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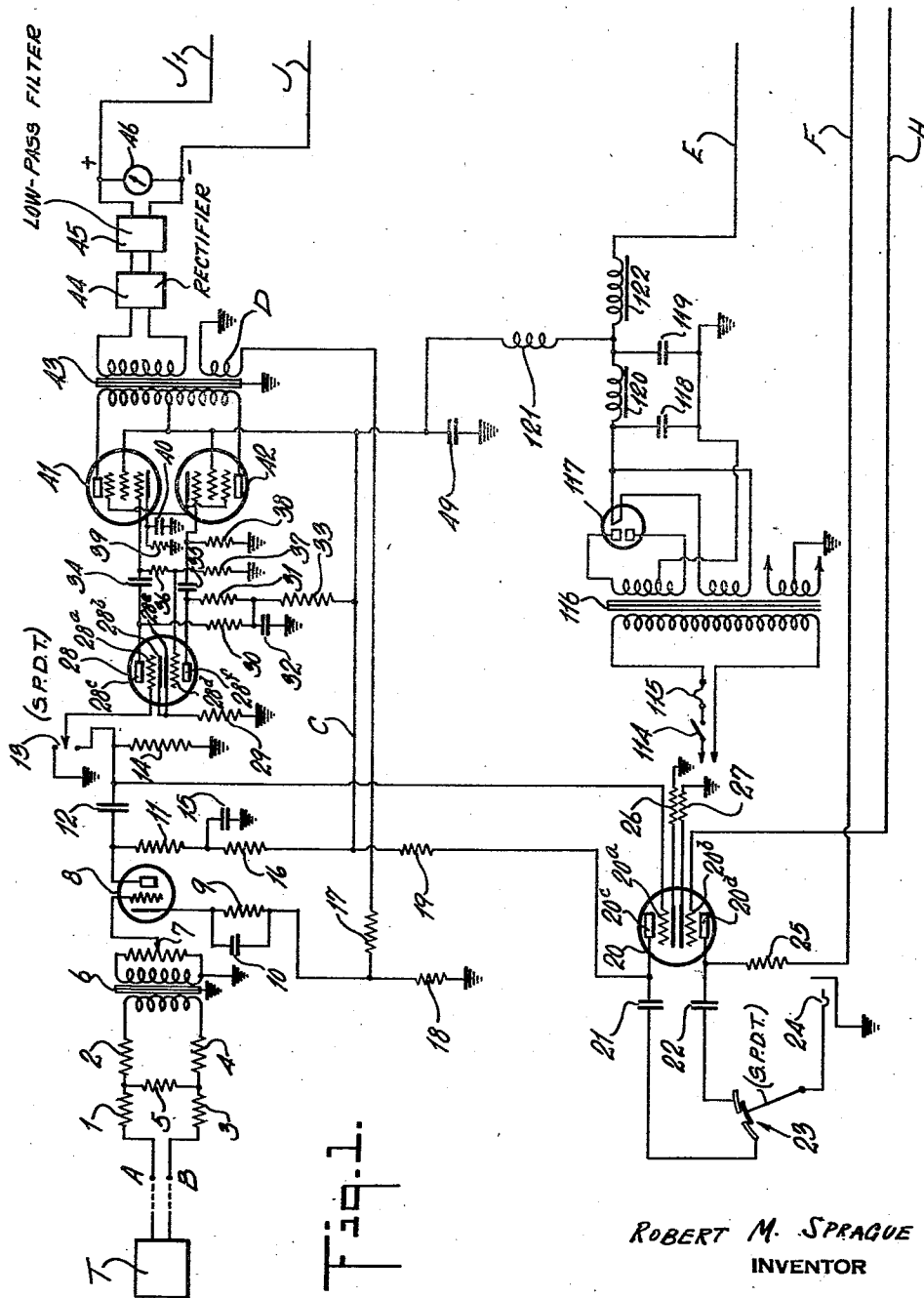
R. M. SPRAGUE

2,398,054

MODULATING METHOD AND APPARATUS

Original Filed Oct. 27, 1939

3 Sheets-Sheet 1



ROBERT M. SPRAGUE
INVENTOR

BY *John J. Logan*
ATTORNEY

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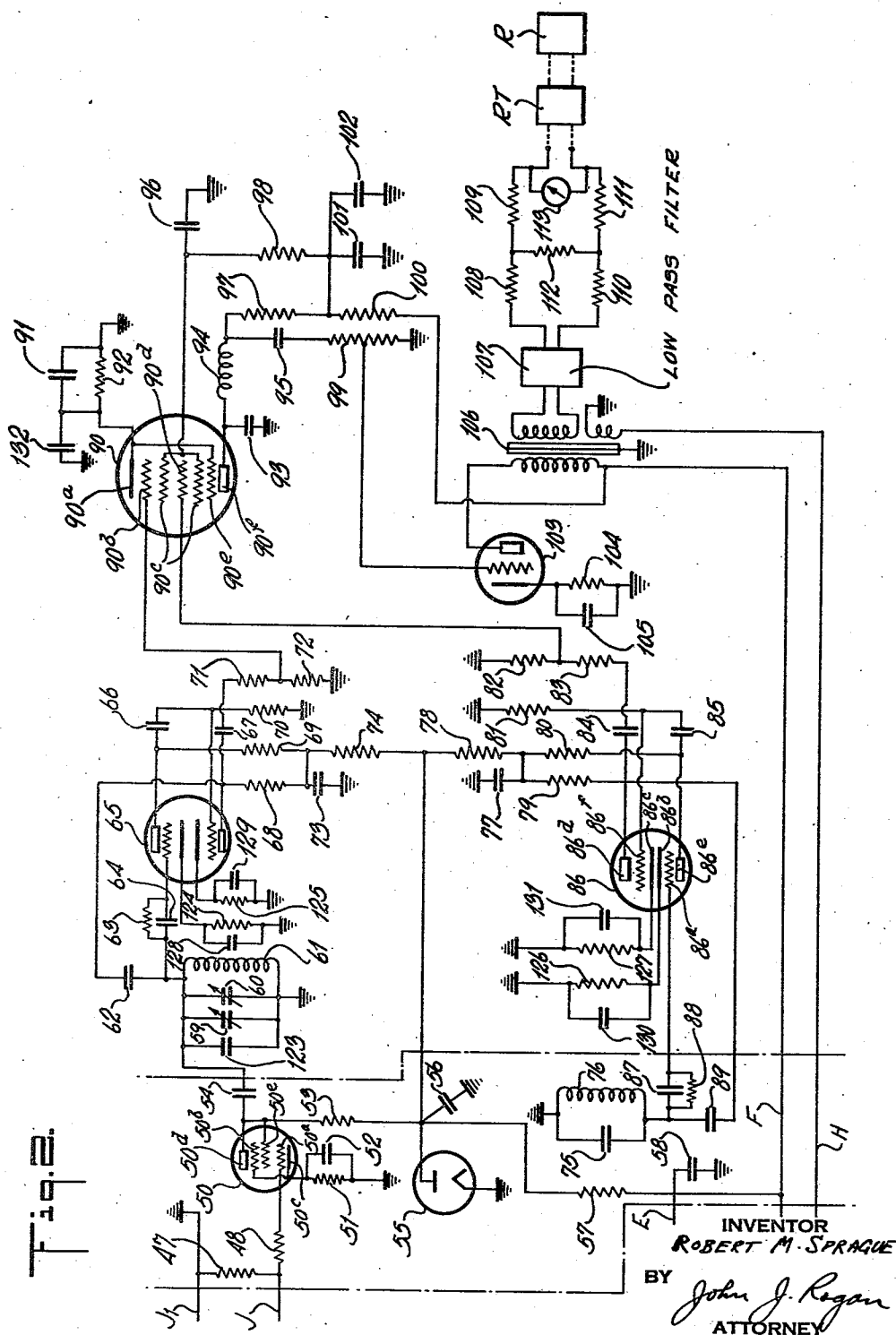
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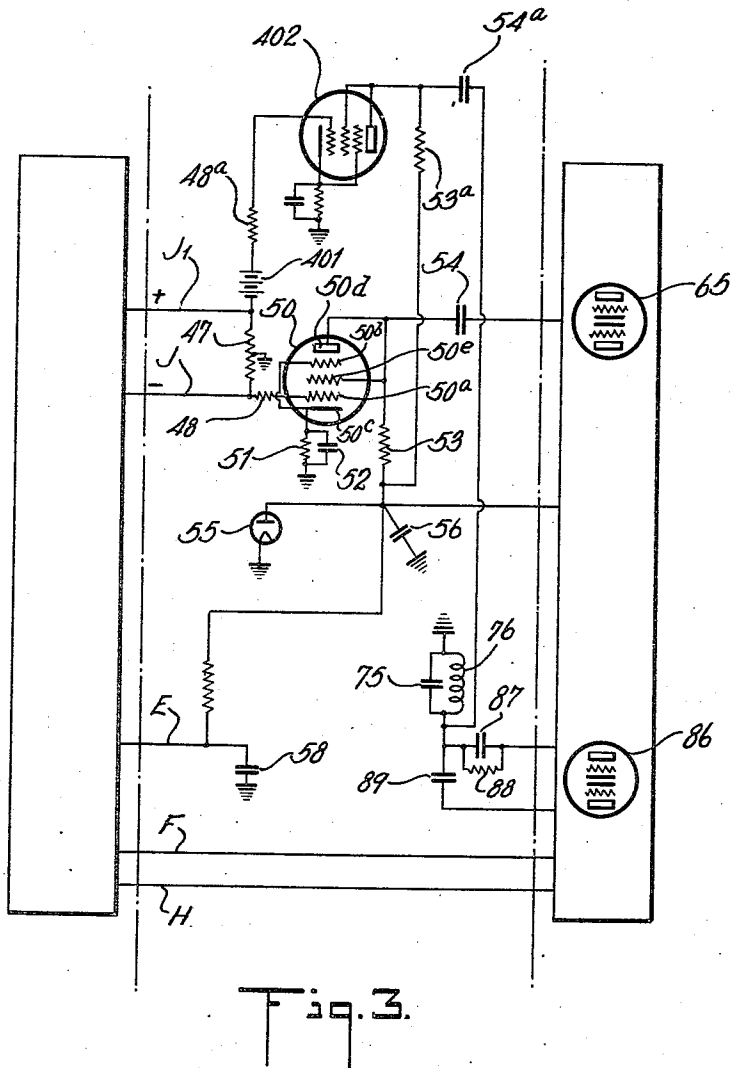
R. M. SPRAGUE

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MODULATING METHOD AND APPARATUS

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ROBERT M. SPRAGUE
INVENTOR

BY *John J. Rogan*
ATTORNEY

UNITED STATES PATENT OFFICE

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MODULATING METHOD AND APPARATUS

Robert M. Sprague, Hicksville, N. Y., assignor to
Press Wireless, Inc., Chicago, Ill., a corporation
of Delaware

Original application October 27, 1939, Serial No.
301,563, now Patent No. 2,299,937, dated Octo-
ber 27, 1942. Divided and this application
March 13, 1942, Serial No. 434,496

5 Claims. (Cl. 179—171.5)

This invention relates to wave signalling systems and more especially to systems of carrier wave transmission wherein the characteristics of the original signal, for example signal-amplitude characteristics, are converted into a corresponding varying frequency spectrum.

A principal object of the invention relates to an improved system for transmitting signals whether oral, visual or control signals in the form of frequency modulations.

A further object is to provide an improved system for transmitting message signals over an amplitude-modulated high frequency or radio carrier channel by amplitude-modulating the carrier by a frequency-modulated subcarrier.

A feature of the invention relates to a novel method of converting amplitude-modulations into a corresponding variable frequency spectrum of substantially uniform amplitude.

Another feature relates to a frequency modulation system employing a pair of oscillators for producing a variable beat frequency wherein the beat frequency is varied in accordance with capacity changes controlled by a grid-controlled electron tube. As a result of this feature oscillators can be employed whose frequency is independent of voltages on their elements thus giving a beat frequency oscillator that is substantially independent of power supply voltage variations on the oscillators.

Another feature relates to the method of frequency modulation wherein the signals are generated in the form of a modulated sub-carrier with the modulations confined to a range less than the second harmonic of the lower limit of said modulations. The signals are then rectified and passed through a specially designed filter of the band-pass type. Preferably, in accordance with the invention, the said lower limit is also chosen so that unattenuated frequency shifts are obtained up to the limits of the filter.

A further feature relates to an improved frequency modulator wherein a linear variation of output frequency with relation to input voltage is obtained over a very wide range.

A further feature relates to a frequency modulating system employing a photo-electric cell or similar device as the source of modulating voltage, and wherein a frequency modulated oscillator is employed and so arranged that the oscillator output is substantially free from amplitude variations of frequency components of the said voltage source.

A further feature relates to a transmitter of the frequency-modulated wave type wherein novel

means are provided for adjusting the frequency bands in accordance with the minimum and maximum amplitudes of the signals to be transmitted. Thus in the case of a facsimile transmitter, it is possible conveniently and expeditiously to obtain the zero or minimum frequency-modulating voltage which is correlated to zero output voltage from the facsimile generator.

Other features and advantages not specifically enumerated will be apparent after a consideration of the following detailed descriptions and the appended claims.

While the invention will be illustrated in connection with facsimile transmitting and receiving systems, it will be understood that this is merely for explanatory purposes and that various features and aspects of the invention can be employed in other kinds of signalling or control systems. Accordingly in the drawings,

Figs. 1 and 2 are a schematic wiring diagram of a transmitting system according to the invention.

Fig. 3 is a modification of the amplitude-to-frequency conversion section of Fig. 1.

Referring to Fig. 1, block T represents any well-known form of signal generator, for example a facsimile converter of the type shown in U. S. Patent No. 2,209,720. Preferably the device T is of a known type whereby the signals to be transmitted are generated in the form of a carrier of relatively low or audio frequency, for example 1800 C. P. S. and having amplitude modulations or variations corresponding to the original signals to be transmitted. It will be understood that the term "carrier" is used in its broad aspect as including either a sustained alternating current, a pulsating current or a chopped current such as that produced for example by a light chopper photo-electric cell combination as is well-known in the facsimile art.

The signal from device T is applied across the input terminals A, B, and thence through the network comprising resistor elements 1 to 5 inclusive and thence through input transformer 6. The output of transformer 6 is fed to any well-known form of linear amplifier preferably through potentiometer 7. Merely for purposes of illustration, this amplifier comprises a three element tube 8 connected into circuit in the usual way and including the grid-bias resistor 9; the plate resistors 11, 16, through which plate voltage is fed over the conductor C from the A. C. power supply, the latter consisting for example of the A. C. power transformer 116, full wave rectifier 117, smoothing filter 118, 119, 120, and thence

through the filter comprising the elements 49, 121. In accordance with conventional practice, condensers 10 and 15 are shunted across resistors 9 and 16. The signal voltage developed across coupling resistor 11 is fed through coupling condenser 12 and thence through the leak resistance 14 and the single-pole double-throw switch 13 to the control-grid 28a of tube 28. Tube 28 may be of any well-known type, for example a type 6C8-G comprising two sets of triode elements with the cathodes 28b and 28c connected together and biased with respect to the grids 28a and 28d by the bias resistor 29. The plates 28c and 28f are connected to the plate supply conductor C through the limiting resistor 33 and the respective coupling resistors 30, 31, so as to provide a balanced input to the succeeding amplifier stage comprising amplifier tubes 41 and 42. The tubes 41 and 42 are coupled to tube 28 through the condensers 34 and 35 in balanced or push-pull relation, the tubes 41 and 42 being preferably of the pentode type. The plates of tubes 41 and 42 are connected to the D. C. supply through the primary winding of coupling transformer 43. Preferably, although not necessarily, transformer 43 is provided with an auxiliary secondary or feed-back winding D which is connected through resistor 17 to the cathode of tube 8 to reduce distortion in the amplifier. The main secondary of transformer 43 is applied to a rectifier 44 and thence through the low-pass filter 45 to eliminate the 1800 cycle carrier component. Consequently at the output terminals of filter 45 there is present only the amplitude demodulated signal corresponding to the photo-electric current delivered by the photo-electric cell of machine T.

The frequency inverter or modulator

The demodulated and amplified signal voltages developed across resistor 47 are then fed through the isolating resistor 48 to the control grid 50a of a pentode tube 50 which, in accordance with the invention, is employed as a modulator tube to control the beat frequency developed by the oscillator tubes 65 and 86. Tube 65 is provided with a variable frequency control circuit while tube 86 is of a fixed frequency which is determined by the tuned oscillatory circuit 75, 76, connected between the control grid 86a and the cathodes 86b, 86c, through respective bias resistors 126, 127, and through by-pass condensers 130, 131. The plate 86d is coupled back to the control grid 86a through the feed-back condenser 89 and a grid leak condenser combination 87, 88. Likewise plate 86e is coupled to control grid 86f through condenser 85. As a result of these connections, oscillations of fixed frequency, for example 600 kilocycles are developed across resistor 82. The tube 65 is similarly provided with circuit connections including elements 62, 63, 64, 66, 67, 124, 125, 128 and 129, and a tunable oscillatory circuit comprising coil 61 and shunt condensers 59, 60, 123, whereby sustained oscillations of the desired range, for example 601.8 to 603 kilocycles are developed across resistor 72. Oscillator tube 65 is adjusted to the correct frequency, for example the lower limit of 601.8 kilocycles by variable condensers 59 and 60 and the frequency of this oscillator tube is automatically varied in accordance with a change in the plate resistance or plate-to-cathode capacity of tube 50.

This frequency modulation is accomplished in the following manner. The plate circuit of tube 50 is connected across the oscillatory circuit 59, 60, 61, through series condenser 54. Tube 50

when connected as shown, is capable of varying its plate resistance and to a certain extent its plate-to-cathode capacitance in accordance with the control grid voltage impressed thereon, and since this plate resistance is in series with condenser 54 any change in said plate resistance has the effect of changing the effective capacity of condenser 54 so far as affecting the frequency of the oscillatory circuit is concerned and hence the frequency of the voltages developed across resistor 72. Preferably tube 50 is of the pentode type, for example a type 6F6, which after numerous tests I have found appears to change the output frequency of tube 65 substantially linearly over the widest frequency range. The suppressor-grid 50b of tube 50 is connected to cathode 50c which latter is biased negatively with respect to control-grid 50a by the bias resistor 51 and its by-pass condenser 52. Preferably, plate 50d and screen-grid 50e are connected together and to the plate supply conductor E through resistors 53 and 57 and the filter choke 122 which latter is by-passed by the condenser 58.

I have also found that by using the varied plate resistance or the varied plate-to-cathode capacitance of tube 50 to vary the frequency of tube 65, very little change in the amplitude of the resultant beat frequency between tubes 65 and 86 is produced. Consequently the beat frequency of tubes 65 and 86 is substantially undisturbed by any frequency component that may exist in the photo-electric cell output voltage of machine T.

The beat frequency from tubes 65 and 86 is obtained by applying their respective outputs to respective signal grids of the mixer tube 90 which may be a heptode such as a type 6L7-G comprising the cathode 90a; #1 signal grid 90b; shield-grid 90c; #2 signal-grid 90d; suppressor-grid 90e connected to cathode 90a; and plate 90f. The cathode 90a is biased with respect to grids 90b and 90d in known manner by the biasing resistor 92 with its by-pass condenser 91. The condenser 132 is also provided, and by means of condenser 93 and high frequency choke coil 94, the output currents flowing through coupling resistor 99 are the desired audio frequency signals which vary frequency for example between 1800 C. P. S. and 3000 C. P. S. in accordance with the corresponding shade values of the particular area of the subject matter in machine T which is being momentarily scanned. The D. C. supply for tube 90 is applied over conductor F and thence through resistors 100 and 97, the voltage for screen-grid 90c also being applied over conductor F in series with resistor 98, it being understood that the resistors 98 and 100 are by-passed by respective condensers 96, 101 and 102.

The beat or audio frequencies flowing in the plate circuit of tube 90 are impressed upon the control-grid of a suitable power amplifier tube 103, the grid of which is biased by resistor 104 and by-pass condenser 105. The amplified output of tube 103 is applied through audio frequency transformer 106 to a low-pass filter 107 in order to eliminate any harmonic distortion. Filter 107 is designed to cut-off frequencies above the first octave of the lowest signal frequency. The filtered signals are then fed through the resistor network or pad 108 to 112 to any suitable form of radio transmitter represented schematically by the block RT. The signals are received and reproduced in a receiver R which is described in detail in application Serial No. 301,563, filed October 27, 1939.

Preferably, and in accordance with the invention, the system is so adjusted that for the maximum range of shade values in the subject matter being scanned by the machine T, for example that corresponding to black and white respectively, the signal frequencies are confined to one octave or less. Thus, if a black area is represented by a frequency of 1800 C. P. S., then a white area should be represented by a frequency of less than 3600 C. P. S., for example 3000 C. P. S. since during transmission the second harmonic often appears with an amplitude many times that of the desired fundamental. If the signal frequencies are restricted below the second harmonic of the lowest signal frequency as will be described hereinbelow, then by means of filter 107 the second harmonic distortion during transmission is effectively eliminated so far as any effect on the reproduced signal is concerned.

In order to be able to correlate the upper and lower shade values of the subject matter with the corresponding upper and lower limits of the modulation frequencies applied to transmitter RT, there is provided a tube 20 which is a monitor mixing tube to combine a part of the 1800 cycle subcarrier signal from machine T with the output frequency from tube 103. If as above assumed, the picture shades are represented by a frequency range between 1800 and 3000 C. P. S., with 1800 C. P. S. representing black and 3000 C. P. S. representing white, it is necessary to adjust the output frequency from tube 103 to 1800 cycles when zero or a predetermined minimum voltage is impressed on the grid of tube 50. The 1800 cycle signal which is applied to the tube 20 directly from the output of tube 8 is used as a standard of comparison. For this purpose, tube 20 is preferably of the 6F8-G type comprising two sets of triode elements. The grid 20a of one triode is excited by a part of the 1800 cycle signal from the output of tube 8. The grid 20b of the other triode is excited by part of the output of tube 103. The plates 20c and 20d are supplied with D. C. plate potential respectively over conductors C and E. Likewise plates 20c and 20d are connected through a single-pole double-throw switch 23 to a monitoring jack 24 into which a frequency meter or a pair of head phones may be plugged. Switch 23 is preferably of the type such that in its extreme end positions it makes contact with the respective fixed contacts, but in an intermediate position it makes contact with both fixed contacts. When the blade of switch 23 is in its intermediate position as shown in the drawings, the 1800 C. P. S. signal from machine T and the signal from tube 103 are both applied to jack 24 for comparison purposes. When the blade of switch 23 is in its right-hand position, only the signal from tube 103 is applied to the jack. A single-pole double-throw switch 13 is provided between the tubes 8 and 20, and when the blade of this switch is in its uppermost position, direct ground is applied to the control grid of tube 20. When the blade is in its lowermost position, the switch 13 connects the output of tube 8 through potentiometer 14 to tube 20. By throwing the blade of switch 13 to its uppermost position, no voltage exists at grid 50a of modulator tube 50. A normal white signal is then sent from machine T and is heard at jack 24 with switch 25 in its intermediate position which combines input and output frequencies. The beat frequency of tubes 65 and 66 is there adjusted, for example by condenser 59 until the output from tube 103 appear-

ing at jack 24 is the same as that derived from machine T through tube 8. The switch 13 is then thrown to its lowermost position whereby the amplified picture signal voltages from machine T can be applied to the grid 28a and the gain is adjusted by potentiometer 17 until voltmeter 46 indicates the predetermined magnitude necessary to shift the amplified beat frequency in the output of tube 103 by 1200 cycles that is, from 1800 to 3000 cycles. After this preliminary adjustment, the transmitter and inverter are in readiness for transmission. With switch 23 in its right-hand position, the transmitter output can be monitored.

While in the foregoing description reference has been made to the transmission of a picture by means of frequency modulations between 1800 C. P. S. and 3000 C. P. S., it will be understood that the invention is not necessarily limited thereto. However, I have found from actual tests and demonstrations that the above shift of from 1800 to 3000 C. P. S. is more than sufficient to transmit all the frequencies present in modern picture or facsimile transmitters. On the other hand, I have transmitted with good results with the equipment described, using a frequency shift of from 1200 to 1800 cycles. Furthermore, while particular apparatus and parts have been described, it will be understood that variations may be made therein as will be obvious to those skilled in the art and without departing from the spirit and scope of the invention. With the equipment as described, I have succeeded in passing linearly, frequencies up to 1400 cycles with no apparent attenuation at the upper frequencies and furthermore I have transmitted articular speech and music through the equipment merely by replacing the transmitter T by a voice frequency generator and by replacing the reproducer R by a voice frequency reproducer. With a higher range of frequencies such as between 5000 and 7500 C. P. S., or even 5000 and 6500 C. P. S., frequencies up to 4500 C. P. S. can be passed. The invention is not limited to facsimile transmission or to ordinary voice frequency telephony. The system is well suited for secret radio transmission because the original voice signals that may be impressed by the transmitter T are radiated from the radio transmitter RT in an unintelligible form, and in order that they may be reproduced, a receiver such as shown in Fig. 2 and adjusted and correlated with the transmitter of Fig. 1, must be employed. I have also found that a system as described when used in facsimile or voice communication eliminates to a substantial extent, well-known echo effects.

While in the foregoing, the frequency conversion at the transmitter is effected by a fixed frequency oscillator 36 and a variable frequency oscillator 65, a pair of variable frequency oscillators may be employed. Such an arrangement is shown in Fig. 3 wherein the parts shown between the dot-dash lines may be substituted for the part of Fig. 2 between the dot-dash lines. In Fig. 3 the left-hand rectangle represents diagrammatically the transmitting equipment shown in detail in Fig. 1; while the right-hand rectangle of Fig. 3 represents diagrammatically the part of Fig. 2 to the right of the dot-dash line. In the embodiment of Fig. 3 the signal conductors J, J1 are connected not only to the tube 50 as described in connection with Fig. 2, but are also connected to a similar tube 402 so that the amplitude variations on conductors J, J1, result in si-

multaneous shifting in opposite directions of the frequency of the oscillators 65 and 86. For this purpose the resistance 47 is connected in balanced relation across the control grid of tube 50 and the control grid of tube 402, the connection to the latter grid including a potential source 401 poled as shown and having a potential equal to the peak voltage swing applied to conductors J, J1. The plate of tube 50 is coupled through condenser 54 to a tunable oscillatory circuit such as that represented by 123, 59, 60, 61 (Fig. 2). Likewise the plate of tube 402 is coupled through a similar condenser 54a to a tunable oscillatory circuit 75, 76, associated with the oscillator tube 86. If desired, the tuned circuit 75, 76, may be replaced by a circuit similar to that of Fig. 2 including elements 123, 59, 60 and 61. The arrangement of Fig. 3 has the advantage that the frequency shift for a given amplitude variation on conductors J, J1 is doubled as compared with the arrangement of Fig. 2. It also has the advantage that any non-linearity of frequency shift on one oscillator tube e. g. tube 65 is balanced by an equal and opposite non-linearity on the other tube 86.

Various changes and modifications may be made in the disclosure without departing from the spirit and scope of the invention. Thus, if under certain conditions of operation, for example at very high speeds of transmission, undesirable phase shifts occur in the various filters described, these phase shifts may be compensated for by connecting in circuit with one or more of the filters suitable phase equalizers. However, it has been found that at ordinary commercial transmission speeds, such equalizers are not necessary.

This application is a division of application Serial No. 301,563, filed October 27, 1939, issued as Patent No. 2,299,937.

What I claim is:

1. In a wave signalling system, an electron tube oscillator having a tunable oscillatory circuit, a frequency-modulator tube having a cathode, control grid, suppressor grid, anode, and another grid between the control grid and suppressor grid whose potential varies with the anode potential by being connected to said anode and which other grid controls the inherent plate capacitance of the tube, and means to impress signals on said control grid to vary said plate capacitance and thereby to vary the frequency of said oscillator but without substantial amplitude modulation, said suppressor grid being at substantially cathode potential, said tunable oscillatory circuit being coupled across the anode and cathode output circuit of said frequency modulator tube.

2. In a wave signalling system, a source of signal voltage variations, and means to convert said signal variations into corresponding frequency variations; said means including an oscillatory circuit, an electron tube of the type having a cathode, control grid, shield grid, suppressor grid and anode, the inherent electrostatic capacitance between said anode and control grid forming part of the frequency-determining elements of said circuit, the shield grid of said tube being connected to the anode so as to vary in potential with the variations of the anode potential, and said suppressor grid being connected substantially to cathode potential, and means to impress said variable amplitude signal voltages on said control grid to control said inherent capacitance and thereby to vary the frequency of said oscillatory circuit, said oscillatory circuit being coupled across the anode-cathode output circuit of said tube.

3. A wave signalling system according to claim 2 in which said suppressor grid is connected substantially directly to the cathode to cause said variations in frequency to be substantially free from amplitude modulations.

4. In a wave signalling system, an electron tube oscillator having a tunable oscillatory circuit, a source of signal voltages, an electron tube coupling said source to said circuit, said tube having in sequence a cathode, first, second and third grids and an anode, means to impress said signals across the first grid and cathode, means connecting the second grid to the anode so that the potential of said second grid varies with the anode potential variations, means to connect said third grid to substantially cathode potential, and means connecting said oscillatory circuit across said anode and cathode for the purpose set forth.

5. In a wave signalling system, an electron tube oscillator having a tunable oscillatory circuit, a frequency modulator tube of the pentode type having cathode, control grid, anode, shield grid and suppressor grid, means connecting said shield grid to said anode so that the shield grid potential varies dynamically with the dynamic variations of the anode potential, means connecting said suppressor grid to substantially cathode potential, means to impress signals on said control grid and thereby to vary the inherent plate capacitance of said tube, and an oscillatory circuit having its high potential terminal connected to the anode and shield grid and its low potential terminal connected to said cathode for the purpose set forth.

ROBERT M. SPRAGUE.