Bob's TechTalk #35

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The Class B Amplifier:

This month we're going to look at a complementary Class B Audio Amplifier to drive our code practice oscillator's speaker. However, before we start, perhaps a discussion of amplifier 'Class' is in order. In amateur radio the four primary classes of amplifiers are designated A, B, AB and C. There are also designations for D and above, but these are digital and we won't discuss them – at least not at this time.

Amplifier class is determined by the way the active device (tube, transistor, etc.) is biased. Biasing determines the static condition of the active device: the no-signal plate current of a tube or the no-signal collector current of a transistor. This current is determined by the grid voltage on a tube or the base current on a transistor. Let's look at a vacuum tube (Figure 1). The plate current is controlled by the voltage (V_G) applied to the control grid of the tube. If the voltage is significantly negative with respect to the cathode, no plate current will flow and the tube is said to be in cutoff. As the grid voltage becomes less negative current flows between the cathode and plate. The plate circuit normally contains a load of some sort. In figure one it is a resistor, R_L. As the grid voltage increases the plate current increases. Since this current flows through R_L a voltage drop appears across R_L. When the current reaches the point where all the available voltage is dropped across R_L the tube is said to be in saturation; no higher plate current can flow. Note also that no grid current flows until the grid is driven positive.

Biasing is just setting the initial point of the grid voltage that lets a certain plate current flow. When a signal is coupled to the grid it will cause the plate current to rise and lower in response to its voltage. This change in current causes the voltage across RL to vary. The variation across RL is generally much larger than the change in grid voltage, and this results in an amplified signal.

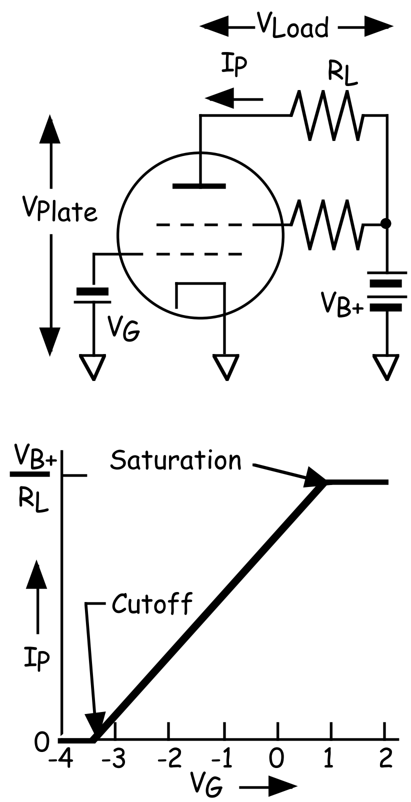

Figure 1 - Biasing of a typical vacuum tube amplifier showing grid voltage vs. Plate current.

Class A: In a class A amplifier there is always plate current flowing (Figure 2a). For low level signals the plate current is usually set where the plate current is small, but where the signal will not cause the tube to reach cutoff. The output signal is a good replica of the input signal and gain can be high with high R_L. Most low-level signal amplifiers in radios are class A. High-level class A amplifiers are also in use. Many low power audio amplifiers are class A, like those that drive a speaker in older tube communications receivers. High-level class A amplifiers are biased so that their resting current is halfway between cutoff and saturation. This allows the highest signal output without significant distortion since if either excess is reached distortion results. High level class A amplifiers are not very efficient, generally under 25% and never over 50%. A one-watt audio output amplifier can require over 4 watts of DC power. You generally won't find class A amplifiers used at power levels more than a few watts. Low-level linearity is good, but at higher power distortion levels increase.

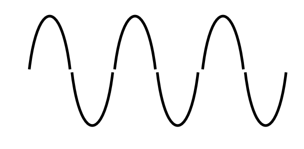

Figure 2a - Class A - The grid voltage never reaches cutoff and plate current flows for 100% of a cycle.

Class B: The bias of a class B amplifier is set right at the tube's cutoff point (Figure 2b). No current flows without a signal. The amplifier only amplifies one half the signal; however, it does it quite efficiently. Audio class B amplifiers are normally in pairs. Each handling one half of the signal, which is then recombined. Push-pull is the terminology used to describe these circuits. Class B is used in AM modulator circuits and high power audio amplifiers. If not operated in push-pull, class B amplifiers will introduce audio distortion. Class B amplifiers can be up to 78.5% efficient with over 70% common.

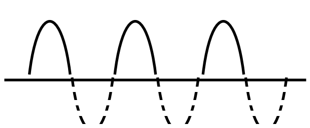

Figure 2b - Class B - The grid voltage reaches cutoff and plate current flows for 50% of a cycle.

Class C: The bias of a class C amplifier is set far beyond cutoff, and the driving signal only causes the tube to conduct for a short period of its cycle Figure 2c). Distortion is high, but when the output contains a resonant circuit good RF amplification is obtained. If the RF being amplified contains modulation however, the modulation will be highly distorted. Class C is used to amplify CW and unmodulated RF. Class C amplifiers can be modulated themselves and are normally the amplifiers used in AM transmitters. Class C is the most efficient of the three classes of amplifiers with efficiency approaching 100%. Typical efficiency is 80% - 85%.

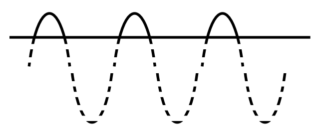

Figure 2c - Class C - The grid voltage reaches cutoff and plate current flows for > 0% and < 50% of a cycle.

Class AB: When the bias point is set so that the tube is conducting with no signal but cuts off during part, or most, of the negative peaks, the amplifier class is called AB (Figure 2d).

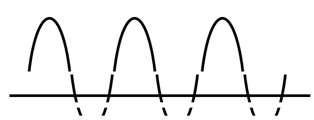

Figure 2d - Class AB - The grid voltage reaches cutoff and plate current flows for > 50% and < 100% of a cycle.

Vacuum tube amplifiers often have a designator of 1 or 2 after the AB. For class AB_1 the grid is never driven positive so no grid current flows. This affords a fairly constant load for the driver, and high power gain, but lower efficiency (typically 50%). With class AB_2 the grid is driven into the positive range giving higher efficiency (typically 60%) but results in higher power requirements for the driver. The driver also sees a varying load over each cycle, which must be compensated for. Some push-pull class B amplifiers actually are biased slightly towards class AB1 to improve linearity. This is particularly true of transistor amplifiers that must overcome the 0.7 volt base voltage drop before conduction. Class AB_1 and AB_2 are good for single ended (i.e. not push-pull) RF linear amplifiers Though only one-half of the envelope is actually amplified by the tube, the flywheel effect of the tuned output circuit reproduces the other half – modulation and all.

Figure 3 shows the circuit for a class B complementary amplifier. D1 and D2 are identical transistors to Q1 and Q2 respectively, with their base and collector tied together (see TechTalk #34). From our study last month, this circuit is just two current mirrors in series. R1 and R2 have identical values. With no input signal, the current i1 flowing through D1 and D2 is:

$$i_1 = \frac{V_{CC} - 2 \cdot V_{BE}}{R_1 + R_2} = \frac{V_{CC} - 2 \cdot V_{BE}}{2R}$$

Where Vcc is the supply voltage (9V) and V_{BE} is the drop across one of the diodes (~0.7V).

Since we are dealing with current mirrors, i_1 is also the current that flows in the transistors. Ideally a class B amplifier's transistor is at cutoff when no signal is flowing. However, the signal must overcome the V_{BE} voltage before the transistor starts to conduct. This 1.3 volt dead-band will cause unwanted crossover distortion. The solution is to run the amplifier with a slight current flowing making it almost a class AB_1 amplifier. If you do a good job of matching the diode and transistor properties, as we discussed last month, this circuit is easy to bias. Just select R to give you the resting current you want, using the equation above.

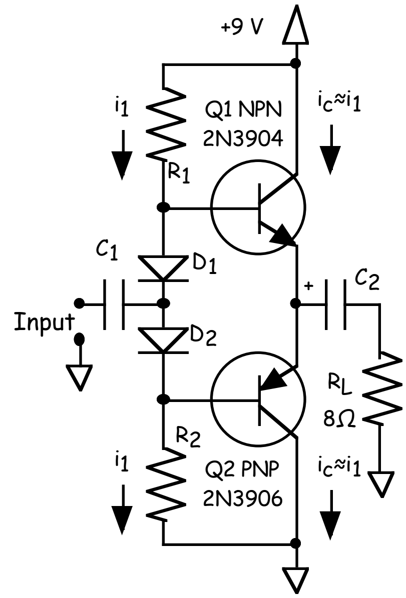

Figure 3: Complementary Transistor Class 'B' Audio Power Amplifier

This circuit is very simple. It needs to be driven by a high level of voltage as each of the current mirrors are also followers and have a gain slightly less than one. The output capacitor C2 charges to about 1/2 the supply voltage in the absence of an input signal. When an audio signal is applied and the signal is positive the top transistor conducts more and the bottom transistor turns off charging C2 and sending current to flow in the speaker. Likewise, when the signal is negative the bottom transistor conducts more and the top transistor turns off, discharging C2 and causing current to flow in the speaker in the opposite direction. The circuit can drive a low impedance, such as an 8-ohm speaker directly. This saves using a heavy expensive audio transformer and provides good frequency response. Circuit efficiency is up to 78.5%, and each transistor only dissipates one-fifth of the output power delivered to the load.

While the voltage gain is less than one, the power gain is high. The input impedance of the amplifier is approximately one-half of R in parallel with $\beta(RL + R'e)$ or:

$$R_{IN} = \frac{R\beta(R_L + R'_e)}{R + 2\beta(R_L + R'_e)}$$

The AC resistance of a forward biased diode is small and can be neglected. We haven't said much about R'e. It is the large signal AC emitter resistance and can be found from the transistor's transfer characteristic given on the data sheet (usually in graphic form):

$$R'_e \cong \frac{\Delta V_{BE}}{\Delta i_e}$$

Here are some key reminders for making this circuit successful:

The transistors must be complementary (have identical characteristics except for polarity.)

The diodes must have identical forward characteristics to their associated transistor.

C_2 is a large electrolytic capacitor with low Xc at audio frequencies.

Next month we'll begin putting all these parts we've been discussing together into a complete code practice oscillator.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the December 2004 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.