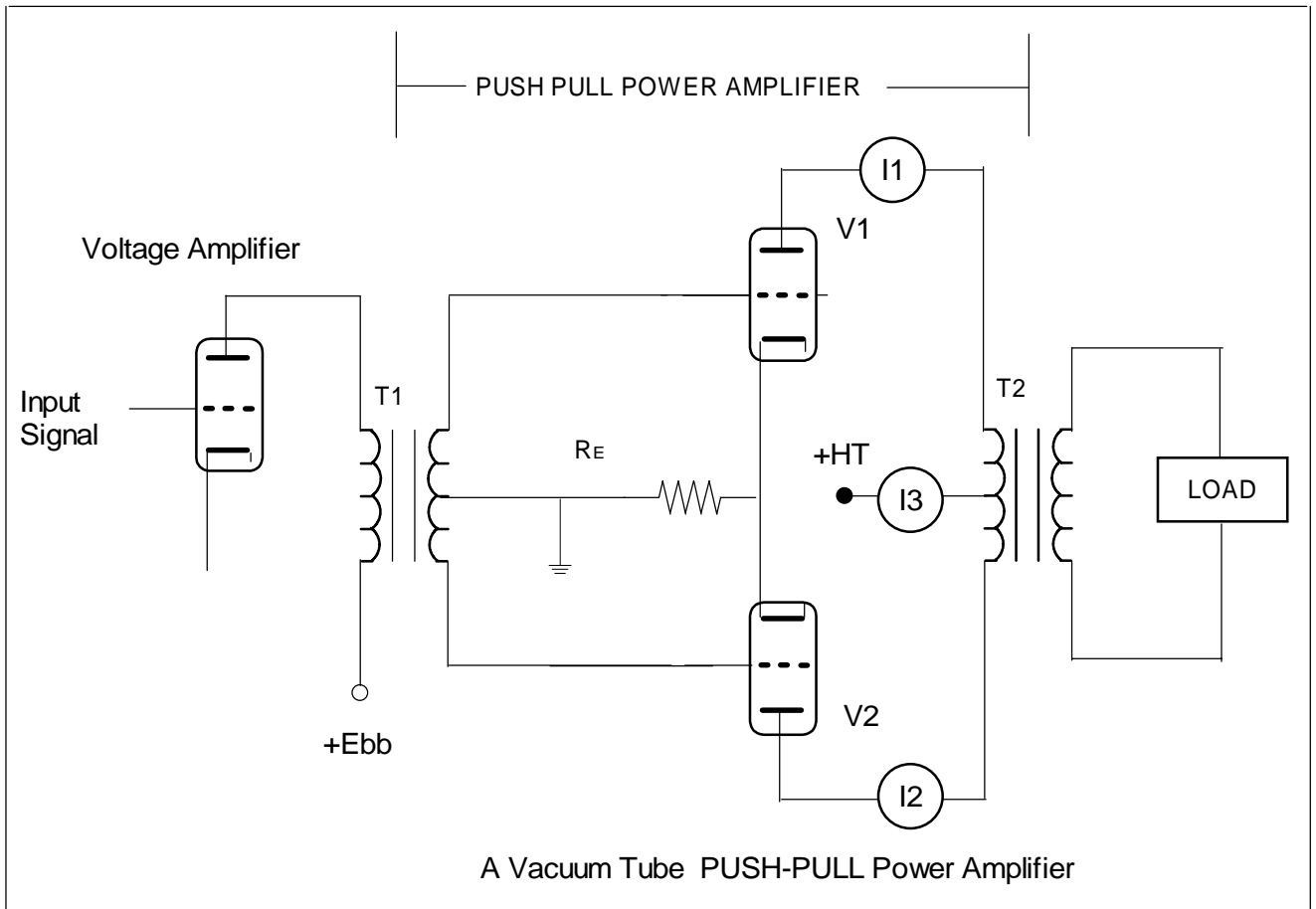
Figure 4.

In other words, the grid voltage on V1 will be 5V *less* negative while on V2 the grid voltage becomes 5V *more* negative. Assume that the reduced negative bias on V1's grid causes V1's anode current to *increase* by 10 mA, then the increased negative bias on V2's grid will cause the anode current to *fall* by 10 mA. I1 will now be 60 mA and I2 will be 40 mA. Notice that as one tube draws more current the other tube draws less, and the current I3 will remain constant.

On the next half cycle V2's anode current will increase and V1's anode current will decrease by a corresponding amount. T2's secondary voltage will be the resultant of each of the top and bottom primary currents. T2 also serves to match the high output impedance of the vacuum tubes to the low impedance of speaker.

The operation of the transistor circuit in figure 5 is the same, except that voltage divider bias is shown. With Class A operation the signal currents that flow through R_E are equal and opposite, and as such, net degenerative signal voltage will appear across the resistor, making the usual emitter bypassing unnecessary.
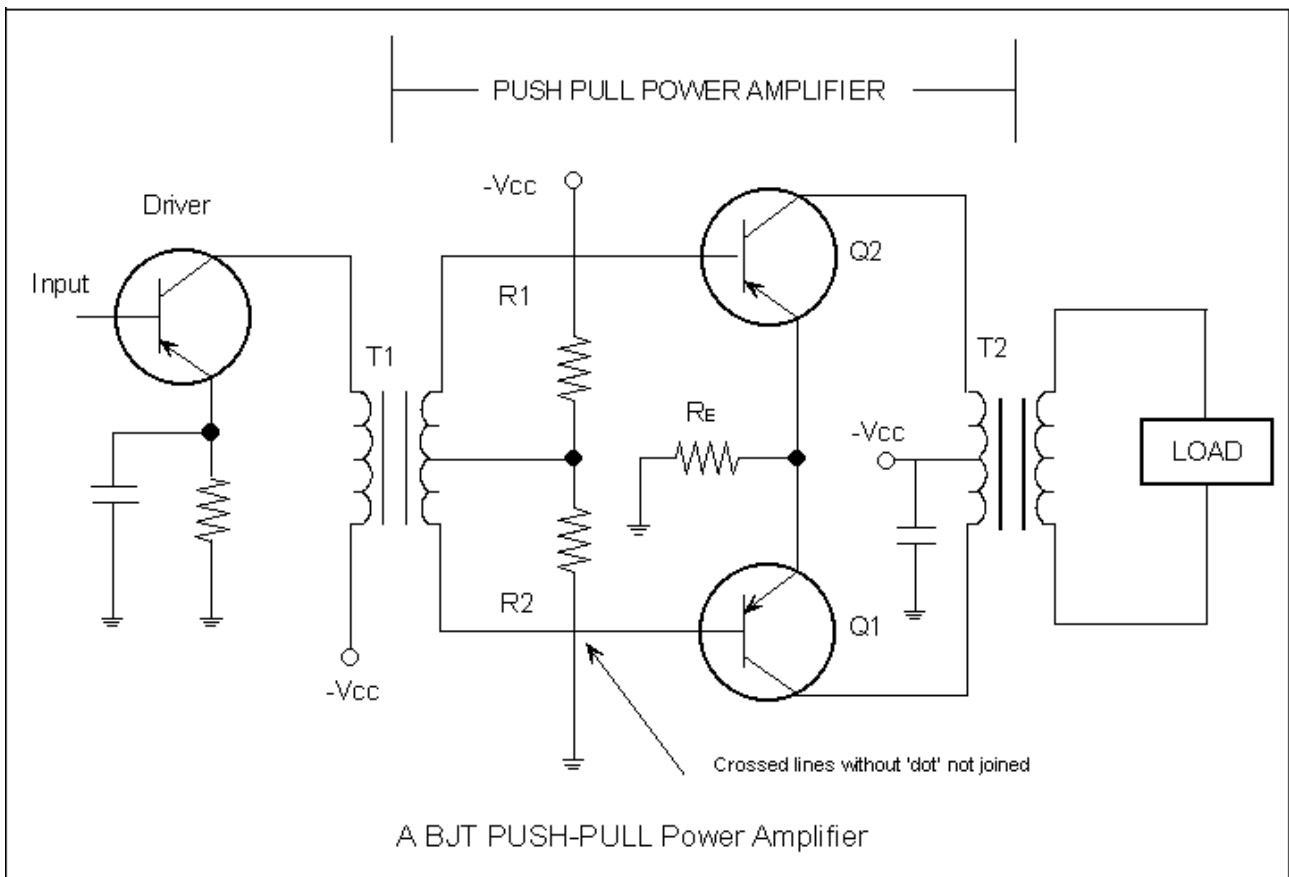
Figure 5.

An important advantage of push-pull operation over the single ended circuit is the tendency to cancel even order harmonics that may develop in the stage. Such even order (ie 2nd, 4th, 6th) harmonics are 180 degrees out of phase in the output and completely cancel.

HARMONICS - Harmonics are distortion products (signals) produced on multiples of the operating frequency. So a radio frequency amplifier operating say on 10 MHz will produce some output on 20, 30, 40 etc. MHz. It is a fact that harmonics always exist, are caused by non-linearity in an amplifier, and that **every amplifier has some non-linearity**. The advantage of the push-pull circuit is that even order, 2nd, 4th, 6th etc. harmonics are less of a problem.

COMPLEMENTARY SYMMETRY AMPLIFIER

For identification purposes only, a complementary symmetry amplifier can look at first glance like a push-pull amplifier.

The schematic of a transistor complementary symmetry amplifier is shown in figure 6.
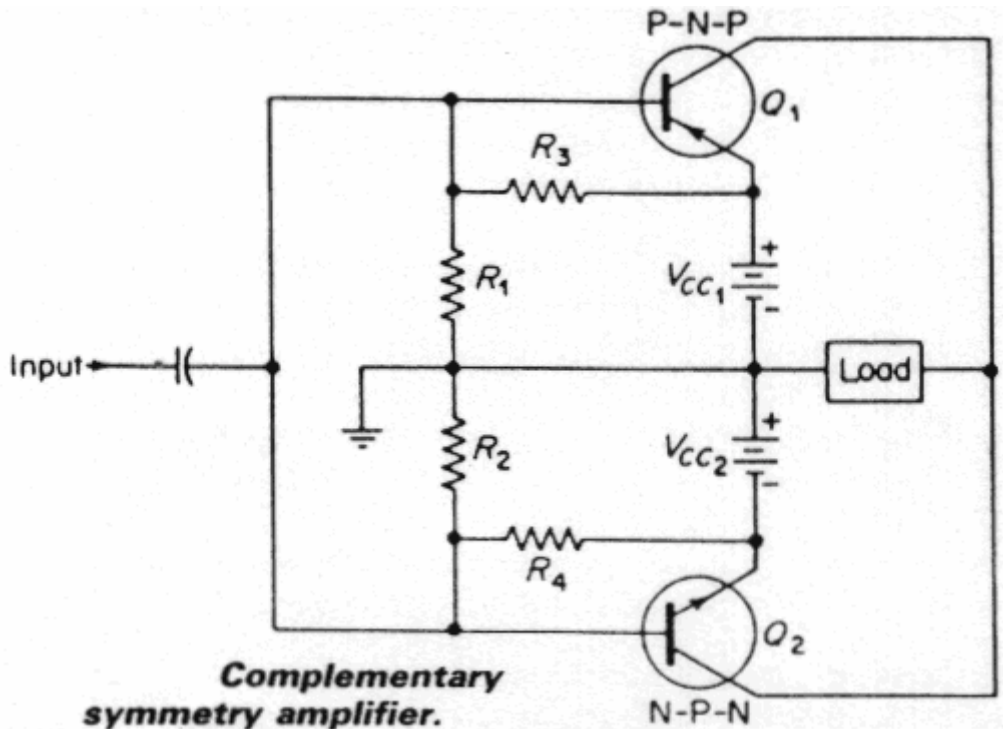

Figure 6.

This amplifier takes advantage of semiconductor devices that are fabricated as the complement of each other. A NPN transistor is the complement of a PNP transistor. A push-pull amplifier normally has an input transformer to provide out-of-phase signals to the input elements of two active devices. With complementary symmetry, phase inversion is unnecessary.

In the figure 6 schematic notice that the base connections of the two transistors are connected directly together. If the input goes negative, the PNP transistor (Q_1) will be biased harder and its collector current will increase. However, a negative-going input signal will reduce the bias current of the NPN transistor (Q_2) causing its collector current to decrease by the same amount.

When the input signal swings positive, Q_1's base and collector current is decreased, while Q_2's base and collector currents undergo a corresponding increase.

The resistor networks on each transistor look complicated, but close inspection shows that R_1 and R_3 provide voltage divider bias for Q_1, while R_2 and R_4 provide the same function for Q_2.

AN INTERMEDIATE FREQUENCY AMPLIFIER

When we come to cover receivers and transmitters, we will come across a stage called the intermediate frequency amplifier. The intermediate frequency or IF amplifiers are a little different from other amplifiers, in that they are designed to operate on one frequency only. Typical intermediate frequency amplifiers operate on 10.7 MHz and 455 kHz.

Because this amplify operates only on one frequency, it can be designed with tuned circuits to only pass that frequency, actually a **narrow band of frequencies**.   An

intermediate frequency amplifier is just like any other amplifier, however, you may need to identify the circuit in an exam. The circuit that I've shown in figure 7 is one that was actually used in an exam, and the question was to identify what the circuit was.
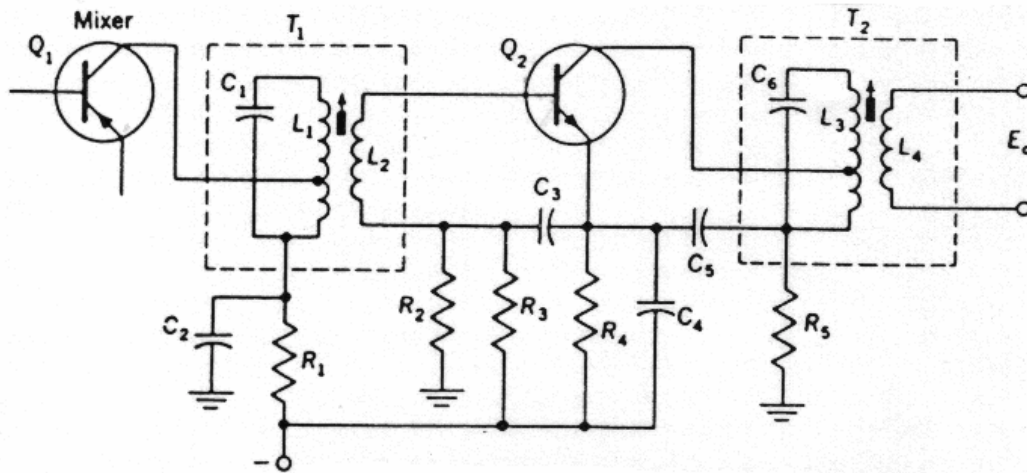

Figure 7- IF Amplifier

The clue to the identification of the circuit is the use of the transformers (radio frequency transformers) T_1 and T_2. They are ferrite slug tuned (indicating radio frequencies) and shielded (the dashed box). This is a circuit of a fixed tuned radio frequency amplifier, or an intermediate frequency amplifier. **The tuned transformer coupling provides greater selectivity**. **The transformer primaries form part of a parallel tuned circuit and have all the properties that go with this.**

FOR INTEREST

Notice how the collectors are connected to a tapping on the transformer primaries. This is to prevent the low impedance of the transistors loading the tuned circuits and reducing Q and hence the selectivity. The turns ratio of T_1 and T_2 also serve to match the output and input impedances of each stage. R_2 and R_3 provide voltage divider bias for Q_2. R_4 is the emitter stabilisation resistor and C_4 is the emitter bypass capacitor.

This circuit really has much more than you need to know, and as long as you can identify it as an intermediate frequency amplifier by the clues I have given, you will do fine. If the circuit looks a little odd, it is because two different types of transistors have been used, NPN and PNP.

FREQUENCY MULTIPLIER

While frequency multipliers are not amplifiers, it seems like an appropriate place to discuss them. The purpose of a frequency multiplier is to do just that, multiply frequency. A 1 MHz signal can be converted to a 2 MHz signal using a frequency multiplier, or to any multiple of 1MHz.

(Frequency multipliers should not be confused with mixers, which is another method of converting a signal from one frequency to another).

Frequency multipliers can only convert to multiples of harmonics of the input signal.

If you remember (if not go back and have a look at the reading on tuned circuits) that a parallel tuned circuit has a property called the **flywheel effect**. A parallel tuned circuit in the output of an amplifier is commonly referred to as a **tank circuit**. Frequency multipliers are designed with output tuned circuits (tanks) that are resonant on either the second, third, and less frequently the fourth, harmonic of the input frequency.

The output waveform of a multiplier is a sign wave produced by the " flywheel effect" of the output tank. Multipliers are also referred to as doublers, triplers, and quadruplers. **Class C** operation is essential, as current pulses into the output tank are required to keep the tank oscillating. In a doubler the output tank is tuned to twice the input frequency, and will receive one input current pulse, and then go through two complete oscillations before the next current pulse arrives just in time to overcome the lost energy (remember damping). Output tanks in quadruplers require a much higher Q since they must sustain four full cycles of oscillation without appreciable attenuation or damping, before receiving a new current pulse.

Multipliers can only be used to multiply signals that have no intelligence in their amplitude, as the stage is nonlinear. I emphasise again that multipliers operate in Class C which is nonlinear.

BUFFER AMPLIFIER

An oscillator is a circuit (to be discussed) which provides weak low power signals on a certain frequency. The power output of an oscillator is very low. If we were to connect something like a BJT amplifier after an oscillator, the oscillator would probably cease to function, as a BJT requires current from the source to be amplified.

A buffer amplifier is any amplifier (typically after an oscillator) **designed to amplify the input signal, without placing any great demands, power wise, on the stage supplying the signal.**

In other words, a buffer amplifier requires very little or no power to drive it, and it prevents overloading the previous stage.

Some microphones have a small pre-amplifier actually built into them, as the microphone insert (crystal, dynamic, etc) cannot provide much power out. A pre-amplifier after a microphone is never called a buffer, but in effect, it is doing the same job as a buffer amplifier.