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R. F. Power Amplifier Operation

By the Engineering Department, Aerovox Corporation

THE final stage of a tube transmitter, unlike the simple voltage amplifier encountered in receiver r.f. stages, is a true *power* amplifier. Its purpose is to supply radio-frequency power to an antenna. R.F. power amplifier action, characteristics, and adjustment are particular features which suggest consideration of this type as a special case for study.

Within the final amplifier the remarkable conversion of commercial a.c. power into broadcast waves is carried out. The power output of the transmitter, whether less than a watt or many kilowatts, will depend upon the characteristics and operation of this amplifier. It follows that the greatest economy of operation and the fullest utilization of available tubes are obtained very largely through efficient final amplifier operation.

It is attempted to condense in this article the host of theoretical and practical data concerning r.f. power amplifier operation for the benefit of transmitter operators desiring a deeper insight into the performance of such stages.

GENERAL ARRANGEMENT

In general circuit configuration, the r.f. power amplifier closely resembles other of the more common amplifier stages. Triode, tetrode, pentode, or beam-power tubes may be employed, as desired, in either the single-ended, push-pull, parallel, push-pull-parallel arrangement. The usual sources of filament, plate, grid, and screen voltage are required and the tube grids must be energized with a signal voltage, at the desired operating frequency, which is developed by an oscillator-amplifier (exciter) unit. The exciter must also be capable of supplying a relatively small amount of power to the amplifier grids. A tank circuit tunable to the operating frequency is included in the power-tube plate circuit and is coupled to an antenna circuit to which it delivers r.f. power. The outstanding difference in the r.f. power amplifier, aside from its special function, is the larger magnitude of electrode potentials and associated currents necessary for its operation.

TYPES

It is customary to classify r.f. power amplifiers according to the point along the grid voltage-plate current characteristic curve at which the tubes are operated, since entirely different varieties of performance are obtained with various levels of d.c. grid bias voltage.

Class-B and class-C type amplifiers are the most common in modern amateur, experimental, and commercial transmitter circuits. In class-B operation, the d. c. grid voltage is maintained at the point of plate-current cutoff, or slightly less; while in class-C operation, the bias voltage is carried many times farther than cutoff, never lower than twice this value.

Class-C r.f. amplifiers are used whenever it is desired to employ high-level modulation (i.e., modulation of the final r.f.stage) and to obtain maximum operating efficiency. Class-B systems find particular application when the output of an already modulated transmitter is to be amplified before transfer to the antenna circuit. At the same time, both types are readily adaptable to radiotelegraphy.

GENERAL CHARACTERISTICS

In the class-C amplifier, power output varies directly as the d.c. plate-circuit power input. In the class-B amplifier, on the other hand, power output varies directly as the square of the r.f. grid excitation voltage. High plate-circuit efficiency is obtained with class-C systems, 70 percent being a reasonable minimum value for a carefully adjusted circuit. The usual efficiency obtained in class-B amplifier practice is in the vicinity of 30 percent. Hence, the same type tubes operated at a given plate voltage as class-C amplifiers will deliver many times the power output obtainable when they are operated in the class-B condition.

Compared with the class-C amplifier, the class-B stage requires a considerably increased plate power input for the same r.f. power output. However, in high-power transmission the saving effected by the smaller and less expensive modulation equipment required in class-B amplification frequently offsets the cost of the larger amplifier plate-power supply. For this reason, a number of standard broadcast stations employ a class-B linear amplifier after a lower-powered modulated transmitter to secure the allocated carrier power.

CLASS-B

The class-B radio amplifier closely resembles the class-B audio amplifier except in one respect—that the former may be single-ended.

The proper amount of d.c. grid voltage, while theoretically stated as the value which will produce plate-current cutoff, actually is slightly less than this value, since for best operation a small amount of plate current should be permitted to flow in the absence of excitation. The approximate value of class-B grid bias required for a given type of tube may be determined by dividing the applied plate voltage by the amplification factor of the tube. The r.f. signal grid voltage must be of such magnitude as to utilize the entire linear portion of the Eg-Ip characteristic.

No plate current flows during the negative half cycles of signal grid voltage. The positive half cycles produce half waves of plate current which extend upward in the direction of saturation and are distorted because of harmonics introduced as the tube grid swings positive on excitation peaks. But the latter distortion is "ironed out" by the plate tank circuit which, through its characteristic flywheel action, also supplies the missing r.f. half cycle, to restore wave symmetry.

Because the class-B grid is carried positive once during each excitation-voltage cycle, giving rise to grid current, it offers a varying impedance to the exciting amplifier. And to dispose of the effects of such a fluctuating load, a "swamping" resistor is generally connected across the class-B grid tank or the preceding driver-amplifier plate tank so that the energy consumed in the grid circuit is a small percentage of the r.f. power normally dissipated.

The term *linear amplifier*, applied to the class-B stage, arises from the fact that the output-circuit impedance of this type of amplifier is so adjusted as to make the dynamic tube characteristic substantially linear.

It has already been stated that the class-B amplifier is most widely employed to boost the power output of an already modulated transmitter. Such an arrangement, embracing oscillator, buffer amplifier, modulated class-B or class-C amplifier, and linear class-B amplifier, comprises a *low-level* modulated transmitter, so called because modulation is applied ahead of the actual final amplifier to a low-level stage.

Although the class-B amplifier is characterized by medium output, medium efficiency, and comparatively low power amplification, low-level modulation is popular in high-power radiotelephony and broadcasting because of its increased economy over plate modulation of a class-C final amplifier for the same carrier power output.

In radiotelephone operation, the class-B linear amplifier must handle a wave that is already modulated between zero and twice its carrier value, and reproduce this wave in its plate circuit. The unmodulated carrier output of the class-B stage is one-fourth of its peak carrier output. The average power output and amplifier *efficiency* are increased with modulation, while the d.c. plate power input remains constant.

Special developments of the class-B linear amplifier, notably the Doherty, Terman, and Woodyard versions, provide higher efficiencies than the usual 30%, or thereabouts, obtainable with conventional class-B systems. 50%, or slightly higher, is the efficiency figure commonly claimed for these adaptations.

CLASS-C

The class-C r.f. power amplifier is the type most widely used in radiotelegraph and radiotelephone transmission. It is noted for its high efficiency, high power sensitivity, and high power output. Its power output is proportional to its d.c. plate power input.

Intermediate (buffer) amplifiers may be operated as class-C stages in the same manner as final amplifiers. Thus, the characteristic efficiency of the class-C circuit may be utilized in working between the crystal oscillator and final amplifier stages.

The d.c. grid bias voltage for a class-C amplifier is set considerably higher than the value required for plate current cutoff at the operating plate voltage. The usual minimum value is twice cutoff.

Biased for class-C, a tube will pass plate current over only a very small part of the excitation voltage cycle. Plate current is completely cut off over most of the cycle. Grid current, which is zero over a large part of the cycle, flows in short pulses only during the short intervals when the r.f. excitation voltage swings positive with respect to the cathode and exceeds the d.c. grid bias voltage. From this it may be seen that the driver-amplifier must be capable of developing r.f. voltage which will exceed the bias voltage at the class-C grid, and must be capable of delivering sufficient power to work into the low impedance presented by the class-C grid during the "conducting" portion of the excitation cycle, and overcoming the grid circuit losses.

Aside from the d.c. component which is indicated by the grid milliammeter, there is also a fundamental component and one or more harmonic components present in the grid current. Still another component, which has been termed the *charging current*, flows through the grid-cathode capacitance of the tube and is 90° out of phase with the r.f. excitation voltage. This charging current becomes quite significant in ultra-high-frequency operation, since it is largely responsible for the increased driving power required by u.h.f. class-C amplifiers.

The short class-C plate current pulses are of relatively large amplitude and flow during less than half of the excitation voltage cycle. This means that plate current does not flow during the entire positive half-cycle of r.f. grid voltage, but during a small interval determined by the magnitude of d.c. grid bias voltage. A desirable angle of flow in most practical class-C amplifiers is approximately 120° with respect to the excitation cycle. Distortion is present in the waves delivered to the plate tank circuit, but this is smoothed out by the latter's flywheel action to render the output waveform very nearly sinusoidal.

The class-C plate-circuit efficiency is generally of the order of 75%, but very high values, such as 89.4%, are attainable by increasing the plate voltage, d.c. grid voltage, and r.f. excitation in large steps, at the same time maintaining the d.c. grid current constant. Amateur operators have made widespread use of this practice in obtaining high power output with tubes normally designed for low- and medium-power application. The so-called "California Kilowatt" is an example of this ingenious application of class-C amplifiers.

Class-C amplifiers are particularly suitable for plate (power) modulation because they present a resistive load to the modulator, and may be modulated linearly by varying the d.c. plate voltage at the modulating frequency.

In radiotelephone service, the class-C plate voltage is seen to be composed of the a.c. modulating voltage superimposed upon the d.c. plate potential. The peak value of the a.c. component equals the d.c. component of plate voltage for the condition of 100% modulation. At 100% modulation, the instantaneous class-C plate voltage, comprising these a.c. and d.c. components, is doubled and the r.f. power output accordingly quadrupled.

Thus, the power output is directly proportional to the square of the plate voltage, and the a.c. component of plate current is directly proportional to the plate voltage.

Because during the process of plate modulation the effective plate voltage is raised, it is necessary in a modulated class-C amplifier to reduce the d.c. plate voltage from the value recommended for class-C telegraph service. It would appear advisable to carry this reduction to 50% of the normal plate voltage, having in mind that the modulation swing will bring the combined value up to the rated level. However, consultation of transmitting tube tables will disclose that the customary plate voltage reductions are approximately 25% of the telegraph values.

DRIVER REQUIREMENTS

It is the purpose of the driver-amplifier to excite the power amplifier grid(s). It has already been shown that the grid of a power amplifier tube offers infinite impedance to the driver during the negative half-cycle of the excitation voltage, but a definitely finite value during the positive half-cycle. Moreover, a charging current flows in the power amplifier grid circuit. From these considerations, it is obvious that the driver must be capable of supplying a proper amount of r.f. *power* in order to establish the rated d.c. grid current flow in the power amplifier and to overcome the various grid-circuit losses.

The *driving power* required by various tubes varies over wide scales, as will be seen by inspecting transmitting tube tables. Lower grid impedances are characteristic of the higher-mu tubes, hence the latter require considerably less driving power than the low mu tubes. Pentodes, tetrodes and beam-power types require little bias and have low grid current ratings, and they, as a result, require small amounts of driving power for very large power gain.

Grid circuit losses mount as the operating frequency is increased. At the ultra high frequencies, these losses become of such magnitude in conventional power amplifiers that additional power requirements are imposed upon the driver-amplifier in order that the rated power amplifier grid current may be established.

ERRATUM NOTICE:

Attention has been called to an error in the November, 1940 issue of the Research Worker. In one of the explanations of multivibrator grid resistor calculation, multiplication is indicated instead of division.

The corrected explanation is "the value of grid resistors required for a desired multivibrator frequency may be calculated by dividing the reciprocal of the frequency in cycles per second by the sum of the capacitances in farads".

Equations (3) and (4) are then:

$$(3)\quad Rg = \frac{\frac{1}{f}}{C_1 + C_2} = \frac{1}{f(C_1 + C_2)}$$

and

$$(4)\quad Rg = \frac{\frac{1}{f}}{2C} = \frac{1}{2fC}$$

Checking for Loose Condenser Plates and Other Mechanical Noise

Of the multitudinous uses for the L-C Checker, constantly being expanded by users, the latest wrinkle is that of spotting loose tuning-condenser plates and other mechanical sources of noise. Every serviceman has experienced such elusive mechanical noise in a considerable percentage of receivers to be repaired. Such noise sources are difficult to spot, particularly when the circuit apparently checks OK.

The way this latest wrinkle works is simplicity itself, as explained in the following letter: "Aerovox Corporation, New Bedford, Mass., Gentlemen: I am writing to describe a new use for your model 95 L-C Checker. A —— model —— was brought in with a bad case of noise. The noise was similar to tube noise but had the peculiarity of not showing up when the tuning condenser was at its minimum capacity position. This caused me to suspect the condenser itself. To verify my suspicions and to locate the actual cause of trouble the tuning condenser was set at approximately half capacity and the L-C Checker connected to and resonated with first the oscillator section then the antenna section. A fibre tuning wrench was moved across the stationary plates; picket fence fashion. The oscillator section showed no trouble, but the antenna section caused the eye tube to flicker every time the plates were touched; indicating loose stator plates. This could have been a difficult case of trouble, but the L-C Checker definitely located the offender and had the job well on the way to repair in less than 10 minutes. Neither was it necessary to unsolder a single connection to make this test. Very truly yours, (Signed) A.M.R.*, Indianapolis, Indiana."

*Name on request.