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PROCEEDINGS
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The emission valve modulator for superheterodyne receivers†

By HAROLD A. WHEELER*

WITHIN the past three years a great deal of attention has been paid to the special problems of the superheterodyne receiver, partly with a view to improving the performance and partly with a view to decreasing the number of tubes required. Many attempts were made to combine the oscillator and the modulator (or first detector) in one tube. There was no fundamental reason why this could not be done, but it was found to be difficult. Even when two separate tubes were used, the modulator conversion gain was much lower than the gain of an amplifier stage using the same type of tube. By conversion gain is meant the gain from the signal-frequency input to the intermediate-frequency output of the modulator stage, measured from grid to grid. The conversion gain was especially low when gradual-cutoff tubes came to be used as modulators to permit the use of a grid bias for controlling the conversion gain. These tubes were given a gradual cutoff of plate current with increasing grid bias, whereas a sharp cutoff is beneficial when high gain is desired in a modulator.

As a result of a large number of experiments, a number of circuits have been developed, which use only one tube to perform both functions of oscillator and modulator. Some of these circuits have been extensively used in commercial broadcast receivers. The problem was attacked from two points of view. First, circuits were devised which made the best use of tubes then commercially available, such as the type 24 tetrode, and the types 57 and 58 pentodes. Secondly, a special hexode tube has been developed which is giving even better performance as oscillator-modulator than the two tubes previously employed for the purpose. The new hexode is called an emission valve modulator, by way of describing the mechanism of modulation in this tube.

All of the circuits to be described are, in some respects, similar to the separate oscillator and modulator circuits shown in Fig. 1. At the time this work was started, a type 24 tetrode was commonly used as modulator and a type 27 triode as oscillator. The former is well adapted for the function of modulator, because it has a fairly sharp cutoff. The presence of the screen makes the tube capable of giving fairly high conversion gain. The triode is a satisfactory oscillator.

In the circuit of Fig. 1 the oscillator voltage is applied to the cathode of the modulator tube by a cathode coil coupled to the oscillator. This coil and the signal circuit are effectively in series between grid and cathode. It is generally desired to couple to the cathode coil as great an oscillator voltage as the grid-cathode bias of the modulator will permit without causing grid current. The optimum value of oscillator voltage is maintained uniformly over the range of signal frequencies by combined condenser and inductive feedback in the oscillator. A series condenser is used in the oscillator tuned circuit to assist in maintaining a constant frequency difference between signal and oscillator circuits, the latter having the

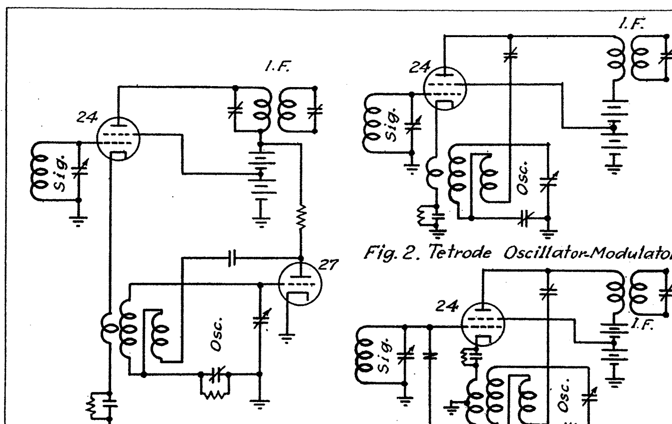

Fig. 1. Tetrode Modulator and Triode Oscillator

Fig. 2. Tetrode Oscillator-Modulator

Fig. 3. Tetrode Neutralized Oscillator-Modulator

Figs. 1, 2 and 3.

†Paper presented before the Radio Club of America, March 8, 1933.
*Bayside Laboratory, Hazeltine Corporation.

higher frequency. This same condenser is used as the main feedback coupling when the oscillator is tuned to lower frequencies, while the inductive feedback is mainly used at higher frequencies. These two are proportioned to apply a uniform oscillator voltage between the grid and cathode of the modulator.

Fig. 2 shows an oscillator-modulator circuit which has the same circuit elements as Fig. 1 except omitting the triode tube, two resistors and a condenser. In Fig. 2, the tetrode is used also as an oscillator, retaining the combined condenser and inductive feedback in the tetrode plate circuit, and using the cathode coil as a link in the feedback arrangement.

The circuit of Fig. 2 requires careful but not critical proportioning of the circuit constants to maintain the oscillations at a level just below that which would cause grid current. Having adjusted the inductive feedback in the plate circuit so that the grid-cathode oscillator voltage is uniform over the tuning range, a value of the cathode resistor is chosen which is sufficiently great to prevent grid current, but is much less than the value required to stop the oscillation. The oscillator circuit is then self-regulating without relying on grid current. When the oscillations start, the cathode current increases by rectification of the oscillation, which in turn increases the grid-cathode bias and regulates the amplitude of oscillation without grid current.

There are several difficulties which are sometimes encountered in the circuit of Fig. 2, for which appropriate corrective measures have been found.

The intermediate-frequency primary coil may cause some trouble because it is effectively across the oscillator feedback circuit. In general, a coil has one fundamental natural frequency, and also a number of overtone frequencies. The latter are each slightly higher than an even multiple of the fundamental. At these overtone frequencies of the primary coil, it is likely to reflect considerable resistance into the oscillator circuit. This is corrected by choosing this coil to have a fundamental frequency at least half the highest frequency in the oscillator tuning range.

There is a tendency for the circuit to oscillate at the natural frequency of the oscillator plate coil, instead of at the oscillator frequency. Where this occurs, a nominal resistance in the plate lead is a satisfactory corrective.

The by-pass condenser across the cathode resistor must be made smaller than usual to avoid periodic blocking of the oscillator at an audio frequency. The maximum safe value is easily determined by trial.

The grid-cathode capacitive coupling of two or three micromicrofarads causes appreciable interaction between signal and oscillator circuits at the higher frequencies. The effects are (1) degeneration in the oscillator circuit, (2) regeneration in the signal circuit, and (3) radiation of oscillator currents from the signal circuit. The best cure for all of these effects is neutralization of the grid-cathode capacitive coupling. Fig. 3 shows a circuit having such neutralization added to the oscillator-modulator circuit of Fig. 2.

When the types 57 and 58 pentodes became available, the connection of all three grids to separate terminals opened up new possibilities in the oscillator-modulator field. In the first place, the type 57 pentode gave improved results in the circuits designed for the type 24 tetrode, the added suppressor grid being connected to ground. Then a number of new circuits were developed, two of which are shown in Figs. 4 and 5. These two circuits differ mainly in that the oscillator circuit of Fig. 4 is connected to the outer electrodes of the pentode while that of Fig. 5 is connected to the inner electrodes. In both cases the plate is connected to the intermediate-frequency transformer, as in the foregoing circuits.

In the oscillator-modulator circuit of Fig. 4, the oscillator includes the suppressor grid and the plate of the type 57 pentode, the feedback arrangement being somewhat similar to that of Fig. 1. The suppressor has such a wide mesh that it must be given a considerable negative bias before it exercises sufficient control over the plate current, which is necessary for the production of oscillations. This bias is provided by the second cathode resistor in Fig. 4. For the same reason, the plate voltage is reduced by another resistor. The modulation is effected by the large oscillator voltage on the suppressor grid. The tube operates under unusual conditions, the screen voltage and current considerably exceeding the plate voltage and current.

The circuit of Fig. 4 has several distinct advantages over those of Figs. 2 and 3. One is the complete shielding of the signal circuit from the oscillator and intermediate-frequency circuits, preventing feedback of any kind and also preventing radiation of oscillator currents. Another is the complete avoidance of control-grid current, regardless of the oscillator voltage, requiring less care in oscillator design. The circuits of Figs. 2 and 3 still have some advantages, especially if the type 57 pentode is substituted for the type 24 tetrode. They are capable of higher conversion gain and usually require fewer circuit elements.

In the circuit of Fig. 5, the oscillator includes the control grid and the screen, while the signal is applied to the suppressor grid. This is an elementary form of the emission valve modulator which will be described in more detail with reference to Figs. 6, 7 and 8. The inner electrodes behave as in a triode oscillator, while the other electrode behaves as in a triode modulator. The latter has a very low amplification factor, because of the wide mesh of the suppressor, and therefore the conversion gain is very low. This circuit is very stable in operation, and is interesting as the forerunner of the new hexode circuit.

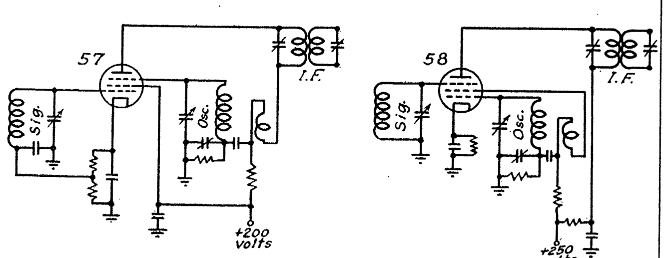

Fig. 4. Pentode Oscillator-Modulator with Outer Oscillator

Fig. 5. Pentode Oscillator-Modulator with Inner Oscillator

Figs. 4 and 5.

All of the circuits using the available tubes were found lacking in one way or another. A circuit was desired which would perform with one tube the following functions:

1. Oscillation;
2. Modulation;
3. High amplification;
4. Grid-bias control of amplification.

Even the separate oscillator and modulator of Fig. 1 failed to meet all these requirements. When a sharp-cutoff modulator such as type 24 or 57 was used, grid-bias control was not satisfactory. When a variable-mu modulator such as type 35 or 58 was used, high conversion gain could not be secured. The arrangements of Figs. 2, 3 and 4 could not be subjected to grid-bias control without stopping the oscillator. That of Fig. 5 gave very low gain, but had the advantage that grid-bias control would not stop the oscillator.

Work was then carried forward on the development of a new tube to perform all four of the desired functions. The third and fourth requirements seemed at first to be incompatible, because high conversion gain requires a sharp-cutoff grid, while grid-bias control requires a gradual-cutoff grid. This problem was solved by locating two separate grids in the same electron stream, each having the structure best adapted to perform its function. The sharp-cutoff grid was used for the oscillator, giving a maximum modulating effect. The gradual-cutoff grid was used for the signal and the grid-bias control.

Figs. 6, 7, and 8.

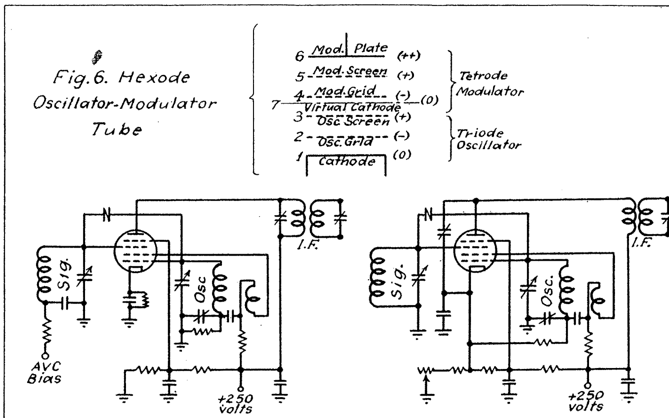

Fig. 6. Hexode Oscillator-Modulator Tube

Fig. 7. Hexode Neutralized Oscillator-Modulator

Fig. 8. Hexode Neutralized Oscillator-Modulator with I-F Regeneration

New Hexode Tube

Fig. 6 is a schematic diagram of the special tube which was selected as the best compromise between simplicity, low cost and low cathode current on the one hand, and a high degree of refinement on the other hand. It is a hexode having a structure generally similar to the 58 tube, but having a fourth grid and a redesign of all the grids. This was found to be the smallest number of grids which could be used and still meet the requirements. The cathode and the inner two grids are used as a triode oscillator. The outer two grids and the plate are used as the grid and plate electrodes of a tetrode modulator. The relative polarities of the electrodes are indicated on the diagram.

In operation, electrons emitted from the cathode 1 are attracted to the positive screen 3 through the meshes of the negative grid 2. As the electrons approach the screen 3, they are travelling at a high speed, so that most of them shoot through the screen 3 and approach the negative grid 4, where they are retarded and then attracted back to the screen 3. The cloud of retarded electrons between the screen 3 and the grid 4 is called a "virtual cathode," because electrons can readily be drawn away from this cloud in the same manner they were originally drawn away from the actual cathode. The relative position of the virtual cathode is indicated by the line 7 (which is not a part of the tube structure).

The modulator section of the tube includes the modulator control-grid 4, the modulator screen 5, and the plate 6, in addition to the virtual cathode 7 (formed by the oscillator section of the tube).

Part of the electrons arriving at the virtual cathode 7 are attracted toward the positive screen 5 and the more positive plate 6 through the meshes of the negative-grid 4. When the oscillator grid 2 is only slightly negative, or even somewhat positive, the virtual cathode 7 has a plentiful supply of electrons available for the modulator section of the tube. When the oscillator grid 2 swings considerably negative, the virtual cathode 7, and hence the modulator plate, are momentarily deprived of their electron supply. This is the "emission valve" mechanism by which modulation is effected in the new tube.

The modulator grid 4 (not the inside grid) is connected to the cap terminal of the tube, and is constructed to have a gradual-cutoff action so that a variable negative bias can be used to control the conversion gain over a wide range without distorting strong signals applied to this grid. It is important that this negative bias has practically no effect on the oscillator behavior, because the modulator grid is incapable of cutting off the major part of the oscillator screen current.

Hexode Circuits

Fig. 7 shows a representative circuit using the new tube. It is now unnecessary to provide any parts for coupling the oscillator to the modulator, since this is accomplished by the emission valve action. The capacitive coupling of two or three micro-microfarads between oscillator screen and modulator grid causes appreciable reaction between signal and oscillator tuned circuits at the higher frequencies. This coupling is readily neutralized by a small neutralizing condenser of about one micro-microfarad, denoted by the symbol "N," which also prevents radiation from the oscillator. In order to prevent feedback from the oscillator screen circuit to the signal circuit through the same capacitive coupling, it is desirable to make the self-reactance of the oscillator screen circuit very small at the higher frequencies. This is done by sufficiently reducing the insulating condenser in this circuit. It is interesting to note that the transconductance from modulator grid to oscillator screen is negative, and therefore a capacitive load in the oscillator screen circuit is regenerative in the signal circuit.

Fig. 8 shows the circuit of Fig. 7 with two modifications, either of which may be used individually. A cathode rheostat is shown for manual gain control, arranged for minimum disturbance of the relative voltages on cathode, screens and plate in the tube. Regeneration in the intermediate-frequency primary circuit is provided by connecting the primary condenser between plate and cathode. The cathode condenser is reduced to increase the amount of regeneration. This expedient is not critical and is under control of the grid-cathode bias.

High Gain

Using a good intermediate-frequency transformer tuned to 175 kilocycles, the conversion gain of Fig. 7 is 120 times. Using a good transformer tuned to 450 kilocycles, the conversion gain of Fig. 8 is 120 times with only 40 per cent regeneration.

One of the interesting possibilities opened up by the new hexode is the five-tube receiver with automatic volume control, having the following order of tubes:

1. Hexode oscillator-modulator;
2. Pentode intermediate amplifier;
3. Diode detector and triode audio amplifier;
4. Pentode audio amplifier;
5. Power rectifier.

In conclusion, it is desired to acknowledge the valuable assistance of other engineers of the Hazeltine Corporation, particularly D. E. Harnett, J. K. Johnson, V. E. Whitman and N. P. Case. It is also desired to express the gratitude owing to the executives and engineers of Hygrade Sylvania Corporation for their cooperation in constructing the many experimental tubes which were needed in the development of the new hexode.

FORUM

THE development of any art, such as radio communication, may be divided into three periods. During the early years, the workers in the new art are busy discovering what the problems are and in getting them clearly stated. Then comes the period during which several solutions for each of the problems are brought forward. The final period is devoted to finding out which of the many solutions is best.

The radio art is 35 years old, and broadcasting is over 12 years old. A great many problems have been solved in a great many ways, and some of the early solutions have already been discarded. But there are, even today, a good many questions which have not been answered. There are many choices still to be made, many solutions to be examined and approved or discarded, and there is the question as to whether even the best solution of any one of the problems, is adequate.

The Radio Club of America includes in its membership many of the oldest and ablest workers in the radio field. Many of these men have worked through all the years of development and research that have brought the radio mechanism to its present state. They bring to its problems a point of view born of experience.

But among the younger members there is the vision of new problems to be solved, and the determination to find better answers for the old problems. They view each new task in the light of the latest technical advances in mathematical analysis and laboratory investigation.

The Forum is a place where these men meet for discussion and an adequate exchange of ideas and opinion. Each month, a question, not yet definitely settled, is proposed and analyzed, and although no record is kept, each participant leaves with one problem much clearer in his mind than it was before. There is no attempt to settle a question, and no vote is taken. The only rule is that each man must confine himself to the question being discussed.

Come to the meetings, listen to the paper, and then participate in the Forum. If there is a particular problem on which you would like to have the ideas and opinions of other radio men, send the question in.

R. H. LANGLEY, Chairman,
Forum Committee.

PAPERS TO BE PRESENTED BEFORE THE CLUB

April 12, 1933

A paper entitled "Radio, Electrons and Stars" is to be presented by O. H. Caldwell, editor of "Electronics."

Mr. Caldwell needs no introduction, and friends and members of the Radio Club of America are cordially invited to attend this interesting lecture.

May 10, 1933

"Ohmmeter and Capacity Meter Circuits for Radio Servicing" is a timely subject for presentation before the Radio Club of America by J. H. Miller, radio engineer of the Weston Electrical Instrument Corporation.

In this paper a new ohmmeter of rather unique design, and a capacity meter are discussed. The ohmmeter derives its power from a small self-contained battery, and the capacity meter derives its power from a normal, convenient outlet.

Friends and members of the Radio Club are earnestly requested to attend.

Probable future papers to be presented soon before the Radio Club of America, include:

"Intermediate - frequency filters for superheterodyne broadcast receivers;" "QAVC circuits for Broadcast Radio Receivers;" "International Radio Developments."

—C. E. BRIGHAM, Chairman,
Committee on Papers.

SUGGESTIONS TO CONTRIBUTORS

CONTRIBUTORS to the Proceedings, by bearing in mind the points below, will avoid delay and needless expense to the Club.

1. Manuscripts should be submitted typewritten, double-spaced, to the Chairman of the Papers Committee.* In case of acceptance, the final draft of the article should be in the hands of the Chairman on or before the date of delivery of the paper before the Club.

2. Illustrations should invariably be in black ink on white paper or tracing cloth. Blueprints are unacceptable.

3. Corrected galley proofs should be returned within twelve hours to the office of publication. Additions or major corrections cannot be made in an article at this time.

4. A brief summary of the paper, embodying the major conclusions, is desirable.

5. The club reserves the right of decision on the publication of any paper which may be read before the Club.

*For 1933 the Chairman of the Papers Committee is C. E. Brigham, 200 Mt. Pleasant Avenue, Newark, N. J.

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