

Dec. 13, 1949

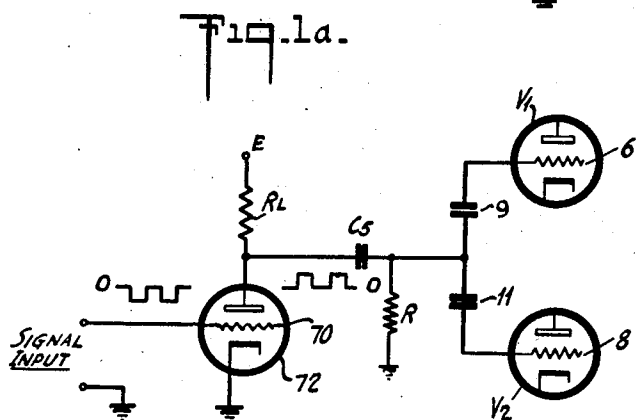
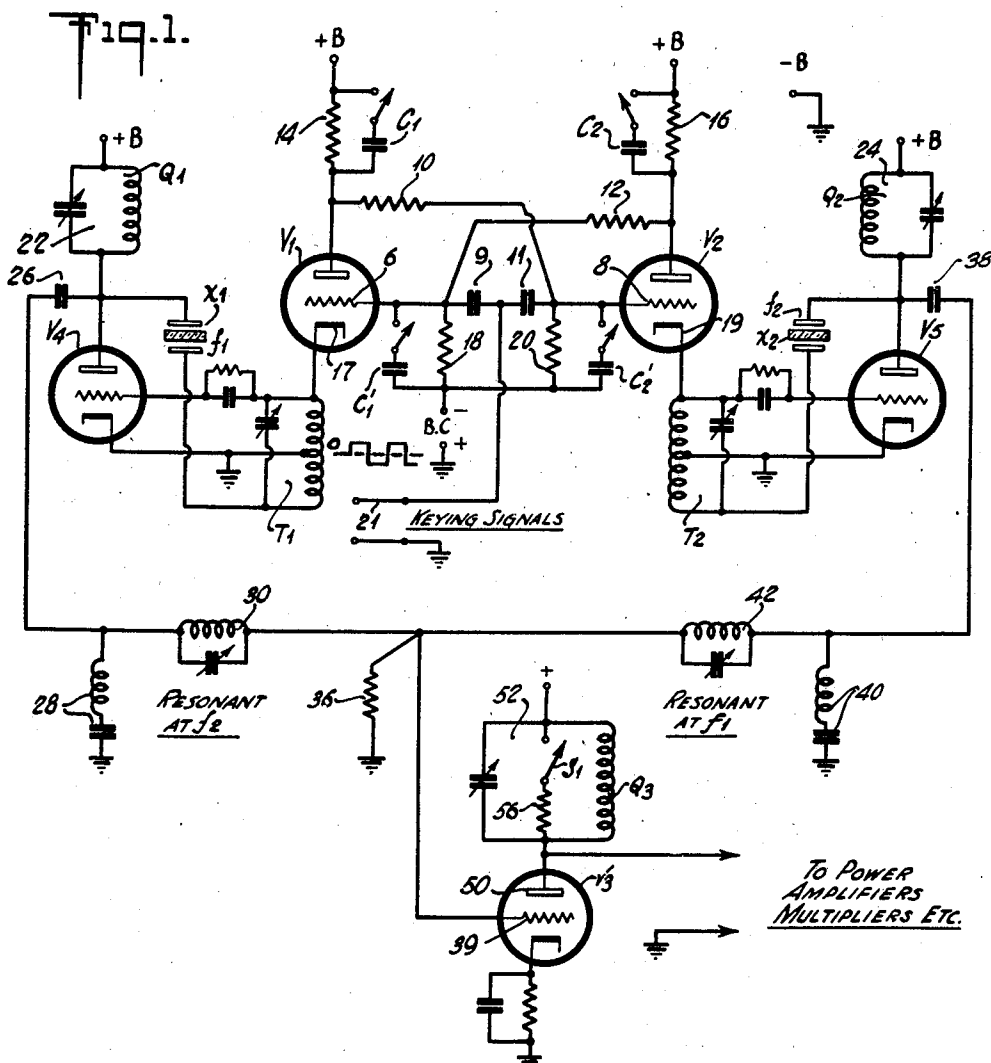
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2,491,387

FREQUENCY SHIFT KEYING

Filed May 3, 1945

2 Sheets-Sheet 1



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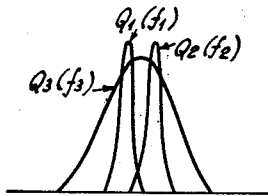
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FREQUENCY SHIFT KEYING

Filed May 3, 1945

2 Sheets-Sheet 2

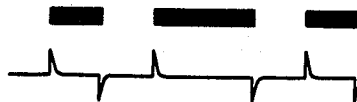
Fig. 2.



Q_1, Q_2 ARE DETERMINED
BY $Q (W/R)$ OF THEIR
RESPECTIVE CRYSTALS
 Q_3 BY $\Delta f = |f_2 - f_1|$

Fig. 3a.

Fig. 3b.



CHARACTER

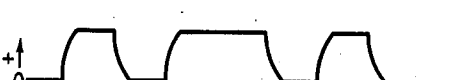
KEYING SIGNALS
POLARITY UNIMPORTANT

Fig. 3c.



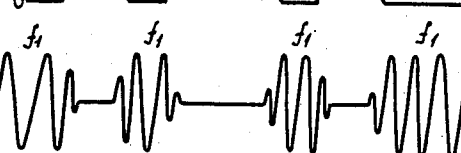
ANODE VOLTAGE V_1

Fig. 3d.



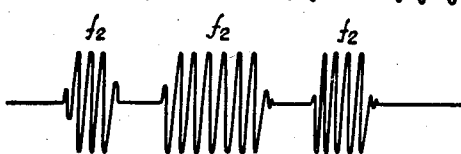
ANODE VOLTAGE V_2

Fig. 3e.



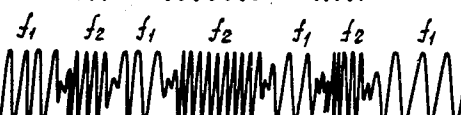
OSCILLATOR OUT.
AT FREQ. = f_1

Fig. 3f.



OSCILLATOR OUT.
AT FREQ. = f_2

Fig. 3g.



COMPOSITE OUT.
ANODE V_3

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2,491,387

FREQUENCY SHIFT KEYING

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Application May 3, 1945, Serial No. 591,730

7 Claims. (Cl. 178—66)

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This application relates to improved methods of and means for signalling by telegraphy. The application in particular discloses an improved telegraphy system of the frequency shift type, wherein a carrier is keyed from a first frequency which may represent mark to a second frequency, separated from the first frequency as desired, which may represent space.

Frequency shift telegraphy systems are known in the prior art. One common method of frequency shift keying involves keying the phase of oscillations from a crystal controlled oscillator and multiplying the phase modulated currents the amount necessary to get the desired frequency difference between marking frequency and spacing frequency. This system has the advantage of using crystal controlled carrier energy, but the amount of frequency shift obtainable is dependent on the number of multipliers used and the amount of frequency shift is not readily changed.

An object of my invention is to provide a frequency shift telegraphy system wherein the carrier energy is derived from crystal controlled generators and wherein the amount of frequency shift may be readily changed. In the system of my invention two crystal controlled oscillators, one operating at mark frequency and the other at space frequency are alternatively turned on and off by the keying signals. In my system the frequency shift can easily be made the desired amount subject only to the band pass capability of the stages in the transmitter following the modulator, and this without recourse to frequency multiplication. All that is required is the retuning of the crystal controlled generators or replacement of the crystal in one or both thereof.

Another commonly known method of frequency shift keying involves an unstable oscillator which is keyed in accordance with telegraphy signals from a first frequency which may represent space to a second frequency which may represent mark. The modulated oscillations are then referred to, i. e., mixed with oscillations of fixed frequency developed, for example, in a crystal controlled oscillator. A beat note is selected and used for signalling purposes. In systems of this type the frequency stability may be poor, particularly since there is generally no insurance that a stopping of the crystals controlled comparison oscillator will stop the transmission, and then the mean frequency may drift radically.

An additional object of my invention is to provide an improved frequency shift telegraphy system wherein the signalling energy is developed in crystal controlled oscillators and wherein the stability of the system is good at all times.

The two systems known in the prior art as described broadly hereinbefore include as stated in one case frequency multipliers and in the other an unstable keyed generator, a crystal oscillator,

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converting circuits, etc., and both are somewhat complicated and use considerable equipment. An object of the present invention is to provide a method of and means for producing frequency shift oscillatory energy the frequency of which is stabilized and yet may be shifted, which means is simple in nature, efficient in operation, and uses a minimum amount of equipment.

In the known method of frequency shift signalling involving phase modulation of the oscillations generated and multiplication of the phase modulated oscillations, the amount of frequency or phase shift of the output of a crystal controlled oscillation generator obtainable is very small unless a poor crystal is used in the oscillation generator. The amount by which a crystal generator frequency can be shifted is nearly a constant percentage of the frequency of oscillation and therefore frequency shift keying by "pulling" the crystal controlled generator frequency is practically impossible in the low frequency and medium frequency ranges. In my improved system I provide a pair of crystal oscillators operating at different frequencies and means for turning the same on and off alternately to generate mark and space frequencies and improved means for supplying the generated oscillations to a common amplifier stage. The difference frequency may be changed merely by changing a crystal or both crystals if desired.

In describing my invention in detail, reference will be made to the attached drawings wherein Fig. 1 illustrates by circuit connection the essential features of a frequency shift telegraphy system arranged in accordance with my invention and operated to carry out my method. Fig. 1a illustrates a wave forming network for use at the input of the keyer of Fig. 1. Fig. 2 illustrates graphically the characteristics of certain circuit elements of the system of Fig. 1; while Figs. 3a, 3b, 3c, 3d, 3e, 3f, and 3g illustrate graphically the operation of the system of Fig. 1.

In Fig. 1 the tubes V1 and V2 are interconnected to form a tripping or triggering circuit. Tubes V4 and V5 are each connected in a crystal controlled generator circuit, including crystals X1 and X2 respectively, one operating at frequency f_1 and the other operating at frequency f_2 . Tube V3 is a buffer and amplifier stage to which the frequency shifted telegraphy signals developed in the prior mentioned tubes are alternately amplified and fed to the following stages not shown, but which may include power amplifier stages, etc.

Tubes V1 and V2 have their anodes and control grids 6 and 8 cross-coupled by resistors 10 and 12, and their anodes coupled to the positive terminal of a source of direct current potentials by resistors 14 and 16 which may be shunted by condensers C1 and C2 respectively. The tube V1

has its cathode 17 coupled to a point of high radio frequency potential on tank circuit T1 and through a portion of the tank circuit to ground and thence to the negative terminal of the source of direct current potential mentioned above. The cathode 19 of tube V2 is similarly connected through a portion of tank T2 to ground.

The control grid 6 of tube V1 is connected by resistor 18 to the negative terminal of a bias source BC, a positive terminal of which is grounded while the control grid 8 of tube V2 is connected to source BC by resistor 20. Resistor 12 may be shunted by a condenser C1', while resistor 22 may be shunted by a condenser C2'. The circuit described herein is somewhat of the nature of the triggering circuit described in Finch U. S. Patent #1,844,950, issued Feb. 16, 1932, and in particular as described in my U. S. application Serial No. 688,742, filed August 6, 1946.

The tube V4 has its anode, cathode and control grid regeneratively coupled by tank circuit T1 and the crystal X1 operating at a frequency f_1 . The tube V5 has its electrodes coupled in a similar regenerative oscillation generating circuit including tank circuit T2 and a crystal X2 operating at a frequency f_2 . The anode circuit of tube V4 includes a parallel tuned circuit 22 coupling the anode to the positive terminal of a direct current source. The circuit 22 is parallel resonant at the frequency of the oscillations generated in tube V4 and at the frequency of the crystal X1, and is of a Q discussed hereinafter. The circuit 24 connected with the anode of tube V5 and to the positive terminal of the source is parallel tuned to the frequency of the tank circuit T2 and crystal X2, and is also of a Q which will be discussed hereinafter. The anode of the tube V4 is coupled by a condenser 26 over a series tuned circuit 28 and through a parallel tuned circuit 30 and over a resistance 36 to the control grid 39 of a coupling and amplifying tube V3. The anode of the tube V5 is similarly coupled by a condenser 32, series tuned circuit 40, and parallel tuned circuit 42 to the control grid of tube V3. Circuit 28 is series tuned to the frequency f_2 at which the tank circuit T2 operates, while circuit 30 which is a stopping circuit is parallel tuned to the same frequency. Circuits 40 and 42 are series and parallel tuned respectively to the frequency f_1 at which the tank circuit T1 operates. Preferably circuits 28 and 30, and 40 and 42, are sharply resonant at the frequency to which they are tuned.

In practice the trigger circuit is so set that the current will be cut off in one tube, say V1, and switched through the other tube V2. In an embodiment the negative bias applied to the control grids 6 and 8 of tubes V1 and V2 is made slightly greater than cutoff. Then the values of resistances 10, 12, 14 and 16 are so proportioned that tube V1 always assumes the nonconducting state, i. e., is initially cut off on the application of direct current potentials to the tube's electrodes. In these circuits, as is known, if current flow is initiated in one tube due to the cross-connections between the anodes and control grids the current is all switched to this tube while the other tube is cut off. In my system the adjustment is such that tube V1 is cut off and the current in the trigger system is switched through the tube V2. When tube V1 is cut off there is no loading on the tank circuit T1 of the oscillator tube V4 and this oscillator will operate to excite the grid of tube V3 by way of the coupling 26 with oscillatory energy at the frequency f_1 . f_1

will be determined by the resonant frequency of the crystal X1 between the grid and anode of tube V4. The Q of the resonant circuit 22 connected to the plate of tube V4 is relatively unimportant except that it must be such that the response is wider than the band of frequencies obtainable from the crystal controlled oscillator V4. The characteristic of this circuit designated Q1 (f_1) is shown in Fig. 2. A similar parallel tuned circuit 24 having similar characteristics with respect to the frequency f_2 is connected with the anode of tube V5. This circuit's resonance characteristic is also illustrated in Fig. 2 and designated Q2 (f_2). The series resonant circuit 28 in the lead between coupling condenser 26 and the grid of tube V3 must not be too sharply tuned, otherwise it may present too much shunting effect at the grid of tube V3, although this in part is prevented by the parallel tuned circuits in the same line. In many cases these two circuits will not be necessary. In other cases where feedback through the cathodes of tubes V1 and/or V2 may hamper the keying action these circuits will be necessary. The same remarks apply to the circuits 40 and 42 in the connection between the anode of tube V5 and the grid of tube V3. The anode 50 of tube V3 is coupled to the positive terminal of a source of direct current by a circuit 52 parallel resonant to a frequency intermediate the frequencies f_1 and f_2 , but this circuit is sufficiently broad to include or pass both frequencies f_1 and f_2 . The resonant characteristic of this circuit is shown in Fig. 2 and designated Q3 (f_3).

When the first pulse of the keying signal, which, for example, may be formed by differentiation of the character, is applied to the leads 21, Fig. 1, the triggering circuit will operate to switch the current from tube V2 through V1 so that now V2 will be cut off and V1 will remain on until the next keying impulse. The triggering circuit is responsive to both signs of pulse energy by coupling both grids to the keying input. For example, assume as stated above that tube V1 is cut off and tube V2 is on. Then if a positive pulse is applied at the lead 21 the grids of both tubes tend to become positive but the current is already at saturation in tube V2. However, in tube V1 current is initiated and the drop of potential through resistance 14 is applied to the control grid 6 of tube V2 to cut down or reduce the current therethrough, and this action is cumulative because when the current through the tube V2 is reduced the potential at the anode of tube V2 and at the grid of V1 rises to increase the current through tube V1. When tube V1 is turned on, i. e., becomes conductive and tube V2 is turned off, i. e., becomes non-conductive by the first keying impulse tube V4 stops oscillating at the frequency f_1 because V1 is of low impedance and is connected across part of its tank circuit. In the meantime, tube V2 has become of high impedance and the load across tank circuit T2 is reduced and tube V5 starts oscillating at frequency f_2 . Oscillations of the frequency f_2 are now supplied to the grid 39 of tube V3 and tube V5 continues to oscillate and excite the grid of tube V3 until the next impulse is applied at lead 21, signifying the end of the signal character.

In the example assumed hereinbefore this signal pulse would be negative and would not affect the flow of current through the tube V2 already cut off, but would reduce the current flow through tube V1 so that the tripping action would again take place, flipping the current through the tube

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V2 and cutting off the current in the tube V1. Then the oscillations would be stopped in tube V5, started in tube V4, and the grid of tube V3 would be excited by oscillations of frequency $f1$ until a change in the pulse applied at lead 21 takes place.

The differentiating circuit may be as illustrated in Fig. 1a. The signal such as, for example, represented at the input lead is applied to the grid 70 of a tube 72 having a load resistance RL connecting the tube's anode to a source of potential E , the anode being coupled by a condenser C5 to the grid coupling condensers 9 and 11 over a time constant element in the form of a resistance R . R , RL and C5 are small so that the time constant of the network is small as compared to the duration of the keying pulses. When the signal appears on the grid 70 the potential swings negative and the anode potential rises, to a value approximating E , rapidly and charges condenser C5. A potential peak (positive) is built up across the condenser C5 and applied to the trigger circuit through condensers 9 and 11. This potential trips the current in the trigger circuit and falls rapidly because condenser C5 discharges rapidly. At the end of the signal pulse the potential on grid 70 swings toward zero potential, the tube draws current and its anode potential drops rapidly. Condenser C5 is charged negative (in the other direction) and a negative potential is built up across the condenser C5 and applied to the trigger tube grids through condensers 9 and 11. This potential switches the current in the tubes of the trigger circuit and falls rapidly because condenser C5 is small. The cycle then repeats as the signal comes in. The grids 6 and 8 of the trigger tubes are excited by potentials represented by Fig. 3b.

In the description of Fig. 1a it is assumed that condensers 9 and 11 are coupling condensers appropriate for the keying rate used and that resistances 18 and 20 serve only as biasing elements. In many cases condensers 9 and 11, and resistances 18 and 20 may be dimensioned to operate also as time constant elements. Then, for example, the signal applied at the input may be as shown adjacent the anode lead from the tube 72 in Fig. 1a. In other words, in practice resistances 18 and 20 of Fig. 1 may each also have the purpose of resistance R of Fig. 1a, and condensers 9 and 11 of Fig. 1 may each have the purpose of condenser C5 of Fig. 1a.

In Fig. 3a I have represented signal characters. In Fig. 3b I have represented keying signals by pulses of opposed polarity but which polarity (relative) is unimportant because as stated above these potentials are applied to the control grids 6 and 8 of both tubes V1 and V2, and irrespective of their polarity initiate a reversal or switching of the currents through the tubes when the same are applied. Suppose that on initiation of the signal character Fig. 3a the pulse applied at lead 21, Fig. 1, is of one polarity, as shown, Fig. 3b, while on the termination of the signal character Fig. 3a the pulse applied at lead 21 is of opposed polarity as shown in Fig. 3b. The anode voltages of tubes V1 and V2 are illustrated in Figs. 3c and 3d. Pulses of oscillations of frequency $f1$ out of the tube V4 supplied to tube V3 are illustrated in Fig. 3e, while the pulses of oscillations out of tube V5 applied to the grid of tube V3 are illustrated in Fig. 3f. The composite output including the alternatively keyed oscillations such as appears on the anode of tube V3 is shown in Fig. 3g. It will be understood that the polarity of the signals at the input may be reversed without al-

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tering the operativeness of the system or the principle of operation thereof. Reversing the polarity of the signals does not reverse the output from the trigger circuit.

The circuits 23 and 30 prevent oscillations of the frequency $f2$ from reaching the oscillator including tube V4, while the circuits 40 and 42 prevent oscillations of the frequency $f1$ from reaching the circuits of the oscillator including tube V5.

The outputs are added as stated above in the anode circuit of tube V3, with the result that the character (mark) and interval (space) are represented by the frequencies $f2$ and $f1$ respectively; thus frequency shift keying has been accomplished.

The Q ($Q3$) of the tuned circuit 52 in the anode of tube V3 must be small enough to allow both $f1$ and $f2$ to pass. This characteristic has been illustrated in Fig. 2. If extreme differences of frequency are to be used $Q3$ may be further decreased by the insertion of a resistor 56 in parallel to the inductance and capacity of circuit 52. This is accomplished by closing the switch S1 in Fig. 1, and is shown in a quantitative fashion by the characteristics in Fig. 2.

Any difficulties such as flashover, excess power dissipation, etc., resulting from the fact that transient currents are set up in the circuits when the frequency of operation is suddenly shifted between two values are overcome in a large measure by addition of the small condensers C1 and C2 in shunt to resistances 14 and 16 and/or addition of the small condensers C1' and C2' in shunt to the grid to cathodes of the tubes V1 and V2. These condensers are small and adjustable and when placed as shown will slow down the changeover of the trigger circuit. Thus the loading will be gradually taken off of the tube V5 oscillator circuit and gradually applied to the tube V4 oscillator circuit at the beginning of a character and vice versa at the end of a character. This results in a damping action on both frequencies $f1$ and $f2$ at the point of changeover, so that the power present at the changeover (which would appear as transient energy) is much reduced over that present at the mark or space operation. This is illustrated by the curves of Figs. 3c and 3d, 3e, 3f, but no attempt to show the same to scale is made here since this operation can be performed in such a short time that very few cycles of either $f1$ or $f2$ will be damped.

What is claimed is:

1. In a signalling system, a first oscillatory circuit operating at a first frequency, a second oscillatory circuit operating at a second frequency, an output circuit coupled to said oscillatory circuits, a pair of electron discharge tubes having input and output electrodes, leads including the impedance between electrodes of one of said tubes in one of said oscillatory circuits, leads including the impedance between electrodes of the other of said tubes in the other of said oscillatory circuits, and means for biasing one of said tubes to cutoff in the presence of energy of one intensity, and for biasing the other of said tubes to cutoff in the presence of energy of a second and different intensity, the arrangement being such that the two oscillatory circuits are rendered operative and inoperative alternately as the tube conductivities are changed by the biases applied by said last named means.

2. In a signalling system, an electron discharge device having electrodes regeneratively coupled by a circuit, including reactance, for the produc-

tion of oscillatory energy, a pair of electron discharge tubes each having an anode, a cathode and a control grid, impedances cross-coupling the anodes and control grids of said tubes, and a source of direct current connected by impeders between the anode and cathode of each tube the arrangement being such that when current flow is started through one tube the other tube is biased to cutoff and vice versa, leads coupling the impedance between electrodes of one of said tubes in shunt to a portion at least of the reactance of said first circuit, and means for applying a control potential which varies between a positive value and a negative value to the input electrodes of said tubes, to render the tubes alternatively conductive and non-conductive, the arrangement being such that when said one of said tubes is conductive its impedance is low and being in shunt to a portion of the reactance of the first circuit loads said circuit to stop generation of oscillatory energy.

3. In a frequency shift signalling system, a first oscillatory circuit operating at a first frequency, a second oscillatory circuit operating at a second frequency, an output circuit coupled to said oscillatory circuits, a pair of electron discharge tubes having input and output electrodes, impedances cross-coupling the input and output electrodes of said tubes, leads connecting the impedance between electrodes of one of said tubes in shunt to a portion at least of one of said oscillatory circuits, leads connecting the impedance between electrodes of the other of said tubes in shunt to a portion at least of the other of said oscillatory circuits, and means for applying energy the intensity of which changes between two values in accordance with signals to the input electrodes of said tubes, to render the tubes alternatively conductive and thereby alternatively load and unload said oscillatory circuits to make the same alternatively operative and inoperative.

4. In a telegraph signalling system, a first oscillation generator having a first generating circuit operating at a first frequency, a second oscillation generator having a second generating circuit operating at a second frequency, a combining circuit coupled to both of said generators, a pair of electron discharge tubes having input and output electrodes, leads coupling the impedance between the output electrodes of one of said tubes in shunt to one of said generating circuits, leads coupling the impedance between the output electrodes of the other of said tubes in shunt to the other of said generating circuits, the arrangement being such that when a tube is conductive the load it introduces in the oscillation generator with which it is in shunt stops operation thereof, means for applying signalling energy the intensity of which varies in accordance with signals to the input electrodes of said tubes, and means coupling said tubes in a triggering circuit such that when the signal level changes one tube becomes conductive and the other tube is cut off, and when the signal level again changes the said one tube is cut off and the other tube becomes conductive.

5. In a telegraph signalling system, a first oscillation generator having a first generating circuit operating at a first frequency, a second oscillation generator having a second generating circuit operating at a second frequency, an output circuit coupled to both of said generators, a

circuit parallel tuned to the frequency of operation of one generator in the coupling between the other generator and the output circuit, a circuit parallel tuned to the frequency of operation of said other generator in the coupling between said one generator and the output circuit, a pair of electron discharge tubes having input and output electrodes, leads coupling the impedance between electrodes of one of said tubes in shunt to one of said generating circuits, leads coupling the impedance between the output electrodes of the other of said tubes in shunt to the other of said generating circuits, the arrangement being such that when a tube is conductive the load it introduces in the oscillation generating circuit with which it is in shunt stops operation of said generator, means for applying signalling energy the intensity of which varies in accordance with signals to the input electrodes of said tubes, and means coupling said tubes in a triggering circuit such that when the signal level changes one tube becomes conductive and the other tube is cut off, and when the signal level again changes the said one tube is cut off and the other tube becomes conductive.

6. In a signaling system, a first oscillation generator having a first oscillation generating circuit operating at a first frequency, a second oscillation generator having a second oscillation generating circuit operating at a second frequency, a combining circuit coupled to both of said generators, a pair of electron discharge tubes having input and output electrodes, leads coupling the impedance between the output electrodes of one of said tubes in shunt to one of said generating circuits, leads coupling the impedance between the output electrodes of the other of said tubes in shunt to the other of said oscillation generating circuits, the arrangement being such that when a tube is conductive the load it introduces in the oscillation generating circuit with which it is in shunt stops operation of said generator, means for applying modulating potentials which vary in accordance with signals to the input electrodes of said tubes, means for biasing one of said tubes to cut off when the signal potential level changes and means for biasing the other of said tubes to cut off when the signal potential level again changes.

7. A signaling system as recited in claim 1 including an output circuit coupled to both of said oscillatory circuits, means in the coupling between said output circuit and said first oscillatory circuit for preventing oscillatory energy of said second frequency from reaching said first oscillatory circuit and means in the coupling between said output circuit and said second oscillatory circuit for preventing oscillatory energy of said first frequency from reaching said second oscillatory circuit.

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