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R. J. HANNON

2,777,062

ULTRAHIGH FREQUENCY SIGNAL GENERATION

Filed June 5, 1953

FIG. 1

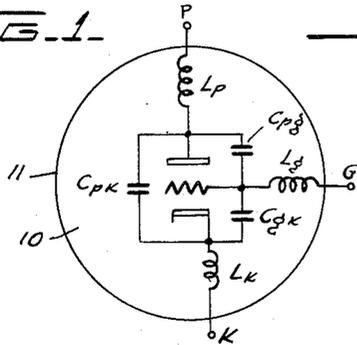


FIG. 2

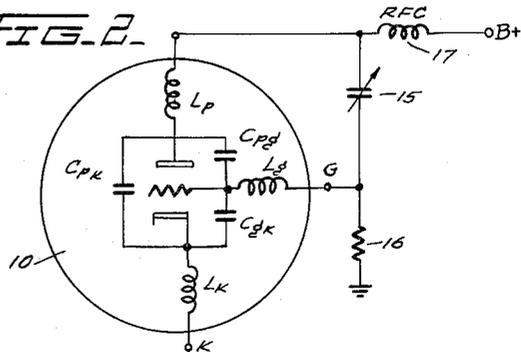


FIG. 3

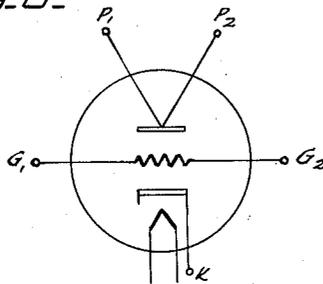


FIG. 4

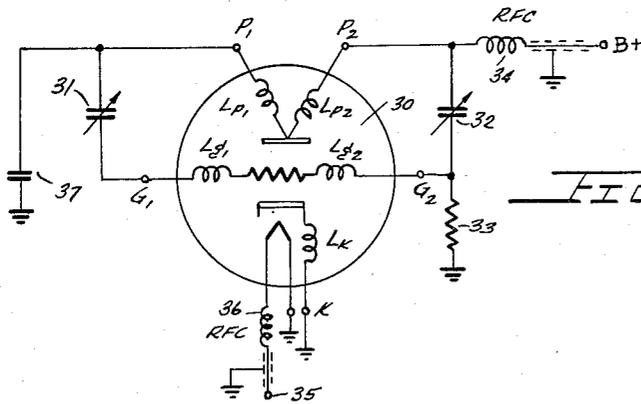
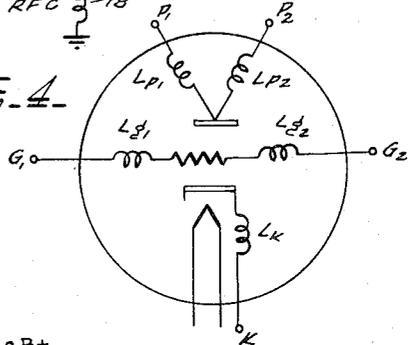
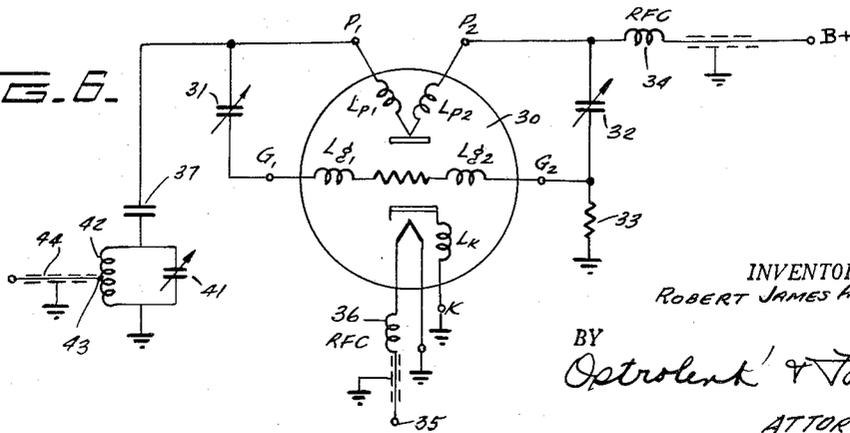


FIG. 5

FIG. 6



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ULTRAHIGH FREQUENCY SIGNAL GENERATION 5

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Application June 5, 1953, Serial No. 359,831

5 Claims. (Cl. 250—36)

The present invention relates in general to the generation of stable high frequency electrical signals and more particularly concerns electronic oscillators, utilizing conventional and commercially available electron tubes and associated circuit components, operative in regions of the high frequency spectrum hitherto thought unattainable for such systems.

For purposes of this discussion, the radio frequency spectrum may be considered as a large number of overlapping bands of increasing frequency. Within each band, signal generation raises characteristic problems which have most often been solved by virtue of the development of a wholly new or improved tube type. Thus, as the upper frequency limitations of standard triodes were gradually recognized, miniaturization was found advantageous. Tube leads were shortened, energy consuming tube bases were eliminated and electrode structures were physically rearranged. Miniature acorn and lighthouse tubes became available so that at the present time, signal generation in frequency bands extending into the order of thousands of megacycles is essentially a straightforward engineering design procedure involving the initial selection of a tube appropriate to the band under consideration together with the selection of circuit components best suited to the tube.

Notwithstanding the availability of a tube type for each frequency range, considerable effort has been expended in attempts to extend the frequency range of each tube and in particular, the conventional miniature electron tube triode. The principal motivation has been equipment cost. For example, lighthouse tubes, though dependable, are relatively expensive in themselves and additionally require coaxial components in the auxiliary circuits, which often are inherently complex mechanisms. Difficulties in interchanging tubes and test and service problems are further complicating circumstances.

A practical need of recent origin has intensified the search for a radio frequency generator using conventional miniature tubes. This is the allocation of commercial television channels in the U. H. F. spectrum. Here the problem is one of obtaining satisfactory performance in a television tuner, encompassing the lowest and highest channel frequencies, with a single oscillator tube to render unnecessary tube switching between bands. Low cost is absolutely imperative and the customary miniature pin base is highly desirable to permit utilization of test equipment already available for simplified service procedure.

To meet these specifications, tube manufacturers have developed, among others, the type 6AF4 which is a miniature triode designed for operation as an oscillator in U. H. F. television receivers and related equipment at frequencies up to 900 megacycles. Featured in this tube are close electrode spacing and double connections to the tube plate and grid in an attempt to minimize the inductive reactance of the lead wires and connection pins.

The problem of extending the upper frequency limit for a given electron tube while maintaining satisfactory and efficient performance has received considerable at-

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tention in the literature. As an example, reference is made to a paper entitled Ultra-high frequency triode oscillator using a series tuned circuit, by J. M. Pettit, which appeared in the June 1950 issue of the Proceedings of the Institute of Radio Engineers. Here it was noted that one or both of two phenomena ultimately fix the upper frequency of oscillation for a given tube. These are interelectrode transit time and self-resonance of the internal tube elements when employed in conventional oscillators. In terms of frequency, self-resonance is reached considerably below the frequency where transit time prevails; particularly in the case of small triodes such as the 6AF4 noted above, and the 6F4 acorn triode discussed in the cited paper. By suitable selection of a series tuned tank circuit instead of the conventional parallel tuned arrangement, it was shown that the self-resonant frequency need not ultimately be determinative of the upper frequency attainable.

In analyzing the operational characteristics of oscillators using series resonant lumped constants, certain practical considerations are found to limit upper frequency which are not ordinarily apparent from a purely theoretical analysis of circuit behavior. Among these are the fact that in the customary feedback oscillator, certain critical phase relations must be maintained between the output signals (as present in the plate to cathode circuit) and input signals (between grid and cathode). Impedances which are usually considered negligible at lower frequencies and whose properties are not clearly recognized at higher frequencies often enter to change the phase relationship and thereby quench oscillation. In addition to the necessary phase relationships between oscillator input and output, an appropriate feedback amplitude must be maintained to sustain oscillation. Here again, impedances not ordinarily apparent in a theoretical investigation combine to preclude the establishment of these necessary amplitude relations.

In the analysis of an oscillatory circuit using a conventional electron tube, investigations heretofore have failed to consider the energy loss from the tube itself due to high frequency radiation. This loss actually may prevent the appearance of sufficient energy in the feedback loop to suppress oscillation. Appropriate shielding often furnishes the answer.

Another factor which is determinative of the phase and amplitude relationships noted above is an effect generally overlooked in oscillator analysis, namely, the effect of impedance in the cathode circuit. Since such impedance is common to both input and output circuits of the tube, its effect may prove quite significant and many unsuccessful attempts at correcting the phase and amplitude relationships within an oscillator have had as their failing omission of this parameter.

The extension of the upper frequency of oscillation of conventional type electron tubes is achieved without sacrifice of reliability and efficiency and without resort to costly external circuit components by oscillators of the type disclosed in the co-pending application Serial No. 363,225, filed June 17, 1953.

In that type of oscillator, a commercially available triode is employed with lumped constants in an essentially series resonant circuit to generate successively oscillations at frequencies by far exceeding the upper limits specified in manufacturers' ratings and in a band heretofore reserved for tubes of special and expensive design.

The above-mentioned invention contemplated essentially the utilization of internal tube impedances including interelectrode capacitances and lead inductances together with a minimum of external elements for the resonant circuits of an oscillator.

In the resulting oscillator the oscillating fields are almost confined within the tube envelope and, therefore,

inductive coupling becomes impractical because of the location of the fields within the tube where they are not accessible.

Capacitive coupling is found to be also impractical because it disturbs the phase characteristics of the feedback network and, therefore, the performance of the oscillator.

An additional problem is the transformation from the low and unknown output impedance of the oscillator to some arbitrary termination impedance.

One object of the present invention is, therefore, to provide means for extracting the output energy of a high frequency oscillator whose oscillating fields are not accessible without disturbing the performance of the oscillator itself.

In the present invention the means for extracting the output energy from the high frequency oscillator mentioned above are the same means which in that oscillator serve to compensate for cathode inductance in the feedback circuit.

Accordingly, another and more specific object of the present invention is the provision of means for extracting the output energy of a high frequency oscillator from a circuit which functions primarily as the means for compensating cathode inductance in the feedback circuit.

This method of extraction does not disturb in any way the oscillator performance and in addition through utilization of these novel techniques the output may be matched accurately to normal resistive load circuits.

Therefore, a further object of the present invention is the provision of means for accurately matching the output of a UHF oscillator to normal resistive load circuits.

These and other objects of the present invention will become apparent from the specification which follows taken in connection with the accompanying drawings in which:

Figure 1 is a schematic high frequency representation of a conventional electron tube triode.

Figure 2 illustrates the use of the tube as shown in Figure 1 in a series resonant oscillator circuit.

Figure 3 illustrates a triode electron tube having paired leads for two of the electrodes thereof.

Figure 4 is a schematic representation of the inductive elements inherent in a tube construction such as Figure 3.

Figure 5 is a schematic circuit diagram illustrating the use of a tube such as that disclosed in Figures 3 and 4 in a novel U. H. F. oscillator circuit.

Figure 6 discloses an output circuit coupled to the oscillator of Figure 5.

With reference now to the drawings, and more particularly to Figure 1 thereof, there is shown an electron tube triode 10 having cathode, grid and plate electrodes within an evacuated envelope 11. In low frequency applications of a triode, it is usually sufficient to consider no more than these elements of the tube in association with the lumped parameters in the external circuit. As the frequency of operation is pushed upward, these neglected internal impedances begin to play a prominent part in determining circuit characteristics and finally it is found that in the frequency region somewhat below the upper limit defined by transit time effects, these impedances are substantially wholly determinative of system operation.

In Figure 1, the internal inductances of the plate, grid and cathode electrodes and leads L_p , L_g , and L_k , respectively, have been indicated within the envelope together with the interelectrode capacitances C_{pk} , C_{pg} , and C_{gk} . It is obvious that theoretical analysis of tube operation in which all parameters of the complex network shown in Figure 1 are considered as active circuit elements is a formidable problem. It is for this reason that many of these factors are often completely ignored, as for example, cathode inductance L_k , with correspondingly erroneous results.

A series tuned oscillator, similar in design to that discussed and analyzed in the above-cited paper by Pettit is

shown in Figure 2. The triode 10 in Figure 2 is, for purposes of this discussion, the same as that already treated in connection with Figure 1. Its external circuit consists of a tuning capacitor 15 for feedback between the plate and grid, and a grid resistor 16 which develops suitable operating bias. Plate power is derived from a positive power source B+ through a radio frequency choke 17 and the tube cathode is grounded through a similar choke 18. The tube heater circuit has been omitted.

The tank circuit for the oscillator of Figure 2 is primarily formed of external capacitor 15 resonating the internal grid and plate lead inductances L_g and L_p in a series circuit relationship. A circuit of this type will oscillate with reasonable efficiency somewhat above the self-resonant frequency limit prevailing when using more conventional external parallel resonant tuning circuits. However, as the operating frequency is increased, a point is reached for the configuration shown where the feedback network does not provide the proper oscillation sustaining phase and amplitude relationships between the system input and output. For the circuit shown in Figure 2, the practical upper frequency limit is of the order of 1200 megacycles. Even if unusual expedients are tried, such as elimination of the tube socket with wiring soldered directly to the pins, a frequency increase is not possible without exceeding rated dissipation.

A triode electron tube with the electrode configuration, shown in Figure 3, has become available in the tube bearing the commercial designation 6AF4. Through the use of close interelectrode separation, transit time has been made substantially insignificant for normal operating frequencies; but in addition, the tube features, as shown in Figure 3, paired output plate leads P_1 — P_2 and grid leads G_1 — G_2 on a conventional seven pin miniature base. In many respects, this tube design overcomes many of the physical limitations associated with tubes of the type shown generally in Figure 1.

Figure 4 illustrates the electrical significance of this electrode and connecting lead organization. The use of paired leads provides effectively two parallel inductances L_{p1} — L_{p2} between the plate pins P_1 — P_2 and parallel inductances L_{g1} — L_{g2} in the leads connecting the grid to the grid pins G_1 — G_2 . The internal cathode inductance L_k is shown in the lead to the cathode terminal K on the base of the tube.

In the use of a tube shown in Figure 4, at frequencies below the U. H. F. band, conductive shorting straps in the external circuit between pins P_1 — P_2 and pins G_1 — G_2 will connect the internal inductances in parallel, thereby reducing the inductive effect. Unfortunately, when an attempt is made to operate in the U. H. F. band, it is found that this effective inductance reduction is not available because as a practical consideration, the physical shorting straps between each pair of pins becomes comparable to twice the value of either L_p or L_g . In other words, when a conventional miniature base is used, the minimum necessary physical dimensions of leads and straps hamper the attainment of the benefits intended by the lead construction shown in Figures 3 and 4. To complicate matters further, when external shorting straps are used, these are found to radiate a considerable amount of energy and, unlike the tube itself, these are not so readily shielded. This radiation, aside from reducing the operating efficiency, also functions to reduce the signal amplitude in the feedback circuit below the value needed to sustain oscillation.

In Figure 5 there is illustrated a novel oscillator circuit utilizing the triode illustrated in Figures 3 and 4. By virtue of the circuit shown, the upper frequency of oscillation has been extended well beyond the limits imposed by self-resonance in parallel tuned oscillators or by series resonance in circuits having the configuration of Figure 2, while a considerable amount of useful power is attainable with producible results. In Figure 5, the triode electron tube 30 having paired plate terminals P_1 — P_2 and

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paired grid terminals G_1 — G_2 is shown with the internal lead inductances as in Figure 4. The interelectrode capacitances which, of course, exist as they do in Figure 1 have been omitted to permit simplification of the drawing.

Rather than use shorting straps to interconnect the paired plate leads and grid leads, the external tuning capacitance required for a series resonant oscillator has been divided and one tuning capacitor 31 is connected between the first adjacent pair of plate and grid pins P_1 — G_1 , while the other tuning capacitor section 32 is connected between the second pair P_2 — G_2 . Grid resistor 33 couples grid terminal G_2 to ground to provide the necessary static bias, and the plate circuit is energized from B+ through a high frequency choke 34. External cathode terminal K is grounded, and the heater energized from a suitable supply at terminal 35 through choke 36 in the conventional manner.

Although in principle the circuit thus far described comprises an oscillator having a series resonant tank circuit, it is observed that the complete elimination of external shorting bars and the operation of lead inductances in series rather than in parallel immediately permits tuning either or both capacitors 31 and 32 to achieve higher frequencies of oscillation than otherwise attainable. The upper frequency limit using this circuit itself is well in excess of the 1200 megacycles noted earlier as the limitation on more conventional circuits.

In examining the basis for the upper frequency limit now imposed on the system, it is found that cathode inductance L_k shown in Figure 5 limits the frequency for which appropriate input output feedback phase relationships exist. Compensation of this cathode inductance is achieved in a novel manner by the connection of small, fixed capacitor 37 from one of the plate pins P_1 to ground.

The introduction of capacitor 37 renders the feedback phase and amplitude relationships correct at still higher frequencies; and it has been found that using a fully shielded 6AF4 in the circuit shown, efficient operation at 2000 megacycles was readily achieved. With capacitor 32 fixed and capacitor 31 variable, an extremely broad tuning range up to the frequency maximum is possible.

It is, of course, necessary in order to realize fully the capabilities of a circuit of this design to employ the construction techniques which have become standardized in the U. H. F. circuit art. The actual length of the grid and plate leads in the external circuits must be minimized, and this is found to include the path through the socket contacts and tube pins. Complete shielding of the tube is required to preclude excessive radiation losses. This design, however, advantageously eliminates the need for high quality, low loss dielectrics in the tube socket, because series resonant impedances are intrinsically low.

Examination of Figure 5 reveals that this novel oscillator circuit uses only lumped external parameters and consequently, to a large extent, the resonant elements are wholly within the tube envelope itself. It is customary in high frequency oscillators using distributed parameters to withdraw high frequency energy by electromagnetic coupling with the oscillatory field, as for example, by a coupling probe or loop. Since in Figure 5 so much of the field is enclosed within the tube, the problem of efficiently extracting a substantial portion of the generated high frequency energy is entirely unconventional. Inductive coupling is not practical due to the inaccessibility of the oscillating fields, while capacitive coupling is also impractical since capacitive elements seriously disturb the phase and amplitude relationships of the feedback network. Furthermore, whatever coupling scheme is ultimately used must be capable of efficiently furnishing output energy into some low impedance, such as 50 ohms, resistive.

A novel output coupling arrangement for an oscillator having the design of Figure 5 is illustrated in Figure 6. All circuit elements in Figure 6, with the exception of

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that of the phase compensating capacitor 37, are the same as shown in Figure 5, and consequently, no further identification thereof is necessary. Advantage is taken of the need for compensating the system. As illustrated, phase compensating capacitor is connected from its plate terminal F_1 to ground through a parallel circuit consisting of variable capacitor 41 and coil 42. By suitable selection of the position of tap 43, the proper impedance transformation may be achieved for matching coaxial cable 44. By adjusting capacitor 41, the necessary phase relationship is obtained. Capacitor 41 offers the further advantage that the phase of the compensating current through capacitor 37 from the tube plate is adjustable.

As a practical illustration, a 6AF4 connected in the circuit of Figure 6 and using short, closely spaced, parallel brass plates for the frequency determining capacitors was found to oscillate in the band between 1700 and 2000 megacycles. Frequency adjustment over the entire range of operation was accomplished by variation of plate spacing and/or plate length. Fixed ceramic capacitors, of course, may be used where a fixed frequency of operation is required. A 50 ohm resistive load was appropriately tapped into coil 42 and, when adjusted, capacitor 41 simultaneously provided appropriate feedback phase relationships and impedance transformation to the load circuit. It was observed that an extremely small capacitor externally placed between the two plate terminals P_1 — P_2 had the effect of increasing the available energy output.

The principles of the present invention have been discussed above with reference to specific frequencies and also with reference to a specific tube type. However, it will be recognized that the novel concepts herein set forth are of general application. Since numerous modifications and departures may now be made by those skilled in the electrical art, the invention herein is to be construed as limited only by the spirit and scope of the appended claims.

I claim:

1. In a high frequency oscillator, an electron tube having a plurality of electrodes and leads extending therefrom, means for resonating the effective inductance of preselected electrode leads for establishing the frequency of oscillation, said means being connected between the plate and the grid terminals of said electron tube, means compensating the effective inductance of the remainder of said electrode leads, and a parallel non-resonant LC circuit in series with said compensating means for providing a high frequency output signal, said series circuit being connected between the plate terminal of said electron tube and ground.

2. In an ultra high frequency oscillator, an electron tube having cathode, grid and plate connections, a capacitive compensation circuit connected between said plate and cathode connections, and a parallel non-resonant LC circuit in series with said capacitive circuit for providing an output for said oscillator, said series circuit being connected between the plate connections of said electron tube and ground.

3. In an ultra-high frequency oscillator, an electron tube having cathode, grid and plate electrodes, a plurality of connecting leads extending from said plate, a like plurality of connecting leads extending from said grid and a lead extending from said cathode, means external to said triode for impedance coupling each of said plurality of plate connecting leads to the corresponding one of said plurality of grid connecting leads for establishing a resonant circuit including the inductances inherent in said grid and plate connecting leads, a capacitor coupling said plate connecting lead to said cathode, and a parallel non-resonant LC circuit in series with said capacitor for providing the ultra-high frequency output of said oscillator.

4. In an ultra-high frequency oscillator, an electron tube having, within an envelope, a cathode, grid and plate, first and second connecting leads for said plate, first and

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second connecting leads for said grid, and a connecting lead for said cathode, a first capacitor external to said envelope connecting said first plate connecting lead to said first grid connecting lead, a second capacitor external to said envelope connecting said second plate connecting lead to said second grid connecting lead, said first and second capacitors thereby establishing a series resonant circuit including the inductance inherent in said grid and plate connecting leads while coupling ultra-high frequency energy between said plate and grid, a third capacitor coupling said plate to said cathode for effectively compensating the inductance inherent in said cathode connecting lead, a parallel non-resonant circuit formed of a coil and an adjustable capacitor in series with said third capacitor, and an output circuit of predetermined impedance tapped into said coil at a point of like impedance.

5. In an ultra-high frequency oscillator, an electron tube having, within an envelope, a cathode, grid and plate, first and second connecting leads for said plate, first and second connecting leads for said grid, and a connecting lead for said cathode, a first capacitor external to said envelope connecting said first plate connecting lead to said first grid connecting lead, a second capacitor external to said envelope connecting said second plate connecting

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lead to said second grid connecting lead, said first and second capacitors and the inductances inherent in said plate and grid connecting leads forming a series resonant circuit determinative of the frequency of oscillation, a third capacitor external to said envelope intercoupling said plate and cathode connecting leads for substantially compensating the inductive reactance inherent to said cathode connecting lead at said frequency of oscillation, a parallel non-resonant circuit comprising a coil and a fourth capacitor in parallel, said resonant circuit being in series with said third capacitor between said plate and cathode, said fourth capacitor being variable for adjustment of said parallel circuit to obtain the necessary phase relationship for oscillators and for adjustment of the compensation afforded by said third capacitor, an output circuit of predetermined impedance tapped into said coil at a point of like impedance therein, and means for applying static potentials to said plate and coil relative to said cathode.

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