HIGH FREQUENCY VACUUM TUBE CIRCUIT

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FIG. 1

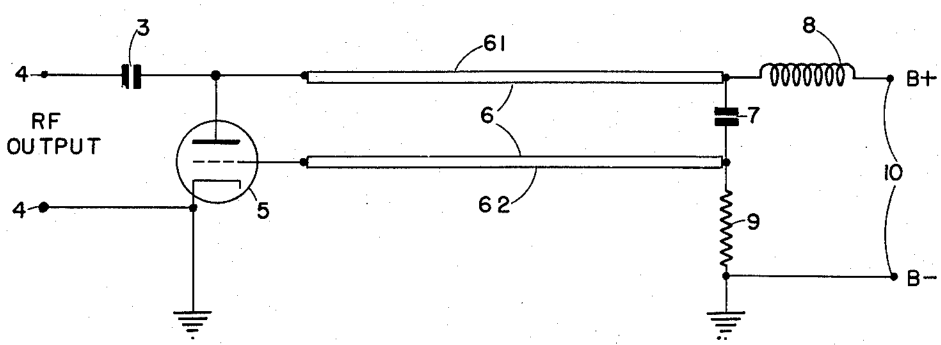

FIG. 2

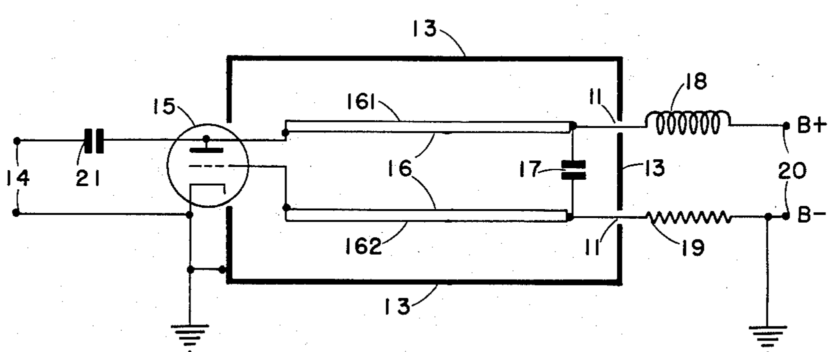

FIG. 4

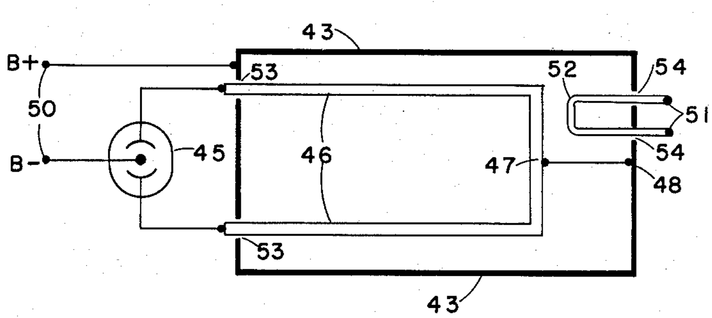

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FIG. 3

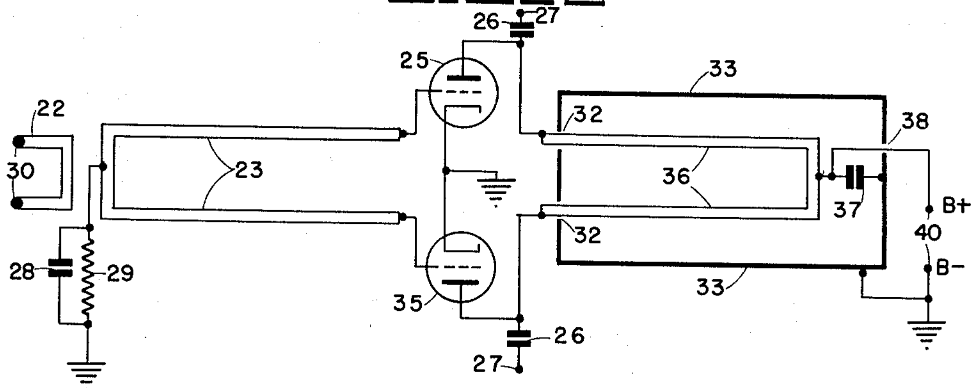


FIG. 5

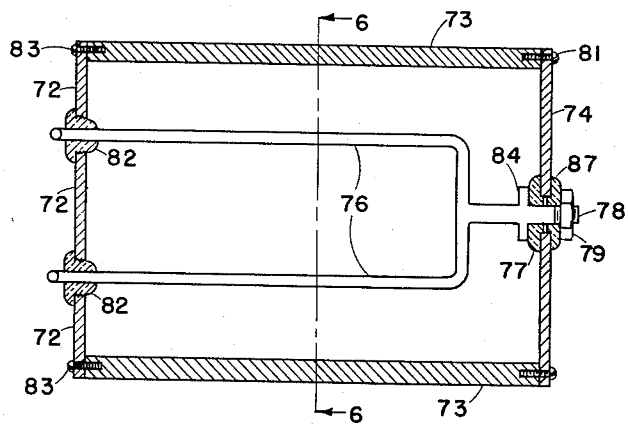
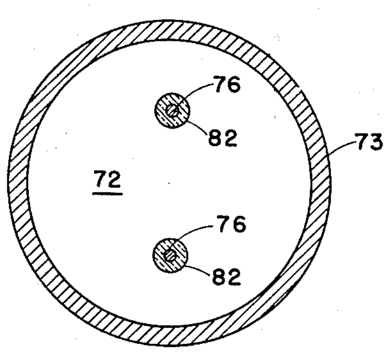


FIG. 6



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HIGH FREQUENCY VACUUM TUBE CIRCUIT

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8 Claims. (Cl. 250—36)

(Granted under Title 35, U. S. Code (1952), sec. 266)

This invention relates to vacuum tube amplifying circuits; more particularly it relates to a means for employing conventional vacuum tubes as oscillators or amplifiers at very high frequencies.

Electron time of flight is the factor which governs the theoretical upper limit of frequency at which a conventional vacuum tube may be usefully employed. When the frequency is raised to such a high value that the time of flight of electrons passing between the electrodes is an appreciable fraction of a period, conventional vacuum tubes and conventional circuits cease to function.

As a practical matter, however, the physical size of the vacuum tube and the distributed capacitance and inductance resulting therefrom have in the past fixed a practical upper limit of frequency much lower than the theoretical limit imposed by transit time of electrons. An object of this invention is to provide a means for overcoming the frequency-limiting effect of distributed reactances in conventional vacuum tubes and thereby to make possible useful employment of conventional tubes at frequencies closely approaching the theoretical transit-time limit.

The invention will be discussed and described with reference to the appended drawings, of which:

Figure 1 is a diagrammatic representation of a high-frequency oscillator employing a conventional vacuum tube in a Colpitts circuit; this figure being used to explain the principle of operation of the invention;

Figure 2 is a diagrammatic showing of a high-frequency oscillator employing an embodiment of the present invention in conjunction with a conventional vacuum tube;

Figure 3 is a diagrammatic showing of another embodiment of the invention wherein conventional vacuum tubes are employed as a frequency multiplying amplifier;

Figure 4 is a drawing which shows diagrammatically an embodiment of the invention employing a split-anode negative resistance magnetron as a high frequency oscillator;

Figure 5 is a view, partly in cross section, of a physical construction of high frequency components for use in the embodiment of Figure 3; and

Figure 6 is another cross section view of the apparatus of Figure 5.

Referring to Figure 1, the oscillator therein shown comprises a triode vacuum tube 5, connected in a form of the Colpitts circuit adapted for ultra-high-frequencies. Transmission line 6 serves as tank circuit for the oscillator; it consists of two conductors, numbered 61 and 62 respectively. One terminal of conductor 61 is connected to the plate of tube 5; the other terminal of conductor 61 is connected through R. F. of choke coil 8 to the positive side of D.-C. source 10. One terminal of conductor 62 is connected to the grid of tube 5; the other terminal of conductor 62 is connected to ground through gridleak resistor 9. Conductors 61 and 62 are joined by condenser 7 at the terminals adjacent choke 8 and resistor 9. Condenser 7 has substantially zero impedance at the operating frequency. Line 6 is, therefore, for high frequency currents, a short-circuited section having its open terminals connected between grid and plate of tube 5. The cathode of tube 5 and the negative side of source 10 are grounded. R. F. power may be taken from the oscillator in any manner appropriate to the nature and impedance of the load; in this embodiment the R. F. output terminals 4 are connected respectively to ground and to the plate of tube 5 through blocking condenser 3.

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The effective length of transmission line 6 includes the length of conductors 61 and 62 plus the length of the leads to and within tube 5 and the actual length of the tube electrodes themselves. According to transmission line theory such a line, open at one end and short-circuited at the other, is capable of oscillating in an infinite number of modes. Of these the fundamental mode is that wherein the total effective length of the line equals one quarter wavelength. The next higher mode has a frequency of oscillation three titmes as great as the fundamental frequency; in that mode the effective length of the line equals three quarters of a wavelength.

It is a property of self-excited vacuum tube oscillators that oscillation will be maintained at that frequency wherein losses are lowest for the particular oscillatory circuit being employed. In conventional oscillators using transmission line tank circuits the frequency adopted is that of the fundamental mode of the line. Consequently, while a line-controlled vacuum tube oscillator is theoretically capable of oscillating in many modes, a particular transmission line tank circuit, employed with a particular tube in a conventional circuit, does by its constants determine a unique frequency of oscillation.

In the light of the foregoing paragraphs, assume that a higher frequency is desired from the vacuum tube oscillator of Figure 1. The obvious procedure to effect an increase in frequency is to shorten line 6. As line 6 is made shorter and shorter, the frequency of oscillation grows higher and higher until at last line 6 is eliminated entirely and condenser 7 is shortened directly between the grid and plate terminals of tube 5. The frequency of oscillation obtained under these conditions is the highest obtainable from the tube by conventional means. Moreover the efficiency and stability become very poor as the external line shrinks in length, and in practice it is often impossible to obtain any oscillation at all when the external line has been reduced to the vanishing point. In any case the maximum frequency obtaintable is well below the theoretical limit imposed by transit time considerations.

With respect to the embodiments of the invention herein described, by enclosing a transmission line tank circuit in an appropriately designed resonant cavity, oscillation at the fundamental mode can be prevented and the tube can be forced to set up and maintain oscillations in the transmission-line tank circuit at one of the line's higher modes. Thus the output frequency of the oscillator may be made an odd multiple of the resonant frequency of the line, and tubes may be employed as oscillators virtually up to the frequency limit imposed by transit time. This result can be obtained because a resonant cavity short-circuits and suppresses all electromagnetic fields within it having a frequency lower than a critical cut-off frequency while allowing electromagnetic fields having a frequency near the cavity's resonant frequency to be maintained within the cavity.

The details of design may be best explained with reference to Figure 2, which shows, in diagrammatic form, one embodiment of the invention. In Figure 2, an oscillator is shown, incorporating tube 15. The tank circuit connected to tube 15 consists of transmission line 16, together with the leads and tube elements associated therewith. Line 16 comprises parallel conductors 161 and

162. One end of conductor 161 is connected to the plate of tube 15; the other end is connected through R. F. choke coil 18 to the positive side of D.-C. source 20. One end of conductor 162 is connected to the grid of tube 15, the other end is connected through grid leak resistor 19 to ground. The ends of conductors 161 and 162 adjacent choke 18 and resistor 19 are joined by condenser 17, which is a substantially zero impedance at the operating frequency. The cathode of tube 15 and the negative side of source 20 are grounded.

Entirely surrounding line 16 and a portion of the envelope of tube 15 is resonant cavity 13. Cavity 13 may be cylindrical in shape or it may have a rectangular or other cross-section. Its size in this embodiment is such as to cause the oscillator to resonate at a frequency about three times the natural frequency of the tank circuit comprising line 16 and the leads and tube elements associated therewith. Cavity 13 is closed except for an aperture in one end adequate to admit a portion of the envelope of tube 15 and two small apertures 11 in the opposite end, necessary to allow the leads from line 16 to be brought out. R. F. output may be taken in any manner appropriate to the impedance of the load; in Figure 2 the R. F. output terminals 14 are connected between ground and the plate of tube 15. D. C. voltage on the plate is blocked from the R. F. load by condenser 21.

Cavity 13 has a physical dimension of approximately three-quarter wavelength at the resonant frequency of the system, but the capacitive loading of line 16 on the cavity 13 decreases its electrical length to a half wavelength. Since cavity 13 is essentially closed at both ends the lowest mode it can sustain is the half wavelength mode, which means line 16, connected for odd quarter wavelength operation, is forced into the three-quarter wavelength mode or higher.

When cavity 13 is oscillating in its fundamental mode the wavelength of oscillation is about twice the length of the cavity, a condition requiring substantially zero electric field at each end of the cavity and maximum electric field at a point about midway between the ends. This set of conditions conforms very well to three-quarter wave oscillation by the tank circuit associated with tube 15, since such oscillation places an electric-field node at the shorted end of line 16, an electric field maximum a quarter wavelength from the end, or about midway between the ends of cavity 13, and another electric field node at the point one-half wavelength from the shorted end. The actual tube elements and the portion of the leads within the tube envelope external to cavity 13 constitute, electrically, a third quarter-wavelength, which places an electric field maximum between the plate and grid. (The electrical quarter-wave within the envelope of tube 15 will normally be much less than a physical quarter-wave in length, because of the loading effect of the plate-to-grid capacitance.)

Whereas the cavity 13 encourages oscillation in the three-quarter wavelength or triple frequency mode, it makes oscillation of tube 15 in the tank circuit's fundamental mode impossible, because the frequency of fundamental mode oscillations is below the cutoff frequency of the cavity and cannot be sustained therein.

By employment of the present invention the upper frequency limit of standard tubes can be greatly increased over the frequencies obtainable with conventional circuits. For example, an RCA 8012 tube, whose upper frequency limit in conventional circuits is about 600 mc./s, has been made to oscillate, by use of this invention, at frequencies above 800 mc./s.

Moreover, because of the high quality factor of the cavity, plus the higher quality factor obtainable in the tank circuit when its length need not be of vanishing proportions, improved efficiency and frequency stability are obtained at very high frequencies with this invention.

This invention may also be applied to a frequency multiplying amplifier. Figure 3 shows a typical embodiment of this sort wherein a pair of tubes are employed in push-pull as a frequency tripler. Referring to Figure 3, transmission line tank circuit 23, approximately one-quarter wavelength long for the frequency of the input signal, consists of parallel conductors short circuited at one end. The open ends of line 23 are connected respectively to the grids of tubes 25 and 35, the short circuited end of line 23 is connected to ground through condenser 28 and resistor 29 in parallel. R. F. energy at the input frequency may be applied to input terminals 30. Coupling loop 22, connected to terminals 30, is inductively coupled to line 23. The cathodes of tubes 25 and 35 are grounded. Transmission line tank circuit 36 consists of two parallel conductors short circuited at one end. The open ends of line 36 are connected respectively to the plates of tubes 25 and 35. The physical dimensions of line 36 are approximately similar to those of line 23. In this embodiment the cavity does not wholly enclose the transmission line and part of the tube envelope as in the embodiment of Figure 2. If the frequency sought is not so high as to approach the absolute maximum, the cavity may be placed around only the transmission line itself as in Figure 3. Cavity 33 in Figure 3 resonates, with line 36 within it, at three times the signal frequency applied to input terminals 30. Cavity is closed but for apertures 32 in one end, to permit the passage of the conductors of line 36, and small aperture 38 in the opposite end. The short circuited end of line 36 is connected to the positive side of D.-C. source 40 by a wire passing out of cavity 33 through aperture 38. Condenser 37 is connected between the short-circuited end of line 36 and the adjacent end of cavity 33. The outside surface of cavity 33 and the negative side of source 40 are grounded. R. F. output from this circuit, as with the previous embodiment shown, may be taken in any manner appropriate to the impedance of the load. In Figure 3 output terminals 27 are connected to the respective plates of tubes 25 and 35 through blocking condensers 26. The output voltage at terminals 27 is balanced relative to ground.

The operation of the embodiment of Figure 3 is similar in principle to that of the oscillator shown in Figure 2. The plate tank circuit is prevented by cavity 33 from oscillating at its normal fundamental frequency and is consequently set into oscillation in its triple-frequency, or three-quarter wavelength, mode by the energy supplied by tubes 25 and 35. The output power taken from terminals 27 has, therefore, three times the frequency of the energy fed to input terminals 30. By employing the principles of this invention, conventional tubes may be made to operate efficiently and stably at frequencies well above the practical frequency limits of conventional frequency multiplier circuits.

Figure 4 shows an embodiment of the invention employing a split-anode negative resistance magnetron as a high-frequency oscillator. The employment of the invention in this manner permits realization of higher frequency output from the magnetron than is available by conventional means and yields a higher degree of frequency stability than is usually obtainable from negative resistance magnetrons. Referring to Figure 4, tube 45 is a magnetron tube of the negative resistance split anode type. It is placed in a steady magnetic field provided by a magnet which is not shown in the drawing. The two anode segments of the magnetron 45 are connected respectively to the open terminals of a short-circuited transmission line section 46, which serves as resonant circuit for the magnetron oscillator. Line 46 is housed in a closed conducting resonant cavity 43, the conductors of line 46 protruding from the closed cavity 43 through apertures 53. The short-circuited end 47 of line 46 is connected to the end of cavity 43 at point 48, situated at a point within cavity 43 whereat the electric field is minimum when the cavity is oscillating in its fundamental mode. The positive side of D.-C. source **50** is connected to the outer surface of cavity **43** and the negative side of source **50** is connected to the cathode of magnetron tube **45**. R. F. output may be taken from the oscillator by connecting a load to output terminals **51**, which are connected to the ends of coupling loop **52**. Coupling loop **52** extends through small apertures **54** in cavity **43** and is inductively coupled to line **46**.

In operation, the properties of the magnetron cause a negative A.-C. resistance to appear across the anode segments of tube **45**, supplying energy to transmission line tank circuit **46** and sustaining oscillations therein. As in the previously described embodiments, cavity **43** prevents the line **46** from oscillating in its fundamental mode. Line **46** can and does oscillate in its three-quarter wavelength mode, however, since oscillation in that mode produces fields which coincide with and reinforce oscillations in the cavity. The net effect, as in the other embodiments of the invention herein shown, is to permit successful and stable operation at frequencies closely approaching the limit imposed by transit time. In an application where the frequency required is very near the limit obtainable, the cavity may be constructed as in Figure 2, to wholly enclose line **46** and part of the envelope of magnetron **45** as well, thus reducing the portion of the tank circuit outside the cavity to the anode segments themselves and a part of the leads within the evacuated tube envelope.

Figures 5 and 6 illustrate typical physical construction which might be employed for the cavity and transmission line assembly used in the invention. Figure 5 is a view, partly in cross section, of an assembly suitable for use in the embodiment of Figure 3. The section in Figure 5 is taken along the axis of the resonant cavity. Figure 6 is a view of the same embodiment taken in section in a plane perpendicular to the cavity axis as indicated by the dotted line "6—6" in Figure 5.

Referring to Figure 5, the resonant cavity in this representative embodiment is cylindrical; the principal element **73** of the cavity is tubular and formed of rigid conducting material. The remainder of the cavity is formed by circular end plates **72** and **74**, also formed of rigid conducting material. End plate **72** is secured to element **73** by a plurality of screws **83**, symmetrically disposed around the periphery of plate **72** and threaded into holes drilled and threaded therefor in element **73**. End plate **74** is similarly secured to the opposite end of element **73** by screws **81**. Transmission line **76** consists of parallel conductors joined at one end, forming a bifurcated conducting member as shown. The open ends of line **76** pass through threaded insulating bushings **82**, which are securely threaded into apertures in end plate **72**. The axial openings in bushings **82** through which the conductors of line **76** pass are proportioned to effect a snug fit therefor.

From the closed or short-circuited end of line **76** a stub extension **78** protrudes along the axis of line **76**, passing through bushings **77** and **87** which are fitted into an aperture in the center of end plate **74**. A flange **84** on stub **78** fits snugly against bushing **77**; the end of stub **78** is threaded and nut **79** is tightly threaded thereon so as to hold bushings **87** in place and effect rigid mechanical support for line **76**. External connection to the short circuited end of line **76** may be effected by connection to the external end of stub **78**. Stub **78** and the surrounding conducting surface of end plate **74** form the condenser shown in diagrammatic form in Figure 3 as condenser **37**.

Figure 6 shows a section of the apparatus of Figure 5 taken in a plane perpendicular to the section in Figure 5. The section shown in Figure 6 is indicated on Figure 5 by the dotted line "6—6," looking toward end plate **72** as indicated by the arrows in Figure 5. Tubular element **73** is seen in cross section, as are the conductors of line **76**. End plate **72** and insulating bushings **82** appear in plan view as shown in the drawing.

It will be understood that the embodiments of the invention shown and described herein are exemplary only, and

that the scope of the invention is to be determined by reference to the appended claims.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. A distributed-constants tanks circuit enclosed at least in part by a cavity resonator and electrically coupled thereto, said cavity resonator having a cutoff frequency higher than the frequency of the fundamental mode of oscillation of the tank circuit.

2. A tank circuit comprising a section of transmission line, said tank circuit enclosed at least in part by a cavity resonator and electrically coupled thereto, the lowest frequency of resonance of said cavity resonator being approximately an integral multiple of the frequency of the fundamental mode of oscillation of the tank circuit.

3. The combination of an oscillator comprising a distributed constants tank circuit having a given fundamental frequency of resonance, and a cavity resonator having a higher fundamental frequency of resonance than said tank circuit enclosing at least in part said tank circuit and electrically coupled thereto, said cavity resonator acting to operatively suppress fundamental mode oscillations in said tank circuit.

4. The combination of an oscillator comprising a tank circuit having a section of transmission line, said tank circuit having a given fundamental frequency of resonance, and a cavity resonator having a higher fundamental frequency of resonance than said tank circuit enclosing at least in part said transmission line and electrically coupled thereto, said cavity resonator serving to operatively suppress fundamental mode oscillations in said tank circuit.

5. An oscillator comprising a vacuum tube having at least first and second electrodes; a tank circuit effectively comprising the first and second electrodes, leads thereto within the tube, and a section of transmission line; and a cavity resonator having a cutoff frequency higher than the frequency of the fundamental mode of oscillation of the tank circuit, said cavity resonator enclosing the section of transmission line and enclosing at least in part said leads within the tube, said cavity resonator serving to suppress fundamental-mode oscillations in the tank circuit.

6. An oscillator comprising a vacuum tube having a grid and a plate; a tank circuit effectively comprising the grid, the plate, leads thereto within the tube, and a section of transmission line; and a cavity resonator having a cutoff frequency higher than the frequency of the fundamental mode of oscillation of the tank circuit, said cavity resonator enclosing the section of transmission line and enclosing at least in part said leads within the tube, said cavity resonator serving to suppress fundamental mode oscillations in the tank circuit.

7. An oscillator comprising a magnetron tube, a distributed constants tank circuit operatively coupled to said magnetron tube, and a cavity resonator enclosing the tank circuit at least in part and of such dimensions as to operatively suppress fundamental-mode oscillations in the tank circuit.

8. An amplifier having input means for applying high frequency energy to the input means, a vacuum tube fed by the input means; a tank circuit having distributed constants; a cavity resonator enclosing the tank circuit at least in part and of such dimensions as to operatively suppress fundamental mode oscillations in the tank circuit, and coupling means operative to feed energy from the vacuum tube to the tank circuit.

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