

Sept. 24, 1946.

E. LABIN

2,408,076

PULSE TRANSMITTER

Filed Aug. 12, 1941

2 Sheets-Sheet 1

FIG. 1.

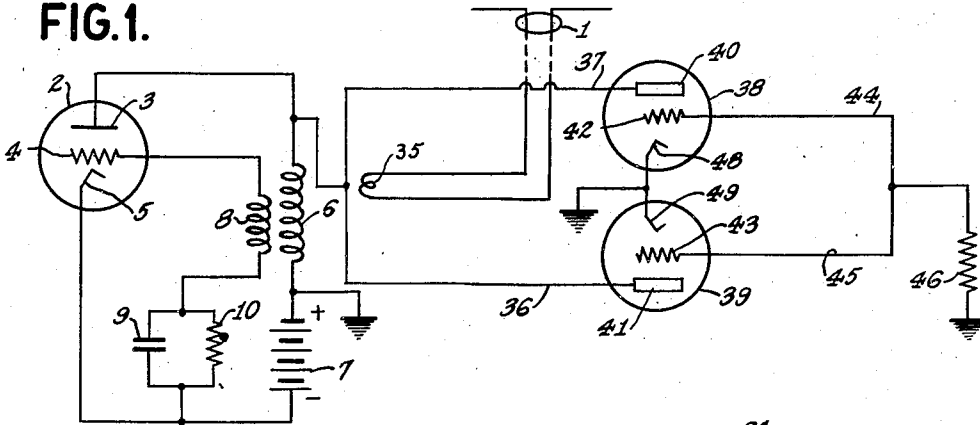


FIG. 2.

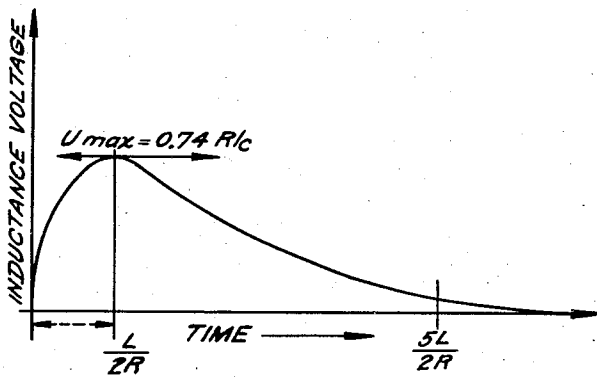
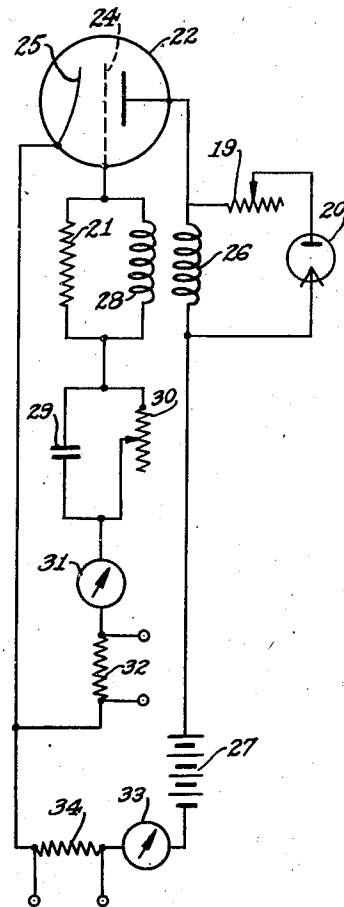


FIG. 3.



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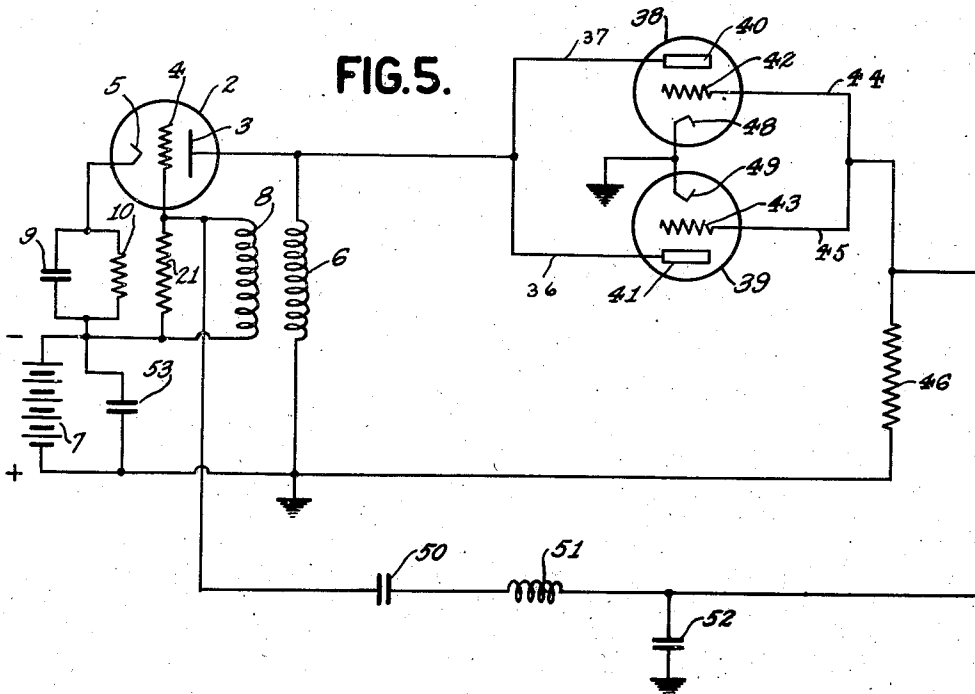
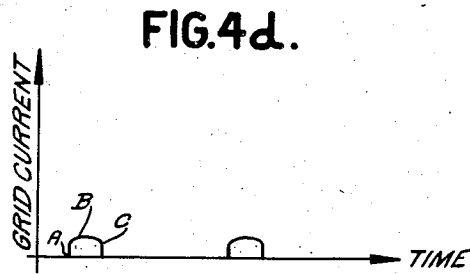
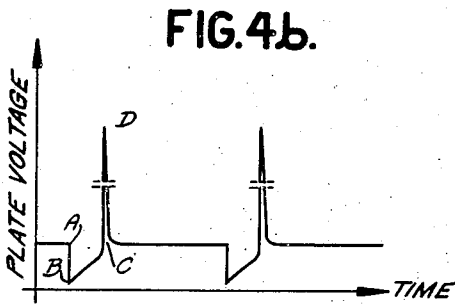
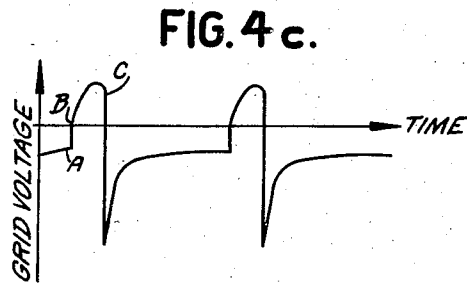
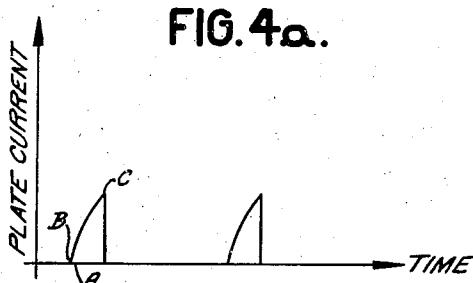
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,408,076

PULSE TRANSMITTER

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Application August 12, 1941, Serial No. 406,499

10 Claims. (Cl. 250—36)

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The present invention relates generally to apparatus for producing brief trains of oscillation and particularly to apparatus for producing brief high power trains of high frequency oscillations.

There are many uses for such a source of brief trains of high frequency oscillations, among them being their use in distance finding apparatus for generating high power impulses. In distance finding apparatus it is necessary and desirable to produce wave trains of large peak power so that these wave trains may be directly radiated without amplification, while still giving a large amount of radiated power and hence a large useful operating range for the apparatus.

It is an object of my invention to provide an efficient apparatus for delivering brief wave trains of high power waves.

It is a further object to provide such an apparatus suitable for delivering high power brief wave trains of ultra-high frequency waves, the wave trains being of accurately controlled length and spacing.

It is a further object to provide such an apparatus which when powered by a plate supply source of given voltage is capable of delivering wave trains of substantially higher power than could be delivered by conventional apparatus using a plate supply of said given voltage.

It has heretofore been proposed to produce high power trains of oscillations by applying to the plate of a suitable oscillation generator tube, brief high power impulses derived from a B supply of moderate voltage by a controlled amplifier having an inductance in its output circuit. In accordance with this system the current in an inductance connected in the plate circuit of the amplifier tube is interrupted by means of control signals of the desired form applied to the grid of this tube and obtained from a separate low power impulse generator. This system operates fairly satisfactorily, but it has several disadvantages:

(a) During the period of charging current flow in the inductance, a high positive voltage must be applied to the grid of this amplifier tube in order that the plate current may approach the maximum emission current of the tube.

(b) Because of the grid current which flows during the charging period, the amplifier or generator which drives the amplifier in (a) must supply a considerable amount of power to a low impedance (the effective grid resistance at this time being from 100 to 500 ohms).

(c) During the period of discharge of the inductance, the instantaneous plate voltage may

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be as much as ten times the plate supply voltage. The negative grid voltage consequently must be raised to several times the normal cut-off value to insure that the tube is blocked during the discharge or pulsing period.

It is both difficult and expensive to build an amplifier which will pass a wide band of frequencies (to allow a very fast blocking action), deliver a large amount of power into a low resistance and supply a high negative voltage to an infinite resistance.

For medium power installations it is possible to reduce some of the above difficulties by employing a pentode tube as the amplifier tube connected to the inductance. However, for high power applications pentodes are costly and introduce circuit complications.

It is an object of my invention to provide a source of brief wave trains of high power and high frequency waves while avoiding the difficulties above mentioned.

According to my invention, I provide as the source of plate supply for a high frequency oscillator an impulse generator comprising an amplifier tube having an inductance coil in its output circuit and means for coupling the inductance coil to the grid circuit of the amplifier tube. In the preferred embodiment of my invention I employ a triode as an amplifier tube.

It is a further object of my invention to provide an improved impulse generator capable of producing impulses of high peak power.

It is another object of my invention to provide a self-excited impulse generator capable of producing impulses of high peak power.

It is another object of my invention to employ in said high power impulse generator a triode as an amplifier-generator tube.

It is another object of my invention to provide apparatus for accurately controlling the duration of high frequency pulses.

My invention will be more clearly understood by referring to the accompanying drawings wherein:

Fig. 1 illustrates an impulse transmitter for delivering brief wave trains of high power in accordance with my invention;

Fig. 2 is a diagram used in explaining my invention;

Fig. 3 shows a circuit employed in operation tests;

Figs. 4a, 4b, 4c and 4d are diagrams used in describing the operation of the impulse generator of my invention;

Fig. 5 illustrates an embodiment of my inven-

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tion wherein a high frequency oscillator is controlled by both positive and negative impulses from an impulse generator.

Fig. 1 discloses an impulse generator connected as the power supply for an oscillator. The impulse generator comprises a vacuum tube 2 having a plate 3, a control grid 4 and an electron emissive cathode 5 which may be directly or indirectly heated. An inductance 6 is connected in series with the energy source 7 in the plate circuit of the tube 2 between the plate 3 and the cathode 5. Positive feedback between the plate circuit and the grid circuit is obtained by means of coil 8 which is inductively coupled to the inductance 6 and which may be considered as one coil of the transformer 6, 8. The pulsing rate is primarily determined by the capacity-resistance timing circuit consisting of condenser 9 and resistance 10. As shown, the condenser 9 and resistance 10 are in series with the grid 4, but they may, instead, be connected in series with the cathode 5.

When the inductance 6 is charging, that is, when current is flowing in tube 2, the plate end of the inductance is negative with respect to the other end of the inductance. When the inductance is discharging (no tube current), the reverse polarity exists.

In practice, the load resistance for inductance 6 will vary between 10,000 ohms for 10 to 15 microsecond impulses, and 2,000 ohms for 1 to 2 microsecond impulses. This load resistance is of the same order as the plate resistance of many commonly employed oscillator tubes. In the preferred embodiment of my invention, I employ the impulse generator as the plate voltage supply for an oscillator. The impulse generator may also act as the power supply for any other power electrode such as the screen grid of the oscillator tube. In Fig. 1, one end of the inductance coil 6 of the impulse generator is connected to the mid-point of a pair of lecher wires 36 and 37. These lecher wires 36 and 37 serve to tune the plate circuit of the tubes 38 and 39, and the lecher wires are connected to the plates or power electrodes 40 and 41 of the tube. The grids or control electrodes 42 and 43 are connected to a pair of lecher wires 44 and 45 which serve to tune the grid circuit of the tubes 38 and 39. A resistor 46 serves as a biasing resistor. The cathodes or electron emissive electrodes 48 and 49 are connected to a common return point.

During the charging and steady state periods of the impulse generator the oscillator comprising the tubes 38 and 39 is inoperative. When the inductance 6 discharges, the tubes 38 and 39 and their accompanying circuits are energized and oscillations are produced. It will thus be seen that high frequency energy is produced for an interval substantially equal to the discharge time of the inductance coil 6. Actually the oscillator will cease to oscillate before the inductance coil 6 is completely discharged, and the high frequency pulse will be a little shorter than that delivered by the inductance coil 6 to a resistance load.

The oscillator stage is preferably coupled to transmitting system directly, but it may also be coupled to an amplifier or amplifiers and then to a transmitting system. As shown in Fig. 1, the oscillator is coupled by means of loop 35 to the transmitting system 1. It is to be understood that although I have shown a push-pull oscillator as a preferred type other types of oscillators may be employed.

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Although impulse generators and oscillators are both known, I shall describe the impulse generator employed in accordance with my invention in more detail in order that my invention may be more clearly understood.

The use of inductive coupling between the plate and grid circuits has the effect of shunting the inductance with a negative resistance. For the present purposes the circuit shown in Fig. 1 may be considered during the charging period as equivalent to an inductance in parallel with a negative resistance and with the capacities of the components of the circuit.

A circuit consisting of inductance, capacity and resistance, which is capable of oscillating at high values of resistance, may become aperiodic if the resistance is small, even though negative. If R_c is the resistance for critical damping, the circuit will be aperiodic as long as the shunt or parallel resistance remains between $+R_c$ and $-R_c$. When the circuit is made aperiodic by damping with a negative resistance ($-R_c$), the operation is not at all normal. Any small current increase develops into a very rapid and large exponential increase. From the moment at which the current begins to rise, it continues to rise to its absolute limit, always in the same direction and with increasing speed. Similarly, a decrease in current will also follow an exponential law.

When the inductance 6 is charging and this inductance is connected to the oscillator as a plate supply for the tubes thereof, the effect of the oscillator tubes may be neglected since, as pointed out above, the polarity of the potential on the inductance is such that the plates of the tubes are at a negative potential with respect to the cathodes and the resistance of the tubes may, therefore, be considered as infinite. When, however, the inductance discharges, its polarity reverses, and the inductance discharges into the tubes as well as the circuit components of the generator itself. During the discharge, the oscillator tubes act substantially as a resistance load.

The discharge of the inductance begins at the instant that the plate current is blocked. The plate current of the tube 2 having been blocked, the resistance of tube 2 may be considered as infinite, and consequently, the circuit consists of the inductance 6 in parallel with the inherent resistance of the oscillator (if substantially resistive) and a capacity consisting substantially of the capacities of tube 2 and the oscillator, the distributed capacity of coils 6 and 8, condenser 9 and other capacities to ground. From the theory of parallel inductance, capacity and resistance circuits, it is known that the discharge of the inductance 6 into the oscillator (considered as a load) will be made in a minimum time and with a maximum peak power if the circuit constants are given critical values which satisfy the equation.

$$L-4CR^2=0$$

Under these conditions, the discharge of the inductance will follow a curve like that shown in Fig. 2.

For a better understanding of the operation of the impulse generator a cycle of operation will be described as follows:

(a) Charge.—As soon as the grid condenser 9 almost completely discharges through the resistance 10, plate current will begin to flow. This current will increase continuously to a value near the saturation current value for the

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tube 2. At the same time the voltage at the plate 3 will decrease due to the reactance drop across inductance 6, and the grid voltage will increase positively due to the feedback between the grid and plate circuits giving a large grid current flow. The power furnished to the grid circuit is obtained from the plate voltage source.

(b) *Discharge*.—The increase in plate current will cease when the plate current approaches the saturation current of the tube. At this time the grid voltage, which has been held at a high value due to the inductive coupling between the plate and grid circuits, will begin to decrease causing a decrease in the plate current. The direction of plate current variation will then reverse, and this effect becomes cumulative causing the plate current to decrease rapidly. The grid voltage will decrease and finally become negative. The result is that the plate current will be stopped in a very short time producing a high voltage at the terminals of the inductance 6. If the coupling between coils 6 and 8 is properly adjusted, a high negative voltage approximately equal to the instantaneous plate voltage will be produced at the grid 4, and this negative voltage will be sufficient to block the plate current during the discharge of the inductance.

(c) *Steady state*.—During the charge of the inductance 6, the grid current of tube 2 will charge condenser 9 with such a polarity that the plate of the condenser 9 connected to the grid 4 will be negative. At the end of the discharge of the inductance there will be no voltage across coil 8, and therefore, due to the charge on condenser 9, plate current will not flow. The condenser will discharge through resistance 10, and finally plate current will again flow and the cycle will be repeated.

For best operation the tube 2 should have a high saturation current to allow high values of charging current, should have a high mutual conductance to provide proper damping for circuit component impedance values other than the critical values and for negative resistance values and should be well evacuated in order to withstand the high peak voltage which is produced during the discharge of coil 6. It may be seen that with the exponential variations which take place the inductance will store a large amount of energy during its charge, and this energy will be released during a very short period. A peak voltage as high as 20,000 volts may be realized across the plate inductance coil with a power supply voltage of only 1000 volts. Accordingly, the circuit components of the impulse generator and associated apparatus must be carefully insulated, and one of the chief points of concern is the insulation between the plate lead of the tube and other apparatus. It has been found possible with well evacuated low power tubes having thoriated filaments to use peak currents and peak voltages from 10 to 20 times the normal operating values without damaging the tubes or shortening the lives of the tubes. These values correspond to peak powers from 100 to 400 times the normal tube rating.

In order to observe the operation of the impulse generator an oscillographic analysis was made with the circuit shown in Fig. 3. In this figure 22 is a high vacuum tube having a plate or anode 23, a grid 24 and a cathode 25. Connected to the anode 23 is an inductance 26, and the grid 24 is coupled to the inductance 26 by coil 28 shunted by resistance 21. Resistance 19 and

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the high vacuum diode 20 in series therewith form a load for the inductance. Resistance 30 in parallel with condenser 29 serves as a timing circuit to control the impulse frequency. Source 27, which maintains a potential of about 350 volts, serves as a power supply for the generator. Meters 31 and 33 serve to indicate the currents in the respective circuits, and resistances 32 and 34 are provided as voltage sources for an oscillograph.

In the circuit of Fig. 3 the following elements were employed:

Tube 22 a type EL-3 receiving tube manufactured by N. V. Philips' Gloeilampenfabrieken of Eindhoven, Holland. The operating characteristics are:

Amplification factor	20
Plate resistance	2000 ohms
Grid resistance	100 do
Plate voltage	350 volts

Tube 20 a rectifier of the so-called "80 type" which is widely sold in the United States.

Condenser 29 a 1 mfd. condenser

Resistance 30 a rheostat variable from 1000 ohms to 200,000 ohms.

Resistances 32 and 34—4 ohm fixed resistors.

Resistances 19 and 21 loading resistors.

Inductance 26 an inductance of about 15 millihenrys and requiring a critical resistance of about 8,000 ohms.

With the above apparatus it has been found possible to produce currents of about 1 ampere and peak voltages as high as 6,000 volts, the peak power being about 4 kilowatts. The development of 4 kilowatts peak power with a small receiving tube and a 350 volt plate supply illustrates the advantage of the present invention. These results for a small tube were duplicated on a much larger scale with larger triodes such as the Eimac tube T2,000 manufactured by Eitel-McCullough, Inc., of San Bruno, California. Tubes of this latter type, using my circuit, can deliver 3 microsecond pulses of 30,000 volts in a 3,000 ohm resistance with a D. C. power supply of only 6,000 volts. This corresponds to a peak power of 300 kw.

With the circuit shown in Fig. 3, a transformation ratio of 0.5 and a coupling coefficient of 0.8, the oscillograms shown in Figs. 4a, 4b, 4c and 4d were obtained. These oscillograms show that at the time A, the grid condenser, has discharged sufficiently for plate current to flow. The flow in plate current decreases the plate voltage due to the drop across the inductance 26 and causes the grid voltage to become positive. At this time grid current will begin to flow.

During the time interval from B to C, the plate current approaches saturation, the plate voltage approaches the voltage of the plate supply, the grid voltage reaches a positive maximum and the grid current remains substantially constant at its original value. When plate current saturation is reached at the point C, the inductance 26 discharges producing a maximum of voltage, the grid voltage suddenly becomes negative and the flow of grid current is stopped. After the discharge of the inductance 26 all of the current and voltages except the grid voltage assume their steady state value, the grid voltage reaching its steady state value only after the discharge of the grid condenser. These oscillograms bear out the series of operations set forth in connection with Fig. 1.

During the oscillographic analysis of the impulse generator operation, it was found that the ratio of transformation and the coupling coefficient have considerable influence on the operation of the generator. It was found that for small values of transformation ratio the grid current is excessive and subtracts from the plate current. For large values of transformation ratio the grid excitation is insufficient. In order to obtain a maximum value of peak plate current, I prefer to use transformation ratios between 0.5 and 0.8.

The leakage reactance of the coupling transformer affects both the length of the charging period and the ratio of the plate voltage to the grid voltage. I have found that the best operating results are not obtained with coupling values near unity. By lowering the coefficient of coupling slightly, that is, by introducing an appreciable amount of leakage reactance, the moment at which the grid voltage reaches its peak value will be retarded. It is desirable that the grid voltage and the anode voltage increase simultaneously for under this condition high peak currents are obtained. The leakage reactance provides a convenient means for regulating the relation between the anode voltage and the grid voltage. I have found that preferable values for the coefficient of coupling are between approximately 0.6 and 0.9.

If the transformer has a transformation ratio of approximately $\frac{1}{2}$ and if no precautions are taken the grid voltage during the discharge of the inductance 26 will be approximately equal to one-half of the instantaneous plate voltage. Such a high grid voltage will cause arc-over between the filament and the grid of the tube and will lower the maximum peak voltage obtainable. For cut-off at the peak plate voltage it is only necessary that the grid voltage be equal to the peak plate divided by the amplification factor of the tube. The amplification factor of tubes commonly employed in amplifiers is usually considerably more than two. Accordingly, the grid voltage may be reduced to a value less than one-half of the anode voltage.

In accordance with my invention, I provide a resistance 21 connected across the terminal of the grid coil 28 of the transformer 26—28 shown in Fig. 3. Due to the effect of the transformer leakage reactance, the resistance 21 across the grid coil will cause the negative grid impulse to be limited to the desired value without changing the maximum voltage obtainable across the plate coil 26.

The use of the resistance 21 in the grid circuit has the added advantage that oscillations in the grid circuit may be substantially eliminated. It has been found that unless a resistance similar to the resistance 21 is employed, oscillations may continue in the grid circuit after the discharge of the inductance 26. With the resistance 21 in the circuit, the grid voltage will increase smoothly in the positive direction after the discharge of the inductance, and therefore, the regularity of the pulsing cycle will be assured.

The length of the transmitted high frequency pulse may be controlled by applying a negative impulse to the grid of the oscillator. Therefore, in accordance with a further feature of my invention I employ the negative impulse which controls the impulse generator for controlling the high frequency oscillator. Fig. 5 illustrates one embodiment of my invention wherein high

frequency oscillator is controlled by a negative impulse from the impulse generator. In this figure the oscillator and generator are substantially the same as those shown in Fig. 1. Since the negative impulse produced at the grid 4 and the positive impulse produced by the coil 6 are produced simultaneously, the negative impulse which is applied to the oscillator must be delayed. The negative impulse may, for example, be applied to the grids 42 and 43 by means of blocking condenser 50 and the time delay circuit consisting of coil 51 and condenser 52 connected to one end of resistance 46. The time delay introduced may be regulated by adjusting the values of the coil 51 and the condenser 52. The ratio of the coil 51 to the condenser 52 is preferably substantially equal to the squared value of the resistance 46. The condenser 53 is a bypass condenser. Although I have shown the timing circuit 9, 10 in series with the cathode, it is to be understood that I still consider that the inductance 6 and the source 7 are connected in series between the anode 3 and the cathode 5.

While I have described particular embodiments of my invention, for purposes of illustration, it will be understood that various modifications thereof may be made without departing from the scope of my invention.

What I claim is:

1. A pulse transmitter comprising an oscillator comprising a vacuum tube having a power electrode, an electron emissive electrode and a control electrode, an output circuit coupled to said power electrode, an input circuit coupled to said control electrode and means for feeding energy from said output to said input circuit, means for supplying operating potential to said power electrodes comprising an impulse generator comprising a vacuum tube having an anode, a control electrode and an electron emissive electrode, an output circuit coupled to said anode, an input circuit coupled to said grid and means for feeding energy from said last-mentioned output circuit to said last-mentioned input circuit, and direct current connections for coupling said last-mentioned output circuit to the power electrode of said oscillator.

2. A pulse transmitter comprising an oscillator comprising a vacuum tube having an anode, a control grid and a cathode, a tuned input circuit connected to said control grid, a tuned output circuit connected to said anode and means for feeding energy from said output circuit to said input circuit, an impulse generator comprising a vacuum tube having an anode, a control grid and a cathode, an inductance connected in series with said generator anode and cathode, means for coupling said inductance to said generator grid and timing means connected between said generator grid and cathode, and direct current connecting means for connecting in coupling relation said oscillator anode to the junction of said inductance and said generator anode.

3. A pulse transmitter according to claim 2 wherein said means for coupling said inductance and said timing means are respectively a coil inductively coupled to said inductance and a condenser and resistance in parallel, said coupling means and said timing means being connected in series between said generator cathode and said generator grid.

4. A pulse transmitter comprising a push-pull oscillator comprising a pair of vacuum tubes each having an anode, a grid and a cathode, said anode and said grid being capacitively coupled,

tuned lecher wires connected between the anodes of said tubes, tuned lecher wires connected between the grids of said tubes, biasing means connected between said grid lecher wires and a common ground point and means for connecting said cathodes together and to said common ground point, an impulse generator comprising a vacuum tube having an anode, a grid and a cathode, an inductance coil connected between said generator anode and said common ground point, a resistance and a condenser in parallel forming a timing circuit, a coil inductively coupled to said inductance, a resistive impedance connected in parallel with said coil, said coil and resistive impedance forming a coupling circuit and said coupling circuit and said timing circuit being connected in series between said generator grid and said generator cathode, a source of energy supply and means for connecting said source between said generator cathode and said common ground point, and means for connecting for direct current coupling the end of said inductance connected to said generator anode to said anode lecher wires.

5. A pulse transmitter comprising an oscillator comprising a vacuum tube having an anode, a control grid and a cathode, a tuned input circuit connected to said control grid, a tuned output circuit connected to said anode and means for feeding energy from said output circuit to said input circuit, an impulse generator comprising a vacuum tube having an anode, a control grid and a cathode, an inductance connected in series with said generator anode, means for coupling said inductance to said generator grid and timing means connected at the cathode terminal of said generator to control the potential of said generator grid, direct current connecting means for connecting said oscillator anode to the junction of said inductance and said generator anode, and a time delay network connected between said oscillator grid and said generator grid.

6. A pulse transmitter according to claim 4 further comprising a time-delay network connected between said grid lecher wires and said generator grid, said network comprising a blocking condenser and a coil connected in series between said generator grid and said grid lecher wires and a further condenser connected between said last-mentioned coil and said common ground point.

7. A pulse transmitter according to claim 4 wherein said oscillator biasing means comprises a resistance and further comprising a time-delay network connected between said grid lecher wires and said generator grid, said network comprising a condenser and a coil connected in series between said generator grid and said grid lecher wires and a further condenser connected between said last-mentioned coil and said common ground point, the ratio of the magnitude of the last men-

tioned coil to the magnitude of said further condenser being substantially equal to the squared value of the magnitude of said biasing resistance.

8. A pulse transmitter comprising an oscillator comprising an input circuit, an output circuit, a vacuum tube having a power electrode, means for connecting said circuits to said vacuum tube and means for feeding regenerative energy from said output circuit to said input circuit, an impulse generator comprising a vacuum tube having an anode, a control electrode and a cathode, means for coupling said anode to said control electrode, an inductance, a source of direct current energy, means for connecting said source and said inductance in series and to said anode, said impulse generator producing a series of impulses having a peak voltage greater than the voltage of said direct current source and means for feeding said impulses to said power electrode of said oscillator comprising a conductive connection from said power electrode to the end of said inductance connected to said anode.

9. A pulse transmitter comprising an oscillator comprising a vacuum tube having an anode, a control grid and a cathode, a tuned input circuit connected between said cathode and said grid, a tuned output circuit connected between said cathode and said anode, and means for feeding regenerative energy from said output circuit to said input circuit, an impulse generator comprising a vacuum tube having an anode, a control grid and a cathode, an inductance, a source of direct current energy, means for connecting said source and said inductance in series between said anode and said cathode, a coupling coil inductively coupled to said inductance, the transformation ratio and the coefficient of coupling between said inductance and said coil being between 0.5 and 0.8 and 0.6 and 0.9 respectively, a timing circuit comprising a condenser and a resistance connected in parallel, means for connecting said coil and said circuit in series between said grid and said cathode, a further resistance, means for connecting said further resistance in parallel with said coil, means for connecting said oscillator anode to the end of said inductance connected to said generator anode, and means for connecting said oscillator cathode to the other end of said inductance.

10. A pulse transmitter comprising an oscillator, a vacuum tube in said oscillator having a power electrode, an electron emissive cathode and a control electrode, an impulse generator, means for feeding positive impulses from said generator to said power electrode and means for feeding negative impulses to one of said electrodes, said latter means comprising a time delay circuit to delay said negative impulses with respect to said positive impulses.

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