Suppressor-Grid Modulation

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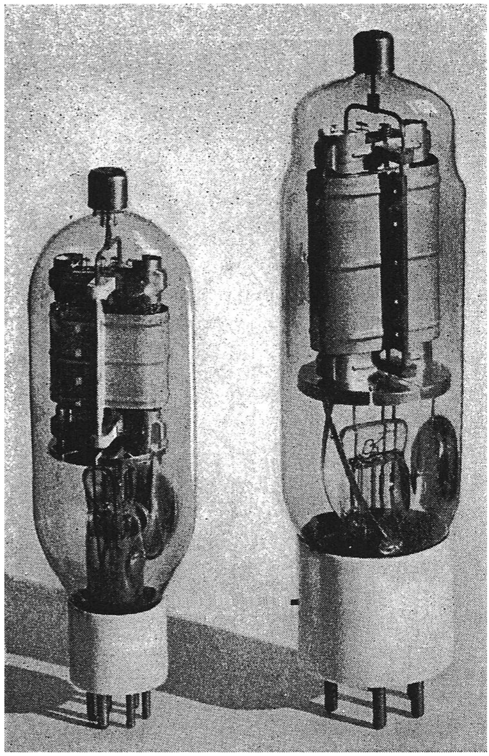
Vacuum Tube Development



ALL radio-telephone transmission—and a rapidly increasing portion of long-distance wire-telephone transmission — is of the "carrier" type. A high-frequency current generated by an oscillator is varied in amplitude by audio-frequencies, with the result that the transmitted signal is a varying high-frequency current conforming to an envelope that duplicates the audio-frequency wave. This process of modulation is usually accomplished by applying the carrier and audio frequencies to one or more electrodes of a vacuum-tube amplifier—the selection of the elements and the design of the tube being such that the carrier-frequency output will vary linearly with the audio-frequency input. Until recently there have been three major types of vacuum-tube modulation, which take their names from the tube element to which the voice-frequency is applied. More specifically they are grid modulation, plate modulation, and plate-and-screen modulation.

Each type has its own advantages and disadvantages. Both plate and plate-and-screen modulators are characterized by a high degree of linearity and a very high plate-circuit efficiency, but they are under the disadvantage that much of the output energy is obtained from the voice-frequency input rather than from the d-c power supply for the plate. As a result the audio-frequency power required is comparable to the modulated output, so that in these two cases large audio-frequency amplifiers are needed between the microphone and the modulator.

In grid modulation where the audio signal as well as the radio-frequency driving voltage is placed on the control grid, modulation is accomplished with much less audio power. This does not imply negligible audio-frequency driving power, since the potential of the control grid may be positive for a part of each radio-frequency cycle. The application of stabilized feedback* to the grid modulator has resulted in linearity equal or superior to that obtained in plate or plate-and screen modulators, and many modern transmitters, especially in the broadcast field, utilize grid modulation.

*Record, *February*, 1937, *p.* 182.

A modulating system requiring neither stabilized feedback nor neutralization, and little or no audio-power amplification, would be a closer approach to the ideal, especially for use in mobile short-wave applications, where weight, size, and multi-frequency operation are complicating factors. A fourth form of modulation, which is nearer this latter ideal, can be employed by taking advantage of the dependence of the output power on the potential of the suppressor grid in tubes which have three grids. These three-grid tubes, or pentodes as they are commonly called, have been used for several years as high-gain amplifiers, but only recently have they been especially designed for use as modulators. Their innermost grid serves as a control grid, as in a triode. The second, or screen, grid serves as a shield to lower coupling capacities and to accelerate the space current, as does the plate of a triode, but its wires are made small so that this grid will collect as little current as possible. The third, or suppressor grid, is usually held at filament potential and is thus negative with respect to both the screen grid and the plate. Its function is to return to the plate the secondary electrons knocked from it by the electron stream coming through the screen. Without it, the secondary electrons would be collected by the screen during the negative peaks of the output voltage, when the plate potential drops below that of the screen. The loss of these secondary electrons from the plate would reduce the net plate current during part of each cycle, and cause distortion and inefficiency.

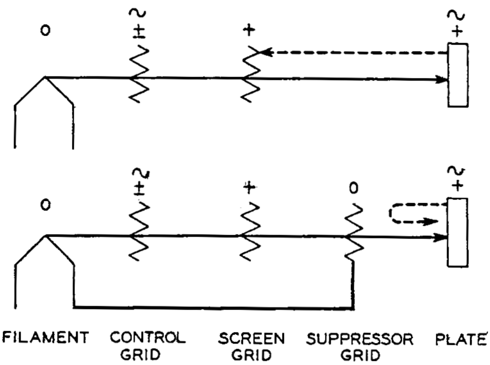


Fig. 1—(Above) In a tetrode tube secondary electrons from the plate will be collected by the screen grid at low swings of the plate voltage; (Below) With a pentode, the zero bias of the suppressor grid turns back the secondary electrons

In a screen-grid tube that has no suppressor grid, distortion and a loss in efficiency occur whenever the plate voltage swings too low. The arrangement of such a tube is indicated in the upper part of Figure 1. The filament is considered to be at zero, or reference, potential, and the screen grid, which is at a constant positive potential, accelerates the electrons toward the plate. The potential of the control grid varies with the carrier frequency, and may be positive during part of the cycle. Electrons accelerated by the screen

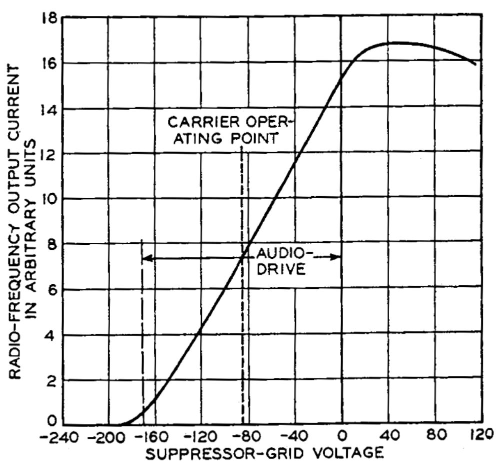


Fig. 2—Dynamic suppressor-grid characteristic of the 312A tube

pass through it and strike the plate, giving rise to secondary electrons. The potential of the plate, although biased more highly positive than the screen, varies with the signal, and if it swings below the screen bias these secondary electrons—indicated by the dotted arrow—will be drawn to the screen. With a suppressor grid, however, as shown in the lower part of Figure 1, the secondary electrons are turned back by the effect of the zero bias, and distortion is avoided.

Hence, when a suppressor grid is used, the plate voltage may be allowed to swing lower with respect to the screen voltage. The losses in the plate circuit are proportional to the product of the instantaneous voltage and current, and since the maximum plate current occurs when its voltage is lowest, the losses are decreased by allowing the voltage to drop to lower values, which is another advantage of this type of tube. This lowering of the instantaneous plate voltage also permits an increase in the amplitude of the radio-frequency plate potential for a given d-c plate voltage.

If the suppressor grid is disconnected from the filament and given a separate negative bias, it will be found that the plate current varies linearly with the suppressor bias over a wide range of negative values. It is thus possible to use the suppressor grid as a modulating electrode. A new type of modulator is obtained in this way which retains the high plate efficiency of the pentode. It is possible to design such a tube so that approximately the maximum output is obtained with zero potential on the suppressor grid. Since no positive swing is required, no current is drawn by the suppressor grid, and negligible power is needed for modulation. This constitutes the principal superiority of

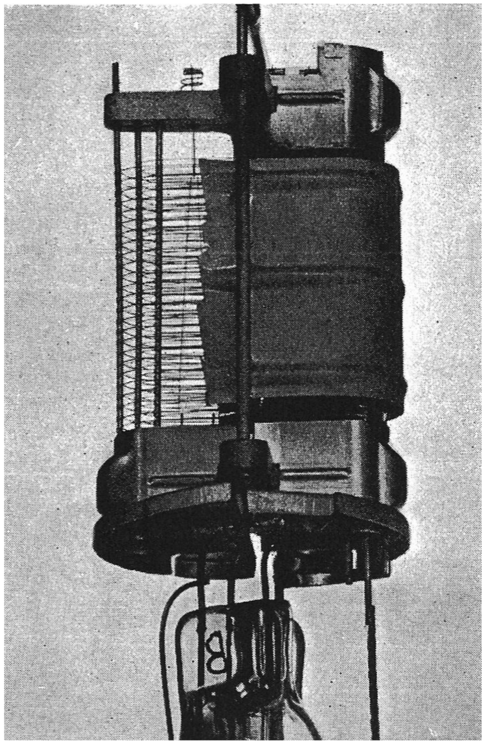


Fig. 3—The elements of the 312A tube with part of the plate and half of one of the end shields cut away

suppressor-grid modulation over both plate and grid modulation. Since the suppressor can be driven on a voltage basis, without the expenditure of appreciable energy, it is not necessary to supply high amplification for the audio-frequency power.

The Western Electric 312A tube, shown at the left in the photograph at the head of this article, was designed for such use, and has the suppressor-grid characteristic shown in Figure 2. The upper end is purposely saturated in the positive region very near zero bias, so as to obtain maximum power without driving the grid positive. The shape of the characteristic near its lower end is affected by the degree of screening furnished by the suppressor grid. At the negative peaks of audio modulation, practically all the electrons should be repelled, reducing the plate current to zero. If the suppressor grid does not shield the plate adequately, as at the end of the grid structure, a non-linear "toe" of the characteristic appears, and the plate current cannot be reduced to zero, which prevents attaining one hundred per cent modulation. In the 312A tube, metal shields, which may be seen in Figure 3, are attached to the ends of the grid structure to reduce the "toe" of the characteristic to insignificant proportions.

In addition to this function, the suppressor end shielding assists the screen grid in reducing the grid-to-plate capacitance. If this capacitance is too high, there will be regenerative feedback from plate to grid and singing may occur. In tubes with a high grid-to-plate capacitance this effect is avoided by neutralization: the circuit is adjusted so that a voltage equal to the feedback but opposite in phase is also applied to the grid. Such neutralization requires additional apparatus, needs adjustment when the carrier frequency is changed, and in addition is a source of distortion in broad-band transmission. In tubes with sufficiently small grid-to-plate capacitance, all these disadvantages are avoided. In the 312A tube, where the capacitance is a tenth of what it would be without the end shields, it is unnecessary to neutralize for any normal use of the tube. This is especially advantageous in mobile radio transmitters where multi-frequency operation, together with severe weight and space limitations, demands a minimum of adjustment in band changing or tuning. The small size and light weight of the 312A also contribute to its usefulness in the mobile transmitter field.

The 322A tube, shown at the right in the photograph at the head of this article, is a later development, and is capable of providing more than twice the output power of the 312A. It has the additional advantage of somewhat higher overall efficiency due to the relatively lower screen-grid current needed. This is secured by lining up the wires of the control grid and the screen grid so that the latter, while having normal electrostatic influence upon the space current, does not intercept as many electrons as it otherwise would.

Although these tubes were developed primarily for use as suppressor-grid modulators, they may also be operated with high plate efficiency as oscillators, as amplifiers, or as either of the other three types of modulators. Like other pentodes they have a high gain and thus require little radio-frequency driving power. These advantages of the new tubes, combined with their comparatively high output for the plate voltage used, give them a wide field of usefulness.