RCA Ham Tips

PUBLISHED - IN - THE - INTEREST - OF - RADIO - AMATEURS - AND - EXPERIMENTERS

VOLUME VIII, No. 1 EDITORIAL OFFICES, RCA, HARRISON, N. J. JAN.—APRIL 1948

ANALYSIS OF CLASS B MODULATORS FOR AMATEUR 'PHONE APPLICATION

Brass-pounding may provide the basic interest in Amateur Radio, but "mike hounding" gives it the flavor of romance. Radiophone communication has the charm of reality—to hear the other fellow's voice as he hears yours—to speak half-way around the globe as if in person—this is a treat the whole family can enjoy.

If you haven't as yet tried 'phone, why not give it a fling? The cost is moderate, and the benefits can be very worthwhile. For instance, putting sound on your carrier will acquaint you with subjects of interest in radio-broadcasting, public address, and the other electronic arts and professions.

Where to start? Probably you are already familiar with microphone and speech amplifier circuits. The modulator is the final link in the radiophone chain, so a review of the theory and design practice of class B amplifiers is in order.

Basic Principles

A class B audio-frequency amplifier employs a pair of tubes, connected in push-pull, and biased near the point of plate-current cut-off, where the grid-voltage—plate-current characteristic starts to bend sharply. At low signal levels both tubes work together in complementary fashion, but at higher levels each tube alternately conducts and rests, and the resulting half-waves are combined in the modulation transformer to produce a composite wave which is an amplified replica of the original signal.

Objectives

One advantage of class B operation is that it provides high peak

(Continued on Page 3, Column 1)

CLASS B MODULATORS

(Continued from Page 1, Column 2)

output power with respect to the no-signal input power. In the quiescent "no signal" condition, audio amplifier tubes dissipate all of the power delivered to them. As a result, if high plate voltages are used, the quiescent plate current must be kept low in order that dissipation ratings will not be exceeded under the no-signal condition.

Good plate circuit efficiency is another characteristic of class B audio amplifiers. One reason is that when the input signal level becomes appreciable, all of the plate current becomes signal plate current. Also, as a result of the grids being driven positive, the plate voltage swings all the way to the diode line on peak positive grid excursions and the peak values of plate current are, therefore, much higher than would be obtained under class A, AB, or AB_2 conditions. In the case of high-perveance tubes like RCA-811's, the voltage at the diode line is small, thus providing an efficiency factor approaching the theoretical maximum of 78.5% which would exist if the plate swing equalled the plate-supply voltage, as shown by the formula:

$$\text{Plate efficiency} = \frac{\pi}{4}\left(1 - \frac{E\,min}{E\,b}\right) 100$$

Where E min is plate voltage at diode point and E_b is the plate-supply voltage. If E min is taken as zero, the plate efficiency is equal to 78.5%.

In a practical circuit, using a pair of RCA-811's at 1500 volts and a load line of 4400 ohms (17,600 ohms plate-to-plate), the voltage at the plates (E min) would be pulled down to 70 volts on maximum signal peaks. Under these conditions, the efficiency formula would give the following results:

$$\text{Plate eff.} = \frac{\pi}{4}\left(1 - \frac{E\,min}{E\,b}\right) 100 =$$

$$0.785 \quad (1 - (70 \div 1500)) \quad 100 =$$

$$0.785 \times 0.954 \times 100 = 75\%$$

This formula holds for pure sine-wave signals only, and does not take into account transformer losses. If considerable harmonic distortion is allowed, the efficiency can be slightly higher, but such distorted power output should not be credited as useful power output. Reputable tube manufacturers indicate conservative values of tube power output from which it is only necessary to deduct transformer losses to obtain actual amplifier power output.

Typical Operation

Although tube handbooks provide tables of typical operating data, it is frequently desirable to establish a set of conditions for a particular application that has not been previously used as an example. To illustrate the procedure, consider the combination of a 1500 volt dc power supply and a pair of 811's, but the need for only 140 watts of audio power.

To be on the safe side and provide for a slightly higher than normal amount of circuit and component losses, a conservative efficiency factor of 70% should be used. The required plate power input to a class B amplifier (P_{in}) can then be determined from its relation to the desired power output (P_o):

$$P_{in} = \frac{P_o}{0.7} = 140 \div 0.7 = 200 \text{ watts}$$

The total dc plate current (I_b) at maximum signal, with a plate-supply voltage (E_b) of 1500 then becomes

$$I_b = \frac{P_{in}}{E_b} = 200 \div 1500 = 133 \text{ ma}$$

The next step is to determine the peak value of signal plate current per tube (I_p):

$$I_p = \frac{\pi I_b}{2} = 1.57 \times 133 = 210 \text{ ma}$$

Reference to the plate family will show that 210 ma is located on the diode line at approximately 50 volts. This means that the plate swings from 1500 down to 50 volts on peak positive grid excursions, and provides a peak plate swing (E_p) of 1450 volts. The load line can now be drawn as a straight line between 1500 volts at zero plate current (E_b) and the point of intersection of 210 ma (I_p) and 50 volts (E min). The load resistance (R_L) represented by this line can be calculated as follows:

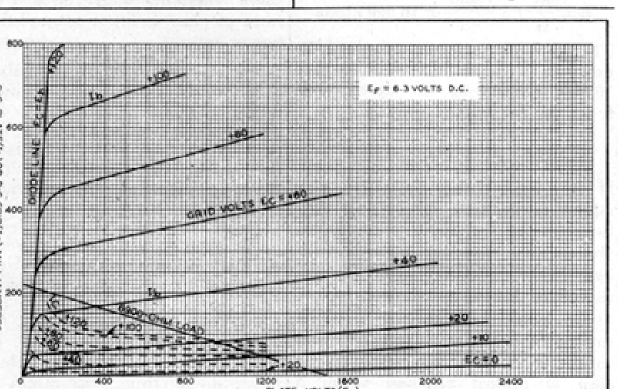
$$R_L = \frac{E_p}{I_p} = \frac{1450}{0.210} = 6900 \text{ ohms}$$

The equivalent plate-to-plate load impedance is four times the plate load per tube, or 27,600 ohms. This value of effective load resistance is optimum for the conditions set up in the problem. If a lower value is used, more power output can be obtained but the efficiency will be slightly lower. Any difference in distortion is negligible. Plate power output for a class B amplifier can now be calculated from the formula:

$$P_o = \frac{I_p\,(E_b - E\,min)}{2} =$$

$$\frac{0.210\,(1500 - 50)}{2} = 152 \text{ watts}$$

This is more than the required 140 watts and provides ample safety factor for higher than normal circuit and component losses.



Average plate characteristics of the 811. Note that emission capabilities far exceed class B amplifier requirements.

Grid-Circuit Conditions

The exact value of negative grid bias (E_c) needed is not critical. A satisfactory approximation can be obtained by dividing the plate-supply voltage by the tubes' amplification factor. In the case of 811's, which have a mu of 160, the value obtained is —9.5 volts. This value would be exact cutoff if the grid-voltage/plate-current characteristic were a straight line. In practice, this theoretical cutoff voltage is very near to the optimum bias voltage.

At plate potentials of 1250 volts or less, the 811's will operate within plate dissipation ratings without any negative grid bias. Because of this feature, they are called "zero bias modulators". High-mu tubes can be used without negative grid bias when the product of plate voltage and quiescent plate current is less than the tubes' dissipation ratings.

Again, referring to the plate family, it will be seen that a peak plate current of 210 ma is drawn at 50 plate volts when the grid goes approximately 55 volts positive. The peak a f cathode-to-grid voltage (E_g) will be 55 plus the bias voltage or close to 64 volts. To determine the grid driving power of a class B amplifier, refer to the plate family of curves and note the peak value of grid current (I_g) that flows when the plate voltage is minimum (50 volts) and when the grid voltage is at the crest of its cycle (+55 volts). It will be seen to be 70 ma. Grid driving power for two tubes (W_g) can now be ascertained by solving the equation:

$$W_g = \frac{I_g\,(E_g + E_c)}{2} =$$

$$\frac{0.07 \times 64}{2} = 2.24 \text{ watts}$$

The minimum effective resistance (R_g) of one modulator tube grid can also be determined for impedance-matching purposes. The formula is

$$R_g = \frac{E_g + E_c}{I_g} = \frac{64}{0.07} = 915 \text{ ohms}$$

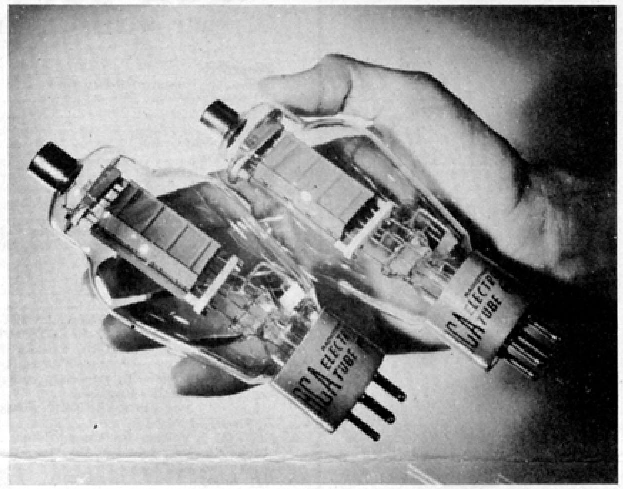
Audio Power Requirements

The ratio of power input to the final amplifier and audio power output from the modulator is usually stated as 2 to 1 for 100% plate modulation. This ratio holds true only when sine-wave modulation is used, since it is based upon the relationship of voltages.

To illustrate with an example, consider a 100-watt class C amplifier drawing 100-ma from a 1000-volt plate supply. 100% modulation requires that the plate voltage be alternately doubled and reduced

(Continued on Page 4, Column 3)

A FAMOUS PAIR—RCA-811'S



These transmitting triodes have long been the Amateurs' favorite class B modulators.

CLASS B MODULATORS

(Continued from Page 3, Column 4)

to zero. This would require an alternating peak voltage of 1000 volts, or an RMS voltage of $1000 \div \sqrt{2}$ or 707 volts. The 1000-volt, 100-ma class C amplifier load appears to the modulator as a pure resistance of 10,000 ohms as determined from the relationship:

$$R = \frac{E_b}{I_b} = \frac{1000}{0.1} = 10{,}000 \text{ ohms}$$

The sine-wave power required to develop 707 RMS volts across 10,000 ohms can be determined from the formula:

$$\text{Watts} = \frac{E^2}{R} = 707^2 \div 10{,}000 = 50$$

If the modulating signal were a square wave, 1000 volts would still be required for 100% modulation. But in this case, the average voltage would equal the peak voltage, therefore 100 watts of square-wave audio would be required to plate-modulate 100 watts of power input to the final amplifier. This condition is almost reached when a "clipter" is used and adjusted for maximum clipping and filtering.

When voice modulation is used, the condition is again different, although 1000 peak volts of audio power is still required. The RMS voltage of an average speech wave is less than half the peak voltage. If a figure of 50% is used, for example, the RMS modulating potential would be 500 volts, and the modulation power would be $500^2 \div 10{,}000$ or 25 watts. This is why some Amateurs figure on a 4 to 1 ratio of class C input to modulator power output.

On the above basis a pair of 811's would be capable of modulating 880 watts input to a final amplifier. However, to get the 1000 peak volts for 100% modulation, the turns ratio between primary and secondary of the modulation transformer has to be reduced. As a result, the transformer reflects a lower than proper load impedance to the modulator plates. Under these conditions, the class B modulator tubes can be quickly overloaded by a sine-wave signal from a test oscillator, or a whistle, or a soft female voice—and we should never do anything that might possibly keep those purring YL's and XYL's out of our Ham Shacks.