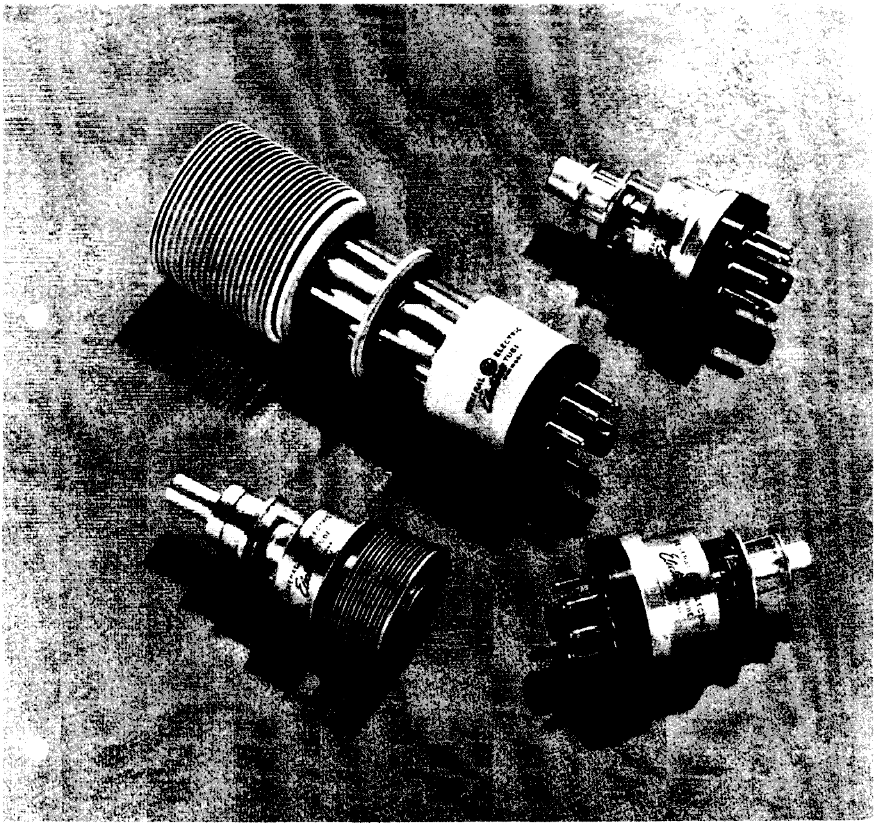
GENERAL ELECTRIC

LIGHTHOUSE TUBES



DESCRIPTION

The disk-seal triodes 2C39, 2C43, and 3C22 are used in transmitting applications as power amplifiers, c-w and pulsed oscillation generators for frequencies up to 3000 megacycles per second or higher. Their unique performance characteristics in the microwave range result from the following mechanical design features:

1. Lead inductances are reduced to a negligible value by use of the disk seals.
2. The parallel-plane structure permits the use of relatively small electrode areas; this makes possible low interelectrode capacitances, even with the close spacing of electrodes which is necessary at the frequencies at which the tubes operate.
3. Although the relatively small anode area makes radiation cooling from the anode surface impracticable, the anode lead has the same cross-sectional diameter as the anode surface, and heat conduction through the lead to the external circuit makes cooling relatively simple.
4. The coaxial structure makes possible practically complete enclosure of the radio-frequency fields in the types of circuits described later. This factor is extremely important in the microwave range where radiation from practical open-wire circuits becomes excessive.
5. Silver-plated parts reduce radio-frequency resistance to a minimum.

Another important application consideration features external cavities which allow continuous tuning and replacement of tubes without changing the cavity.

AMPLIFIER APPLICATIONS*

Power Amplifier

The useful frequency range of the disk-seal tube may be divided into three parts: a low-frequency range, a higher-frequency range, and a transition range. The frequency dividing lines are not actually fixed but depend upon the operating voltages, the external circuit used, and, of course, the tube type. For general purposes the lower range may be taken as those frequencies below 500 megacycles per second, the upper range those above 1000 megacycles per second, and the transition range those frequencies between 500 and 1000 megacycles per second. In the lower range, parallel-wire-line-type circuits are most commonly used, transit-time effects in the tube are negligible or small, and end effects due to the tube are small though not completely negligible. Efficiencies of operation in the low range are good and performance may be calculated with satisfactory accuracy from the d-c characteristics by using standard techniques. Ordinary precautions in the circuit assembly are sufficient to give good circuit efficiency, since shunting impedances due to ordinary losses are appreciably higher than the low load impedance required by G-E lighthouse tubes. Plate modulation may be used to give audio modulation without appreciable frequency-modulation and with reasonably low harmonic distortion.

In the higher-frequency range, the output, efficiency, and power gain fall off, and eventually reach zero at some frequency which depends upon the tube type but is appreciably above 3000 megacycles per second for the 2C39 and 2C43 tubes, but nearer 2000 megacycles per second for the 3C22. Self-enclosed coaxial circuits are used almost exclusively and much greater care must be used in guarding against radiation losses, poor contacts, leaky by-pass capacitors, and corrosion of circuits, since the tubes require much higher load impedances in this frequency range. Plate modulation produces phase as well as amplitude modulation because of transit-time effects in the tube.

The intermediate range is defined as the range of transition which lies between the two frequency extremes, and so has characteristics somewhere between the two.

Grounded-grid amplifier circuits are used almost exclusively with these tubes in all the ranges from 200 megacycles per second up. That is, one resonator is connected between plate and grid, and a second resonator between grid and cathode. This is done at the lower frequencies to decrease regeneration due to the grid-plate capacitance. The plate-cathode capacitance, the feedback element in a grid-return circuit, is smaller than the plate-grid capacitance by a factor of about 100, resulting in negligible regeneration in the lower-frequency range. This eliminates the need for undesirable neutralizing circuits. In the highest ranges of usefulness, the feedback susceptance arising from the finite plate-cathode capacitance is not completely negligible, and may give regeneration difficulties. It is possible, but not easy, to neutralize this feedback with the proper amount of external feedback. With self-enclosed coaxial circuits used at the highest frequencies, the grounded-grid type of circuit is also the only choice from mechanical considerations, for it is physically impossible to connect a self-enclosed, cathode-return-type circuit to the tube.

** Circuits shown in ETX-110 are examples of possible tube applications and the description and illustration of them does not convey to the purchaser of tubes any license under patent rights of General Electric Company.*

AMPLIFIER APPLICATIONS (CONT'D)

Low-Frequency Amplifier

The circuit in Fig. 1 using 2C39 tubes is an example of the parallel-wire-line circuits used with the disk-seal tubes in the few hundred megacycles per second range.

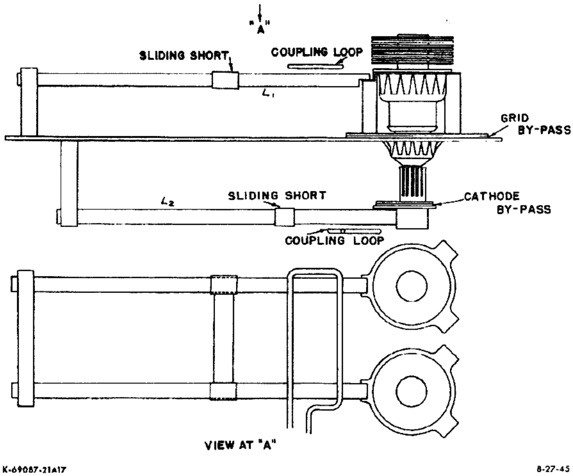


Fig. 1—Push-Pull Power-Amplifier Circuit for 2C39 Using Parallel-Wire Lines

The circuit is a grounded-grid connection and the two tubes are set with axes parallel, their grid rings making good contact with the conducting grid plane. One parallel-wire line is connected between the two anodes and runs parallel to the grid plane on the upper side, a second similar line is connected between the two cathodes on the under side. Both lines have sliding, shorting bars for tuning, and conducting plates should be connected to these bars to close off the dead region of the line from the active region. B-supply voltage is applied between the plate-to-plate line and the cathode-to-cathode line; bias voltage is applied between the cathode-to-cathode line and ground. This bias usually may be obtained by means of a grid-leak resistance, a cathode resistance, or a combination of the two. The filament leads are brought out through the hollow conductors of the cathode-to-cathode line. Power may be coupled in and out by means of loops placed with their planes parallel to the plane of the cathode-to-cathode and plate-to-plate lines respectively. Suitable matching arrangements should be provided on the lines to match to the driving source and to the load.

The entire circuit described above may be enclosed in a shielded box to prevent the occurrence of stray losses and feedback effects. If regeneration difficulties still persist, the contact to the grid ring should be investigated, for slight leaks through this contact invariably cause trouble. A lead sleeve placed around the grid ring before the grid ring makes contact with the circuit will often eliminate this difficulty.

AMPLIFIER APPLICATIONS (CONT'D)

Higher-Frequency Amplifier

The power-amplifier circuit in Fig. 2, also using Type 2C39, is an example of the coaxial circuits used with disk-seal tubes in the few thousand megacycles per second range.

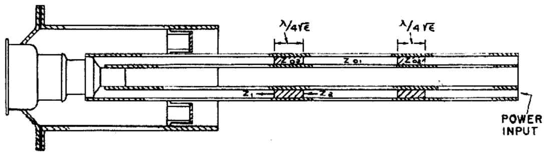


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Fig. 2—Coaxial Power-Amplifier Circuit for 2C39

The input line in this example is not so much a tuned circuit as it is a transmission line matched to the grid-cathode impedance by the dielectric slug matching system. This is possible because of the low value of the grid-cathode impedance. The output resonator must develop a high impedance for good operation in this frequency range, and much more care must, therefore, be taken in its design than in the design of lower frequency circuits. As shown, it consists of a larger coaxial line connected between plate and grid, with a by-pass capacitor breaking the d-c continuity at the plate end. A by-pass capacitor is also provided in the center conductor of the grid-cathode line to allow application of bias. A sliding plunger closes the resonator and tunes the circuit. Power is coupled out from the grid-plate resonator by introducing a loop or probe through the open tube provided for this purpose, and is connected to a coaxial line with proper matching controls.

OSCILLATOR APPLICATIONS

C-W Oscillator

Since the triode oscillator circuit may always be considered as a power amplifier with its r-f input supplied by feeding back a portion of its output in proper phase, the design of an oscillator consists in making the best possible power amplifier and then adding a feedback which delivers the right fraction of the output back to the input with proper phase. The power output from the oscillator would be expected to be less than that from a similarly operating power amplifier by the amount of the input driving power. Nearly all of the considerations discussed under Power Amplifier apply directly, and it remains only to design a satisfactory feedback system.

The feedback inherently present in the plate-cathode capacitance was discussed under Power Amplifier. Under certain conditions it is sufficient to cause oscillations, but usually not of sufficient strength to make a good power oscillator. Loops,

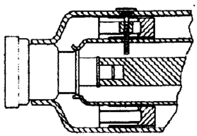

Fig. 3A—Movable Probe Feedback, Folded-Back Cavity

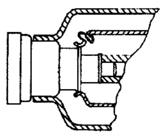

Fig. 3C—Loop Feedback, Folded-Back Cavity

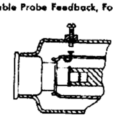

Fig. 3B—Loop-Probe Feedback, Folded-Back Cavity

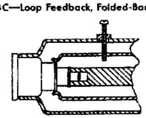

Fig. 3D—Fixed-Probe Feedback, Folded-Back Cavity

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OSCILLATOR APPLICATIONS (CONT'D)

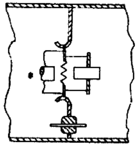

Fig. 3E—Probe Feedback, End-to-End Cavity

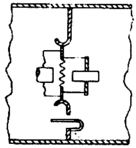

Fig. 3G—Loop-Probe Feedback, End-to-End Cavity

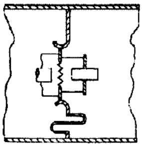

Fig. 3F—Loop Feedback, End-to-End Cavity

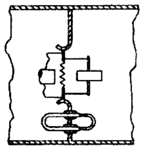

Fig. 3H—Adjustable Loop Feedback, End-to-End Cavity

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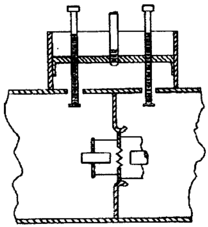

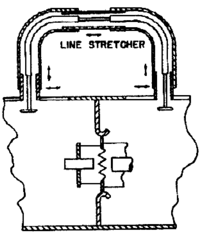

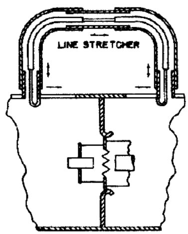

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Fig. 3J and 3K—Adjustable Probe Feedback with Phasing Network End-to-End Cavity

Fig. 3L—Adjustable Loop Feedback with Phasing Network, End-to-End Cavity

OSCILLATOR APPLICATIONS (CONT'D)

probes, or holes between the input and output cavities are favorite means of obtaining additional feedback. Several methods of applying loop and probe feedbacks in their simplest forms are shown frequency for this circuit. In the re-entrant circuit the radio-frequency fields from the grid-plate space are coupled directly back to the grid-cathode space. The figures shown below and the explanation fol-

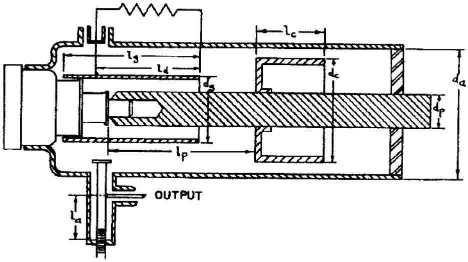

Fig. 4—Re-entrant Oscillator Circuit

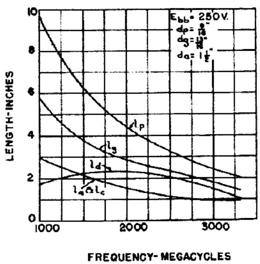

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Fig. 5—Curves of Approximate Dimensions for Circuit Shown in Fig. 4

in Fig. 3A to 3H on page 5, together with cavities suitable for the 2C40 and 2C43 lighthouse tubes.

The limitations on the use of the simplest loop and probe feedbacks arise mainly because these feedbacks do not have parameters enough to adjust both the phase of feedback and the magnitude of feedback to optimum. Fig. 3J and 3K illustrate the addition of phasing networks between the two loops or probes to control the phase separately.

A modified oscillator circuit particularly useful above 2000 megacycles is shown in Fig. 4 above. This circuit is commonly called a re-entrant oscillator. Fig. 5 shows a curve of essential dimensions versus lowing describe the operation of this type of circuit.

The radio-frequency fields between grid and anode are propagated along the grid-plate line to the point at which the grid cylinder is terminated. At this point, the presence of the choke or plunger causes this energy to propagate along the grid-cathode line in the direction of the base of the tube. A certain amount of the power propagated in this direction is coupled to the output by the output probe, and enough additional power to supply the tube loss is fed back into the grid-cathode circuit, thus sustaining oscillation. The length of the grid cylinder, l_x, is the most im-

OSCILLATOR APPLICATIONS (CONT'D)

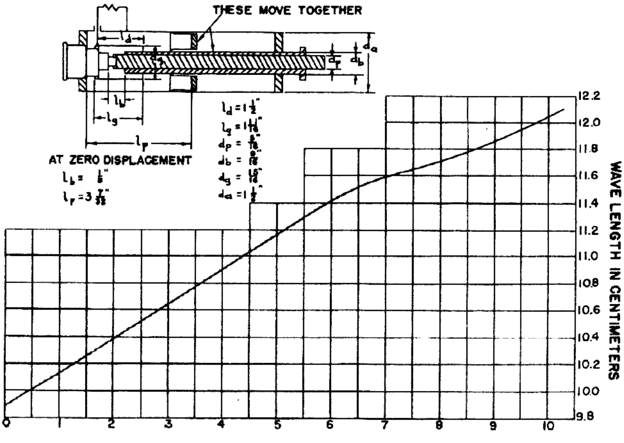

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Fig. 6—Method for Tuning Re-entrant Oscillator

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portant factor in determining frequency. The position of the choke, l_b, with respect to the anode of the tube has some small effect upon frequency, but for the most part, the choke is primarily important in its ability to change the phase of the feedback to the cathode. In this respect its position affects quite materially the efficiency of the oscillator. The length of the choke, l_d, is made one-quarter wave length at the center of the frequency band to be tuned. This provides essentially a radio-frequency short circuit on the tube side of this choke, yet provides for isolation of d-c voltages.

Tuning of the re-entrant oscillator can be accomplished in a number of ways; two recommended methods are illustrated here. Fig. 6 above shows a method of tuning which utilizes a two-piece concentric rod which makes connection to the plate of the tube. The inner rod is held in a fixed position and the outer cylinder slides over it. The

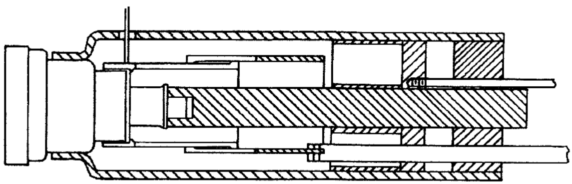

Fig. 7—Method for Tuning Re-entrant Oscillator Circuit over a Wider Range than Is Possible with Circuit in Fig. 6

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OSCILLATOR APPLICATIONS (CONT'D)

tuning range of this particular oscillator versus the tuner displacement is shown. A simple explanation for this tuning action follows:

With the tuner at zero displacement, the grid-plate line has a surge impedance determined primarily by a ratio of d_g to d_p. As the tuner is withdrawn, the surge impedance of the line is determined more and more by the ratio of d_g to d_t. The result is that as the tuner is slowly moved outward, the effective surge impedance of the line is increased. This in turn results in more effective capacitance foreshortening of the line, and will therefore make the oscillator operate at a lower frequency. It can be seen from this explanation that the primary factors affecting the tuning range are the ratios d_g/d_p and d_t/d_p. As either of these ratios is made larger, the possible tuning range will be increased.

Where a wider tuning range is necessary, tuning can be accomplished in the manner indicated in Fig. 7 shown at the bottom of page 7. Here the grid cylinder is made so that its length can be extended and the anode plunger is moved independently. In this case, frequency is primarily determined by the length of the grid cylinder and frequency decreases as the length of the grid cylinder increases. The phase of the feed-back in the oscillator is controlled independently by the position of the plunger on the anode line.

Pulsed Oscillator

Pulsed oscillators using the 2C43 tube are not essentially different from c-w oscillators except that the plate by-pass capacitor must not break down under the high voltages of plate pulsing. For this reason the plate by-pass capacitors in pulsed oscillators are generally of the choke-by-pass type, as used in the re-entrant oscillator of Fig. 4. A given oscillator, if operated for both pulse and c-w applications, will have a different frequency under pulse conditions from that under c-w operation for the same circuit adjustment. The circuit settings for optimum output are also different for the two operations and a c-w oscillator designed for optimum conditions occasionally will not oscillate under pulsed conditions until the circuit is readjusted. All of these phenomena occur because of the transit-time phase shift inside the tube, expressed as the phase angle of transadmittance, which changes with the plate voltage.

OPERATING NOTES

Contacts

Losses have greater effect as frequency increases and more consideration must be given to avoid them. Poor contacts cause much of the difficulty in circuits which operate inefficiently at the higher frequencies. For this reason, all contacts should be carefully soldered if possible. When an unsoldered contact cannot be avoided, the contact should be kept clean and subjected to pressure. Sliding contacts, as on tuning plungers, should be designed so that the finger contacts are stiff enough to exert a firm pressure against the member on which they slide without binding or gouging.

By-Pass Capacitors

Suitable by-pass capacitors in c-w oscillators may be made by using a sheet of mica between two plates for a flat by-pass capacitor and between two cylinders or conical surfaces for a coaxial by-pass capacitor. The capacitance value may be estimated from the approximate formula.

$$C = \frac{0.0885\ E'A}{d}, \text{ in micromicrofarads}$$

where A is the area of effective surface in square centimeters, d, the thickness of the mica in centimeters, and E', the specific dielectric constant of mica, which is about 5.4. The capacitance required depends upon frequency and the location of the by-pass capacitor in the circuit. However, values of at least 100 micromicrofarads are recommended in critical parts of the circuit even at 3000 megacycles. Space limitations sometimes make it difficult to provide this capacitance since the mica thickness must be maintained large enough to withstand the voltage; 100 volts per millimeter of mica is conservative.

The choke-type by-pass capacitors used in the oscillator of Fig. 4 and shown again in Fig. 8a are in reality transmission line filters. The impedance, Z_3, is infinite if the length l is one-quarter wave length. Impedance, Z_4, is usually low, so that the terminating impedance, Z_2, which is equal to Z_3, and Z_4 in series, is infinite. The input impedance Z_1 is then zero, omitting losses, and the plunger acts as a perfect short circuit to radio-frequency and is open to d-c. The adjustment is exactly correct only for a single frequency, but is reasonably good over bandwidths of 10 to 20 per cent. More choke sections may be added if one is not sufficient (Fig. 8b) and, for wide-band tuning, these may be adjusted to slightly different frequencies.

Fig. 8—Circuit Illustrating Filter Effect of Choke-Type By-Pass Capacitors

OPERATING NOTES (CONT'D)

Modulation

Conventional plate modulation of disk-seal power amplifier tubes may be used to obtain amplitude modulation approaching 100 per cent with reasonable distortion at the lower-frequency range where transit times are negligible. When the transit time and consequent phase angle of transadmittance is important, plate voltage changes cause changes in phase as well as amplitude, thus producing phase modulation as well as amplitude modulation.

For similar reasons, plate voltage changes in an oscillator at transit-time frequencies, produce frequency modulation as well as amplitude modulation.

Back Heating of Cathode

All space-charge control tubes, when operated with relatively high-power signals (class B or C) in the transit-time range, exhibit effects of cathode bombardment caused by electrons returned to the cathode by the reversal of electric field before the electrons reach the grid-plate region. This effect is noticeable in the disk-seal triodes near the upper limits of useful frequency, and may appreciably decrease cathode life if heater power is not reduced. The energy in the returned electrons comes from the radio-frequency driving source, so that the phenomenon is accompanied by an increase in effective input conductance.

The returned electrons are also responsible for some of the decrease in output, since they represent a decrease in the useful current passing into the grid-plate region. Since the phenomenon becomes more marked with increased degree of Class-C operation, extreme Class-C conditions should be avoided at frequencies where this is an important factor in tube performance.