Feb. 24, 1953 LA VERNE R. PHILPOTT 2,629,821

HIGH-FREQUENCY SIGNAL TRANSLATION CIRCUIT

Filed June 7, 1945

FIG. 1

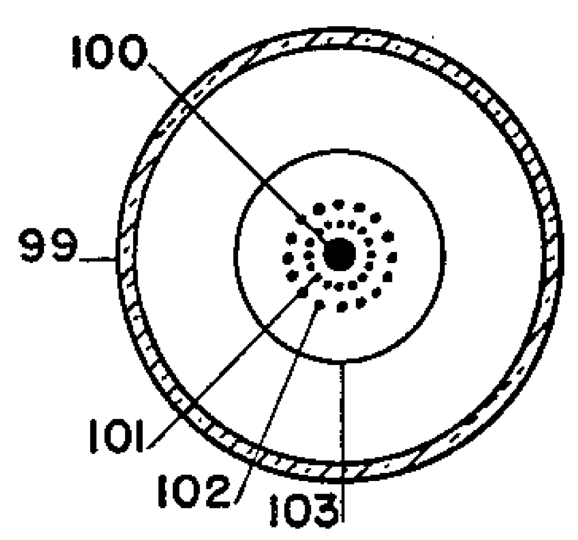


FIG. 2

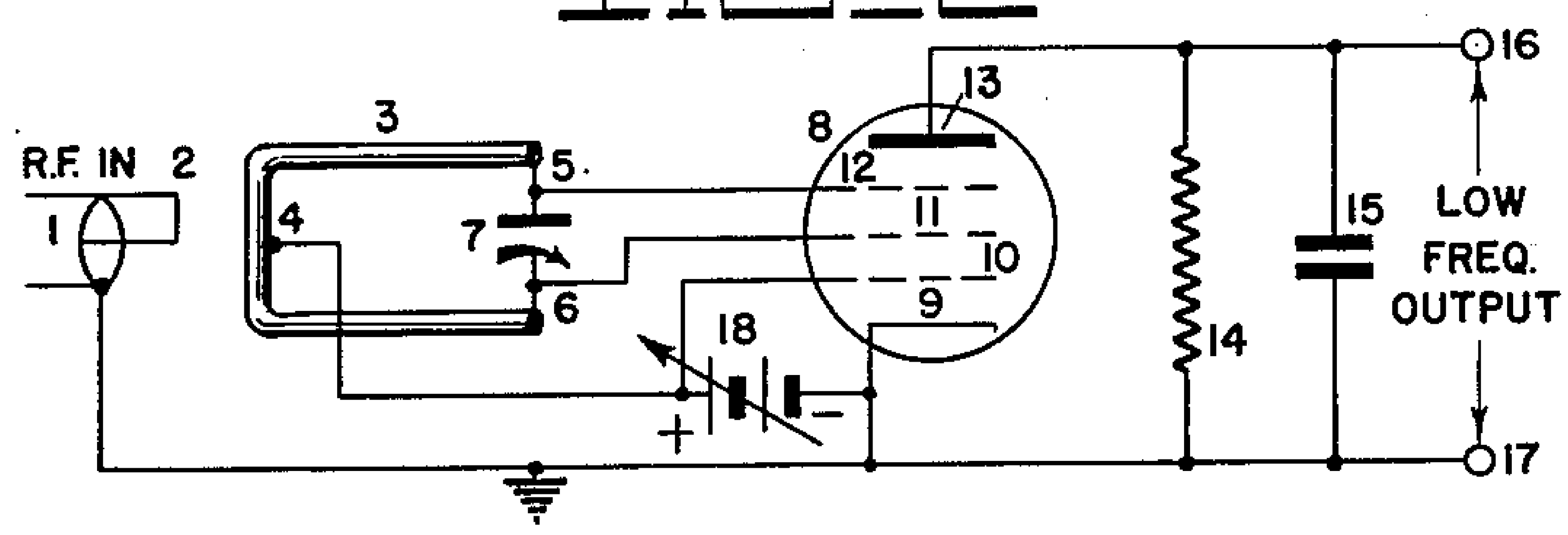


FIG. 3

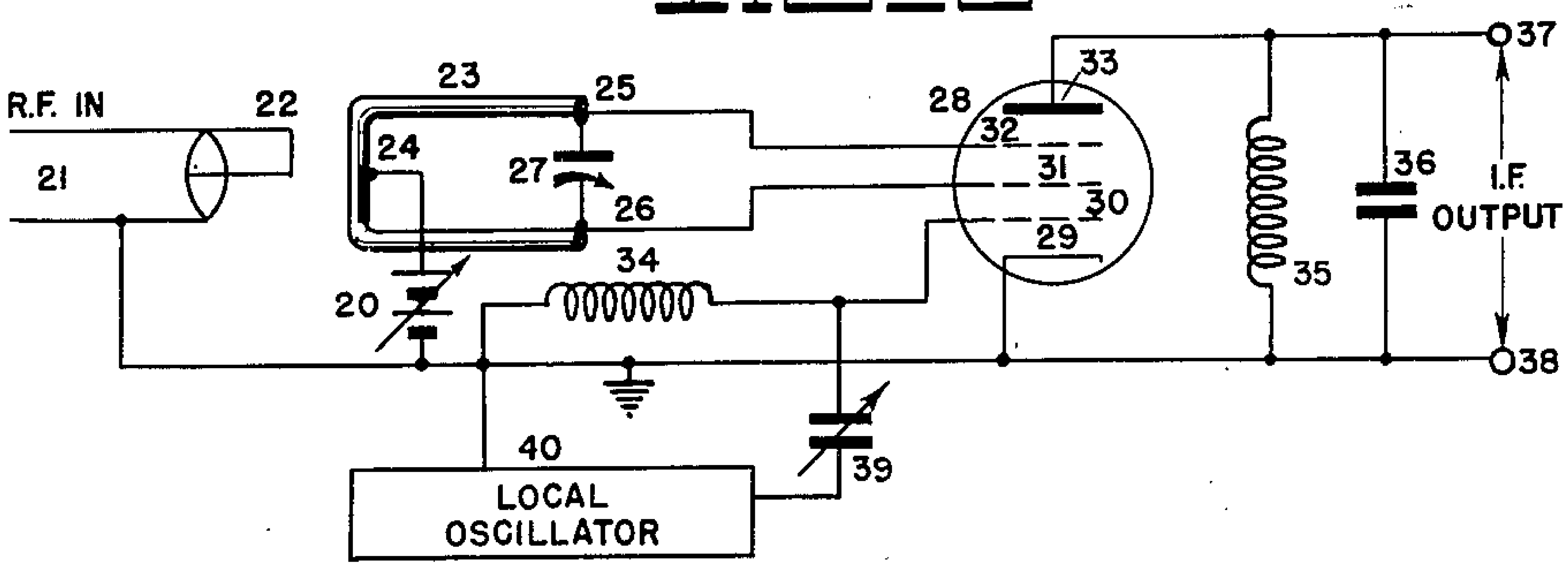


FIG. 4

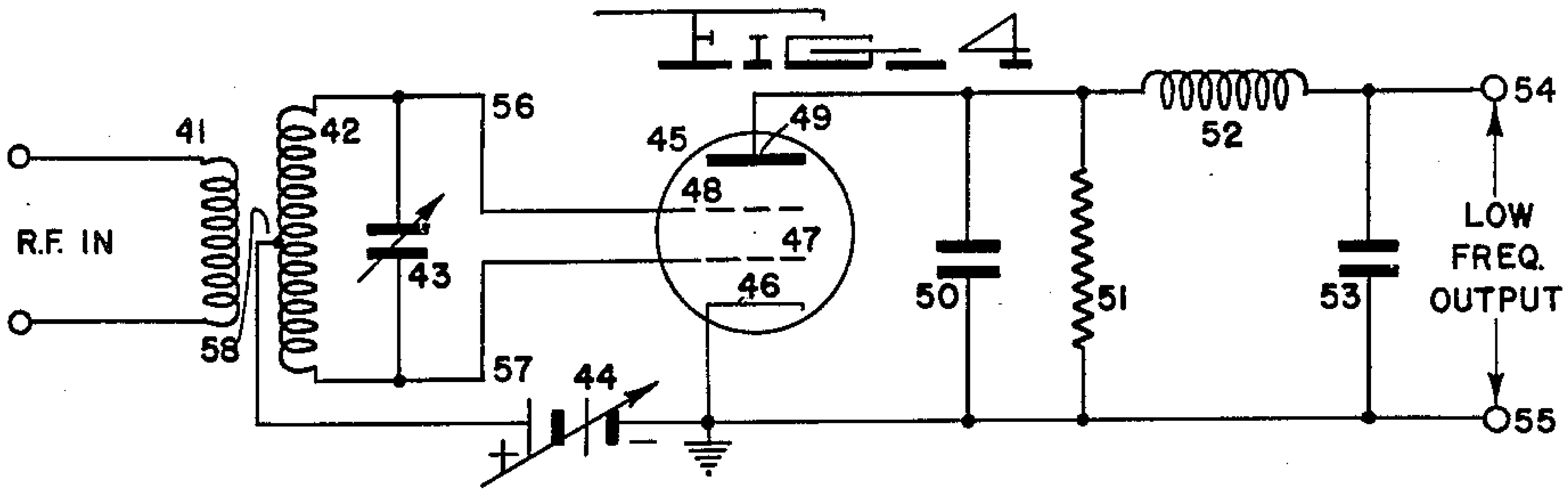
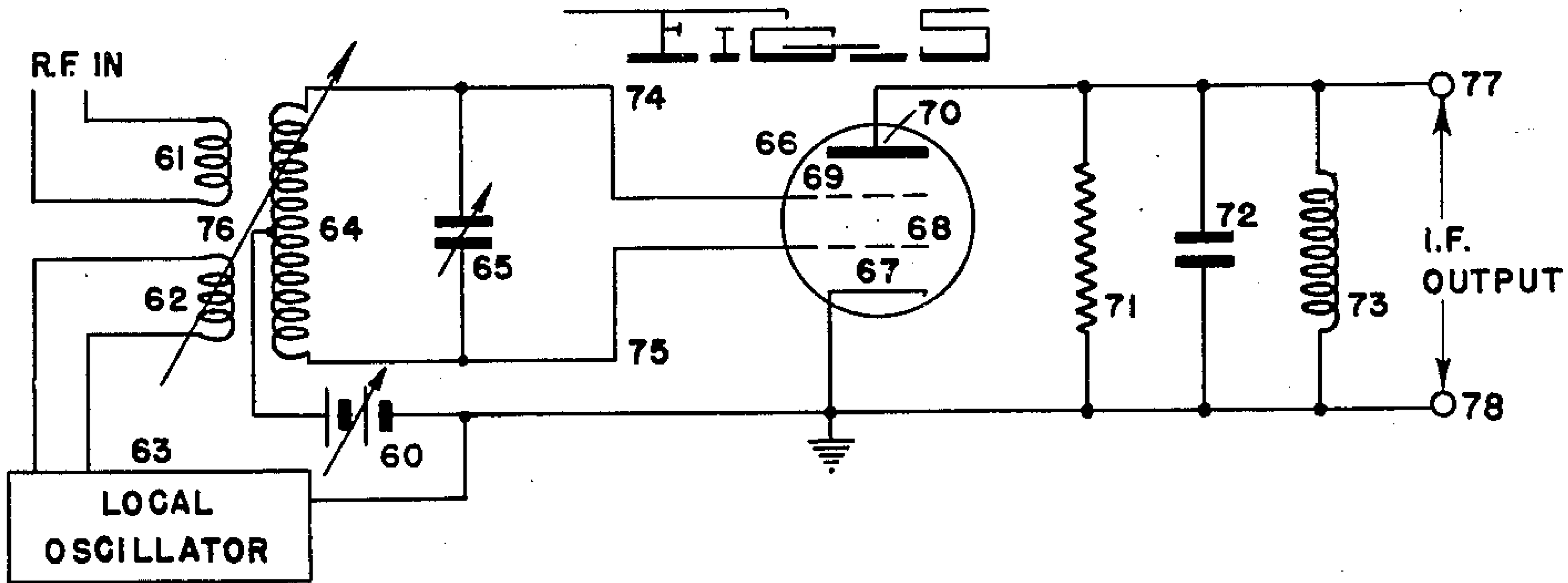


FIG. 5



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HIGH-FREQUENCY SIGNAL TRANSLATION CIRCUIT

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11 Claims. (Cl. 250—20)

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This invention relates to the transmission of a high frequency signal through a network comprising an electron tube, and is particularly directed to a method and means for doing so.

It is an object of the invention to transfer a high frequency signal by employing the electron transit time in a vacuum tube.

It is another object of this invention to provide a method and means by which the electron transit time in a vacuum tube is usefully employed to effect detection or frequency conversion of high-frequency radio signals.

Another object of the invention is to provide a method and means for using conventional grid-control vacuum tubes for detection and frequency conversion of radio signals at frequencies higher than heretofore possible.

Still a further object of this invention is to provide a method and means for detection or frequency conversion of high frequency radio signals at very low electrical noise level, making possible high signal to noise ratio in receivers employing this invention.

This invention employs a vacuum tube with an external circuit so designed as to make use of the phenomenon of "transit time." Transit time refers to the time required for an electron to travel between the electrodes of a vacuum tube. The magnitude of transit time in a given tube depends primarily on the element spacings and the tube voltages, which respectively govern the length of the path and the electron velocity.

In this invention, because transit time is taken into account and put to use, grid-control vacuum tubes of conventional structure may be operated successfully as detectors or frequency converters at frequencies very much higher than with pre-existing circuits. Moreover, due to the small voltages employed in this circuit, electron velocity is low and in consequence electrical circuit noise is very low, permitting high signal-to-noise ratio in high-frequency radio receivers employing the invention.

Further description of the invention will be made with reference to the appended drawings of which,

Figure 1 is a cross-section view of a conventional tetrode vacuum tube, looking downward along the axis of the cathode;

Figure 2 is a schematic diagram showing an embodiment of the invention as a detector of high-frequency modulated signals;

Figure 3 is a schematic diagram showing an embodiment of the invention employing a pentode tube as a frequency converter for high-frequency radio signals;

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Figure 4 is a schematic diagram showing a form of the invention in which a tetrode tube is employed as a detector; and

Figure 5 is a schematic diagram showing a form of the invention in which a tetrode tube is employed as a frequency converter.

All the embodiments of the invention herein described employ electron transit time phenomena in vacuum tubes of conventional design. Figure 1 illustrates in cross-section the physical structure of a conventional tetrode tube that might be employed in this invention. The electrodes, enclosed within evacuated glass envelope 99, comprise cathode 100, anode 103, and grids 101 and 102, interposed concentrically between the cathode and the anode.

Effects caused by electron transit time limit the usefulness of such tubes in conventional circuits to frequencies wherein the period is very much longer than the transit time. In this invention that limitation is not present, and the upper useful frequency limit is greatly extended.

The form of the invention illustrated in Figure 2 is adapted to serve as a detector of modulated radio frequency signals. In a specific construction in the form illustrated in Figure 2, circuit parameters were chosen to make the invention primarily responsive to amplitude modulated voltages.

The radio frequency signal voltage is brought in on coaxial line 1, which is terminated in coupling loop 2. The currents in loop 2 induce radio frequency currents in the anti-resonant tank circuit consisting of inductive transmission line section 3 and tuning condenser 7. The radio frequency voltage developed at line terminal 5 is applied to grid 12 of vacuum tube 8, and the radio frequency voltage developed at line terminal 6 is applied to grid 11 of vacuum tube 8. Center tap 4 of line section 3 is connected to grid 10 of vacuum tube 8 and is also returned to cathode 9 of vacuum tube 8 through battery 18, which has negligible impedance to radio frequency currents. Cathode 9 is heated, and serves as an electron source. The heater element is not shown. Plate 13 of tube 8 is returned to cathode 9 through the load circuit consisting or resistor 14 and condenser 15 in parallel. Since plate 13 receives electrons from the cathode 9, it is hereinafter referred to as the anode. The magnitude of condenser 15 is so chosen that it possesses very low impedance to currents of the radio frequency, but high impedance to the modulation frequencies for which the radio frequency signal serves as carrier. Low frequency output terminals 16 and 17 are connected across the load circuit comprising resistor 14 and condenser 15.

All three grids of tube 8 are at the same positive D. C. potential relative to cathode 9, thus potential being equal to the voltage of battery 18. The voltage of battery 18 is so adjusted that a substantial part of the electrons passing from cathode 9 to anode 13 require approximately half a radio frequency period to travel from grid 11 to grid 12. This voltage adjustment is not critical, and in a typical application the voltage of battery 18 may be 3 or 4 volts. The voltage on grid 10 is constant; this grid screens cathode 9 from grids 11 and 12 and influences the average electron velocity.

The radio frequency voltage applied to grid 12 should lag the radio frequency voltage on grid 11 by an amount of time approximately equal to the transit time of the electrons passing from grid 11 to grid 12. In this particular embodiment the electron velocity is so adjusted as to make a half-period of time the approximate lag. In consequence the input circuit is so connected that the voltage on grid 12 lags the voltage on grid 11 by 180°. Hence any electrons which are accelerated toward the anode by grid 11 will be further accelerated by grid 12, if their travel time from grid 11 to grid 12 is approximately half an R. F. period. This occurs because, after the electrons have passed grid 11, the latter becomes negative and pushes the electrons on toward grid 12, whereas grid 12 at the same instant becomes positive and attracts them. After the said electrons pass grid 12, they are further accelerated toward the anode because sufficient additional time has by then elapsed to cause grid 12 to become negative.

Electrons whose average velocity is of the order specified cannot reach the anode if they approach grid 11 at a time when it is negative, since they are repelled toward the cathode by grid 11. Even if their kinetic energy is sufficient to carry them past grid 11 while it is negative they then approach grid 12 a half-period later when it also is negative and the electrons are thus repelled from the anode again. Such electrons either never reach the anode or they move about in the electron cloud for a half-period of time and return when voltage conditions are favorable for their passage. As a result the anode current of tube 8 contains impulses at the radio frequency. The effectiveness of the segregation or bunching process just described is a function of the amplitude of the radio frequency voltage applied to grids 11 and 12; and the anode current impulses are therefore of varying magnitude if the R. F. signal voltage is amplitude modulated. Consequently the anode current of tube 8 contains components at the low modulation frequencies as well as the R. F. carrier frequencies. The load circuit, condenser 15 and resistor 14, offer high impedance to these modulation frequencies, and accordingly modulation-frequency voltage is developed across output terminals 16 and 17.

The embodiment of the invention shown in Figure 3 functions as a frequency converter for high frequency radio signals. Radio frequency signal voltage is brought in on coaxial line 21, terminated in coupling loop 22. The currents in loop 22 induce radio frequency currents in the anti-resonant tank circuit consisting of inductive transmission line section 23 and tuning condenser 27. The radio frequency voltage developed at line terminal 25 is applied to grid 32 of tube 28, and the radio frequency voltage developed at line terminal 26 is applied to grid 31 of tube 28. Center tap 24 of line section 23 is returned to the cathode 29 of tube 28 through battery 20, which has negligible impedance to radio frequency currents. Grid 30 of tube 28 is connected to cathode 29 through radio-frequency choke coil 34. Grid 30 is also coupled to local oscillator 40 through condenser 39. The amplitude of the voltage impressed on grid 30 by local oscillator 40 may be controlled by varying the capacitance of condenser 39. Cathode 29 is heated and serves as an electron source. The heater element is not shown. The anode 33 of tube 28 is returned to cathode 29 through the load circuit consisting of inductance coil 35 and condenser 36 in parallel. The output terminals 37 and 38 are connected across the load circuit, coil 35 and condenser 36. Coil 35 and condenser 36 are so chosen that they will be anti-resonant at the desired intermediate output frequency. The frequency of local oscillator 40 is adjusted so that its frequency will bear a relation to the radio signal frequency such that the sum or difference of the signal frequency and the oscillator frequency will equal the desired intermediate output frequency. The amplitude of the voltage impressed on grid 30 by local oscillator 40 is set at a suitable value by adjusting condenser 39.

The operation of this frequency converter circuit is similar to that of the detector circuit shown in Figure 2, with one important difference. Whereas in the detector the average electron velocity is controlled by the grid-polarizing battery alone, in this circuit it is also dependent upon the instantaneous value of the voltage impressed on grid 30 by local oscillator 40. When the voltage on grid 30 is appreciably negative, anode current is cut off entirely. When grid 30 is positive, the average electron velocity is varied greatly as the potential of grid 30 swings over a range of several volts. During a substantial portion of each interval when grid 30 is positive, the transit time of many electrons in the stream is such as to permit grids 31 and 32 to function as bunch-forming elements, as in the detector circuit just described. In this frequency converter circuit, therefore, the amplitude of the impulses of anode current is governed not only by the voltage conditions on grids 31 and 32, but by the local oscillator voltage on grid 30 as well. Consequently the anode current contains components of many frequencies including the desired intermediate frequency. Since the load in the anode circuit, comprising coil 35 and condenser 36, is anti-resonant at the desired intermediate frequency, it will offer high impedance to current of that frequency and a voltage of that frequency will be developed across the output terminals 37 and 38.

Figure 4 is a schematic diagram of another embodiment of the invention, connected as a detector of modulated ultra-high frequency radio signals, using in this case a tetrode vacuum tube. The vacuum tube 45 is shown in Figure 4 as containing cathode 46, grids 47 and 48, and anode 49. Cathode 46 is heated and serves as an electron source. The heater element is not shown.
45 is shown in Figure 4 as containing cathode 46, grids 47 and 48, and anode 49. Cathode 46 is heated and serves as an electron source. The heater element is not shown.

The radio frequency signal voltage is applied to coil 41, and the resulting currents in coil 41 induce radio frequency currents in the anti-resonant tank circuit consisting of coil 42 and condenser 43 in parallel. The radio frequency voltage developed at tank circuit terminal 56 is applied to grid 48 of tube 45 and the radio frequency voltage developed at tank circuit terminal 57 is applied to grid 47 of tube 45. Center tap 58 of coil 42 is connected to the cathode 46 of tube 45 through battery 44, which offers negligible impedance to radio frequency currents. Anode 49 of tube 45 is connected to cathode 46 through the load circuit comprising condenser 50 and resistor 51 in parallel. A filter consisting of radio-frequency choke coil 52 and condenser 53 in series are connected across the anode load circuit, and low frequency output terminals 54 and 55 are connected respectively to the two sides of condenser 53. Condensers 50 and 53 are so chosen as to offer very low impedance to radio frequency currents but very high impedance to currents of modulation frequencies. Coil 52 is so chosen as to offer high impedance to radio frequency currents but low impedance to the modulation-frequency currents.

The voltage of battery 44 is set to such a value that a substantial fraction of the electrons moving from cathode to anode in tube 45 will require approximately half a radio-frequency period to travel from grid 47 to grid 48. This value of voltage is not critical in general, and if a standard miniature tube is used, will normally be three to four volts for frequencies of the order of 1000mc/s. For lower frequencies, less voltage is required.

Although grids 47 and 48 are at the same positive D. C. potential, their instantaneous potentials are free to vary with the oscillations in tank circuit 42—43. The radio frequency voltage of grid 48, moreover, is 180° out of phase with the voltage on grid 47. Electrons approaching grid 47 when it is in the positive portion of its A. C. cycle will be accelerated by grid 47 more than will electrons approaching grid 47 during the negative part of its A. C. cycle. Hence for each cycle of A. C. voltage on grid 47 the electron stream beyond grid 47 will include a group of more-accelerated electrons "outrunning" the group of less-accelerated electrons. Since approximately half an R. F. period will have elapsed by the time the more accelerated group reaches grid 48, the group finds grid 48 near its maximum positive potential also, and hence that group is accelerated again by a more-than-average amount. The less-accelerated group, arriving at grid 48 about a half-period later than the faster group, finds grid 48 in the negative portion of its A. C. cycle and hence near its least-positive potential. Consequently the slower group is again given less accelerative impetus than the first group of electrons, and the electrons reach the anode, not uniformly spaced, but in bunches, resulting in an anode current which contains A. C. components, of the radio frequency and of the modulation frequencies. The radio frequency components of the anode current are readily passed to the cathode by condenser 50, but condenser 50 and resistor 51 offer a high impedance to the modulation frequency components, and modulation frequency voltage is thus developed across resistor 51. Any R. F. components of voltage across resistor 51 are filtered out by coil 52 and condenser 53, and voltage containing only modulation frequency components appears at output terminals 54 and 55.

The schematic diagram in Figure 5 illustrates an embodiment of the invention which uses a tetrode tube, in conjunction with lumped-constant circuit elements, as a frequency converter.

Vacuum tube 66 contains a cathode 67, grids 68 and 69, and anode 70. Cathode 67 is heated and serves as an electron source. The heater element is not shown.

The radio frequency signal voltage is applied to coil 61, and the resulting currents in coil 61 induce radio frequency currents in the tank circuit comprising coil 64 and condenser 65 in parallel, which is anti-resonant at the signal frequency. Local oscillator 63 is connected to coil 62, which is also inductively coupled to tank circuit coil 64. Thus currents of the local oscillator frequency are also induced in the tank circuit 64, 65. Center tap 76 on coil 64 is connected to cathode 67 of tube 66 through battery 60, which offers negligible impedance to radio frequency currents. Tank circuit terminal 74 is connected to grid 69 of tube 66, and the other tank circuit terminal 75 is connected to grid 68 of tube 66. Anode 70 of tube 66 is returned to the cathode 67 through a load circuit comprising resistor 71, condenser 72, and inductance coil 73, all in parallel. Condenser 72 and coil 73 are anti-resonant at the desired intermediate frequency. Resistor 71 is a damping resistor whose function is to broaden the frequency response characteristic of the anode load circuit. Output terminals 77 and 78 are connected respectively to the anode 70 and the cathode 67 of tube 66.

The coupling between coil 62 and coil 64 is adjusted until the peak voltage across coil 64 at the local oscillator frequency is several volts. The frequency of the local oscillator is so adjusted that the difference between the signal carrier frequency and the frequency of the local oscillator is equal to the desired intermediate frequency.

Like the other embodiments of the invention described in this specification, this circuit functions as a transit-time mixer. When grid 68 is appreciably negative electrons cannot pass through it toward the anode. When grid 68 is positive, however, electrons are attracted to and through it; and during the portion of the cycle when the electron velocity is correct, grid 69 becomes positive at a sufficient time later to further accelerate toward the anode those electrons which have passed grid 68. The resulting pulses of electrons striking the anode produce A. C. components of anode current including a component at the desired intermediate frequency. This component of anode current encounters a high impedance in the anode load circuit. As a result a voltage of the desired intermediate frequency is developed across the anode load, and this voltage appears at output terminals 77 and 78.

It will be understood that the embodiments shown and described are exemplary only, and that the scope of the invention will be determined with 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 non-linear transmission circuit comprising an electron tube having at least anode, cathode and two grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials thereat, a biasing means connected between said grids and said cathode applying a small positive potential to each of said grids to

produce a low average electron velocity, a source of high frequency signals having a frequency whose half period is substantially equal to the electron transit time between said grids, an input circuit coupling said high frequency signals to said grids in opposite phase.

2. A non-linear transmission circuit comprising an electron tube having at least anode, cathode and two grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials at said cathode and anode, a high frequency signal source, an input circuit coupling said signal source to said grids in phase opposition, a biasing means connected between said grids and said cathode applying a small positive potential to each grid to produce a low average electron velocity, and means for adjusting the potential of said biasing means to obtain an electron transit time between said grids equal to a half period of said signal.

3. A non-linear transmission circuit comprising an electron tube having at least anode, cathode and two grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials at said cathode and anode, a high frequency signal source, an input circuit coupling said signal source to said grids in phase opposition, a tap on said input circuit at a center point with respect to said grids, a biasing means connected between said tap and said cathode applying a small positive potential to each grid to produce a low average electron velocity, and means for adjusting the potential of said biasing means to obtain an electron transit time between said grids equal to a half period of said signal and a rectified signal at said anode.

4. A non-linear transmission circuit comprising an electron tube having at least anode, cathode and two grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials at said cathode and anode, a high frequency signal source, a transformer having a primary connected to said signal source and a secondary with opposite ends connected respectively to said grid electrodes, a center tap on said secondary, a biasing means connected between said center tap and said cathode applying a small positive potential to each grid to produce a low average electron velocity, and means for adjusting the potential of said biasing means to obtain an electron transit time between said grids equal to a half period of said signal and a rectified signal at said anode.

5. A non-linear transmission circuit comprising an electron tube having at least anode, cathode and two grid electrodes, a source of modulated high frequency signals, an input circuit tuned to said high frequency signals and coupling said signal source to said grids in phase opposition, a tap on said input circuit at a center point with respect to said grids, a biasing means connected between said tap and said cathode applying a small positive potential to each grid to produce a low average electron velocity, an output load circuit tuned to the modulation frequency and conductively connecting said anode and cathode to establish equal quiescent potentials thereat, and means for adjusting the potential of said biasing means to obtain an electron transit time between said grids equal to a half period of said signal frequency and produce the modulation signal in said output circuit.

6. A non-linear transmission circuit comprising an electron tube having at least anode, cathode, and three grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials thereat, a biasing means connected between said grids and said cathode applying a small positive potential to each of said grids to produce a low average electron velocity, a source of high frequency signals having a frequency whose half period is substantially equal to the electron transit time between adjacent grids, an input circuit coupling said high frequency signals to the two grids more remote from said cathode, said signals being coupled to the grids in opposite phase.

7. A non-linear transmission circuit comprising an electron tube having at least anode, cathode, and three grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials at said cathode and anode, a high frequency signal source, an input circuit coupling said signal source to the two grids more remote from said cathode, said signals being coupled to the grids in phase opposition, a biasing means connected between said grids and said cathode applying a small positive potential to each grid to produce a low average electron velocity, and means for adjusting the potential of said biasing means to obtain an electron transit time between adjacent grids equal to a half period of said signal.

8. A non-linear transmission circuit comprising an electron tube having at least anode, cathode, and two grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials thereat, a biasing means connected between said grids and said cathode applying a small positive potential to each of said grids to produce a low average electron velocity, a source of high frequency signals having a frequency whose half period is substantially equal to the electron transit time between said grids, an input circuit coupling said high frequency signals to said grids in opposite phase, and a local oscillator coupled to said grids.

9. A non-linear transmission circuit comprising an electron tube having at least anode, cathode, and two grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials at said cathode and anode, a high frequency signal source, an input circuit coupling said signal source to said grids in phase opposition, a biasing means connected between said grids and said cathode applying a small positive potential to each grid to produce a low average electron velocity, and means for adjusting the potential of said biasing means to obtain an electron transit time between said grids equal to a half period of said signals, and a local oscillator coupled to said grids.

10. A non-linear transmission circuit comprising an electron tube having at least anode, cathode, and three grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potential thereat, a biasing means connected between said cathode and the two grids more remote therefrom applying a small positive potential to each of said remote grids to produce a low average electron velocity, a source of high frequency signals having a frequency whose half

period is substantially equal to the electron transit time between said remote grids, an input circuit coupling said high frequency signals to said remote grids in opposite phase, and a local oscillator coupled to the grid adjacent said cathode.

11. A non-linear transmission circuit comprising an electron tube having at least anode, cathode, and three grid electrodes, an output load circuit conductively connecting said cathode and anode electrodes to establish equal quiescent potentials at said cathode and anode, a high frequency signal source, an input circuit coupling said signal source to the two grids more remote from said cathode, said signal source being coupled to said remote grids in phase opposition, a biasing means connected between said remote grids and said cathode applying a small positive potential to each remote grid to produce a low average electron velocity, and means for adjusting the potential of said biasing means to obtain an electron transit time between said remote grids equal to a half period of said signal, and a

local oscillator coupled to the grid adjacent said cathode.

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