

Aug. 26, 1947.

S. C. HIGHT

2,426,216

APERIODIC PULSE TIMING SYSTEM

Filed Oct. 19, 1942

4 Sheets-Sheet 1

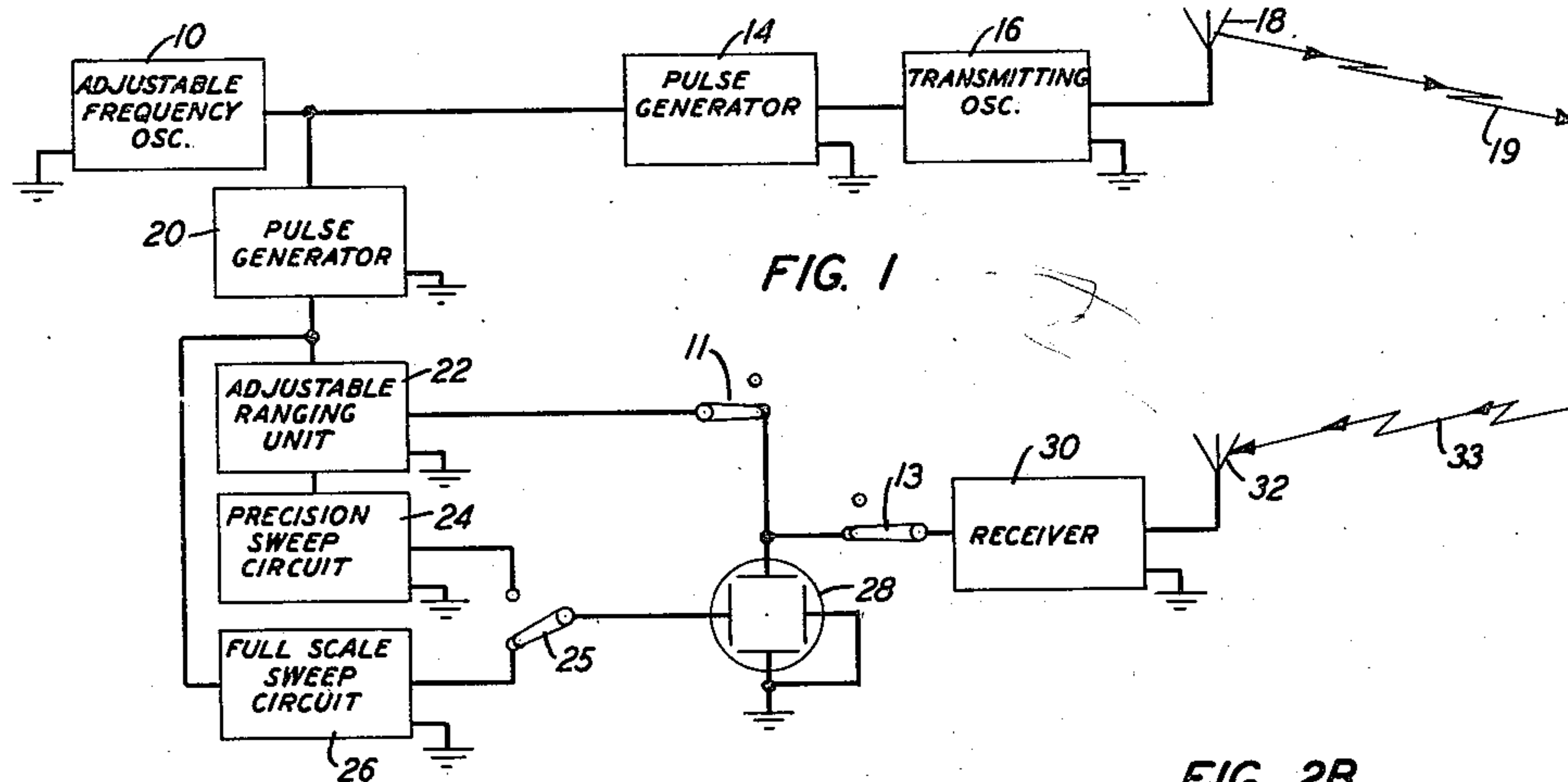


FIG. 1

FIG. 2B

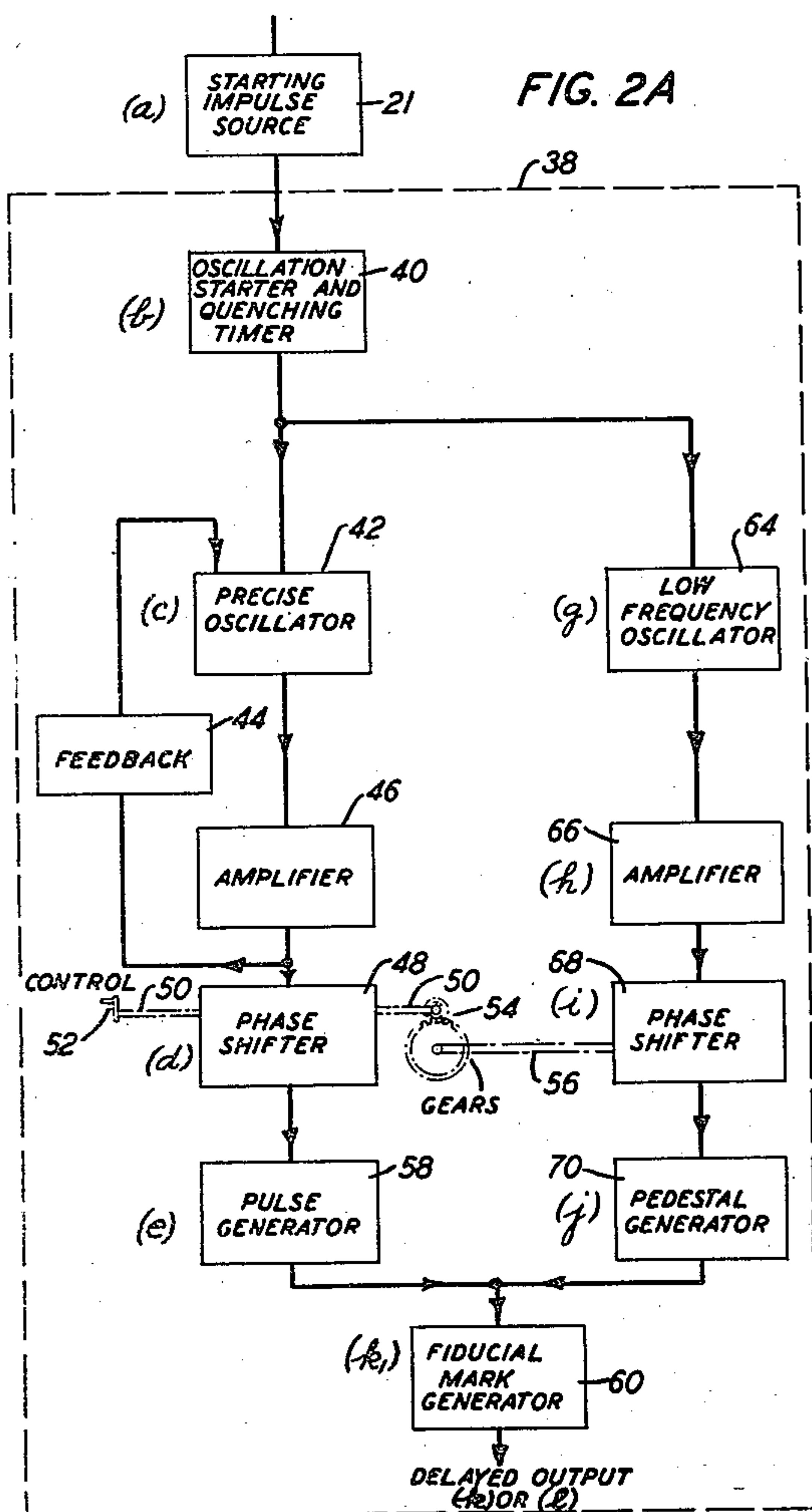
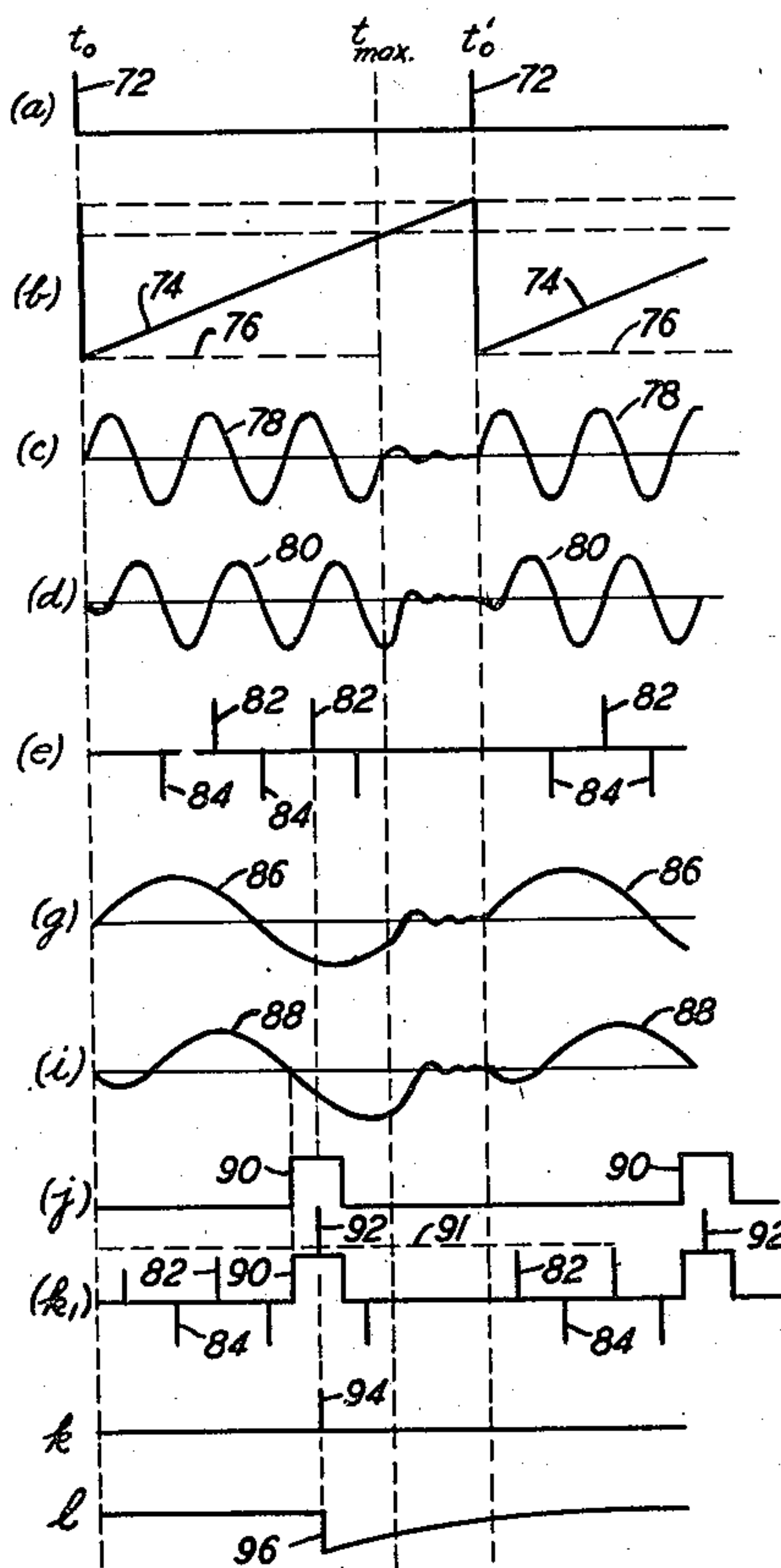


FIG. 2A



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4 Sheets-Sheet 2

FIG. 3A

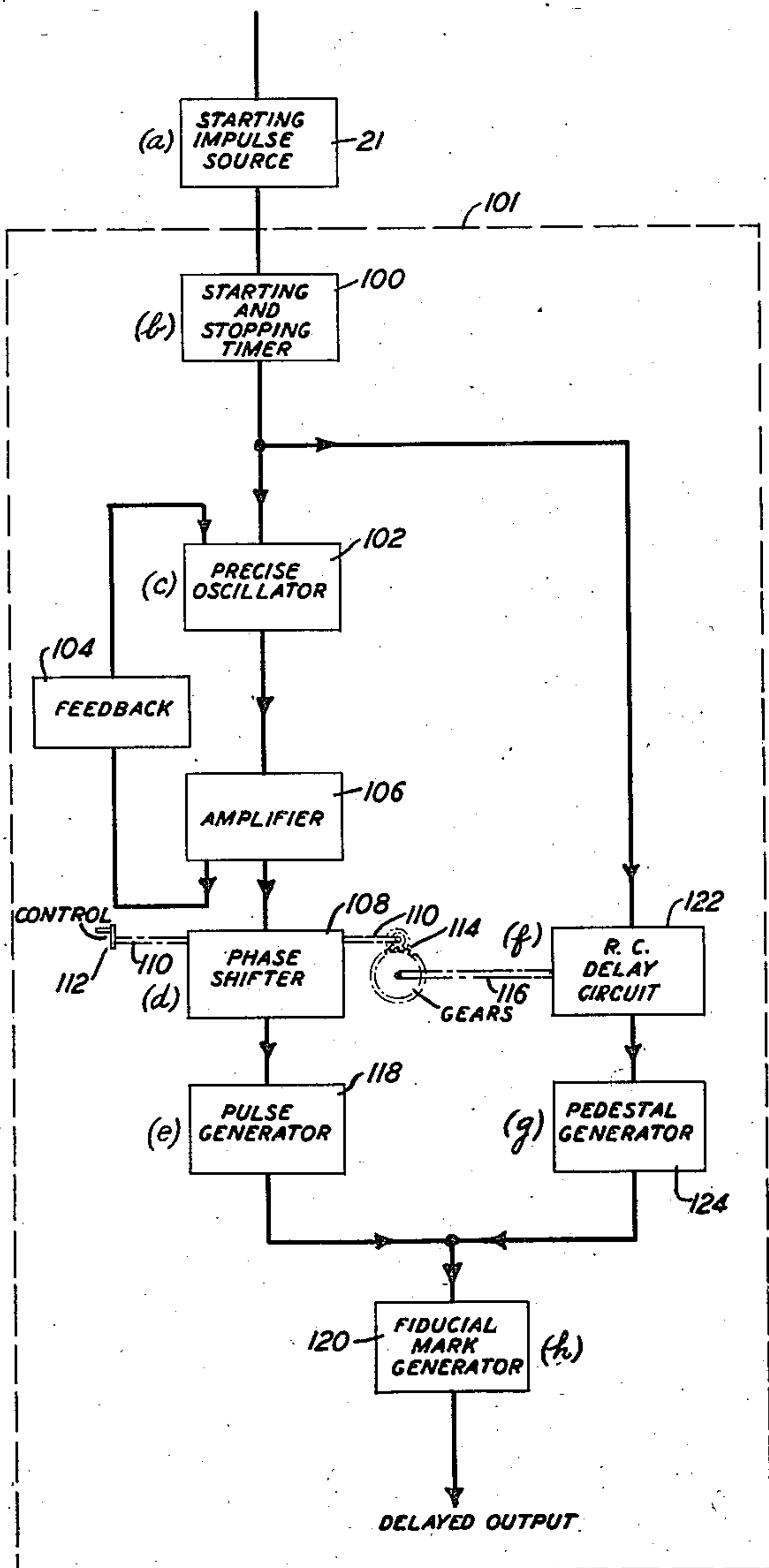
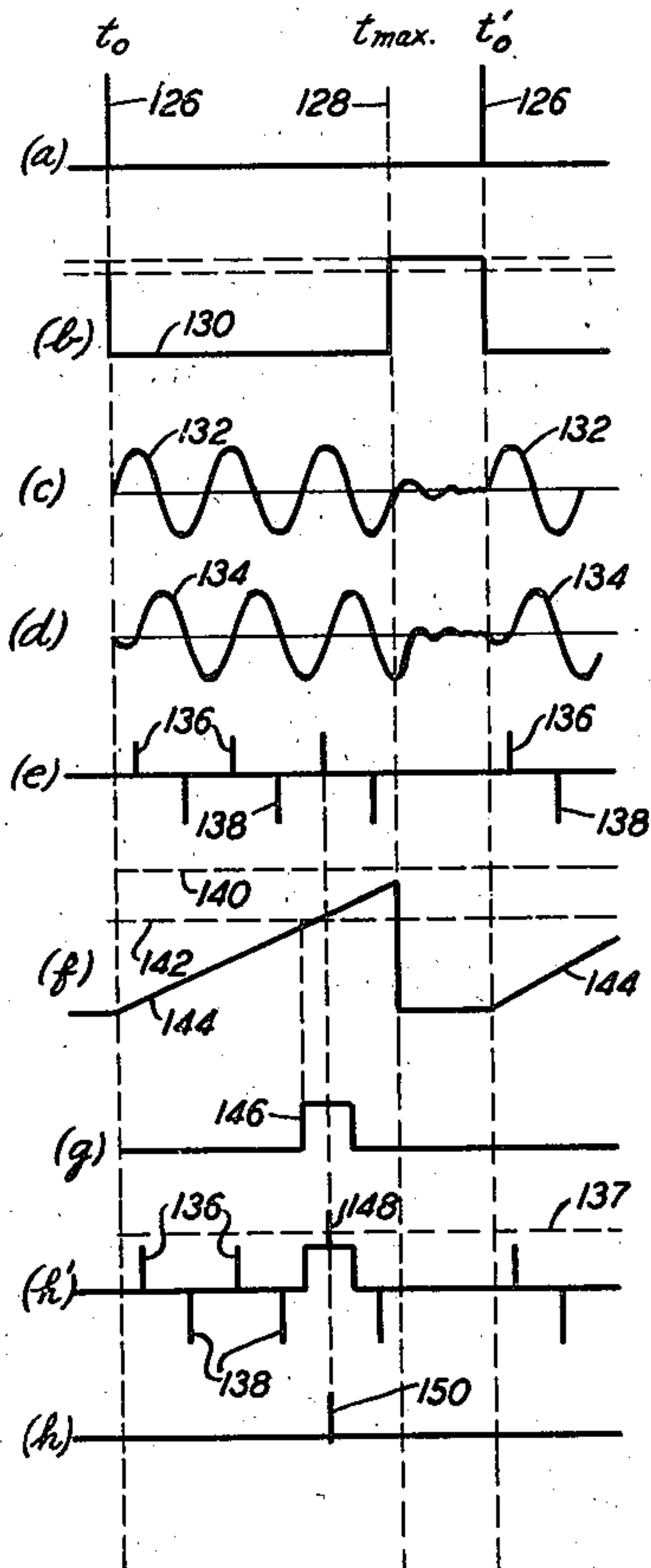


FIG. 3B



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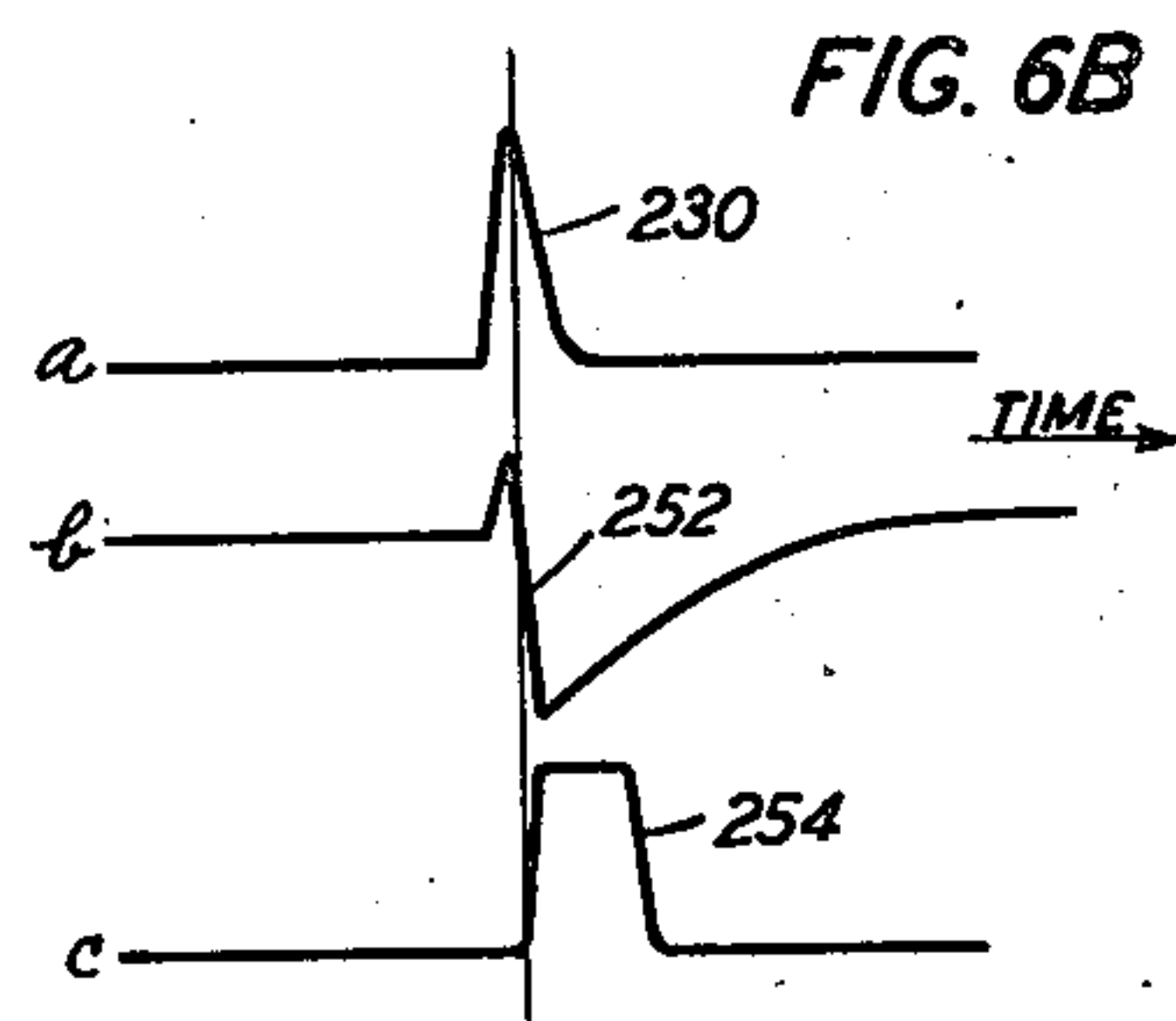
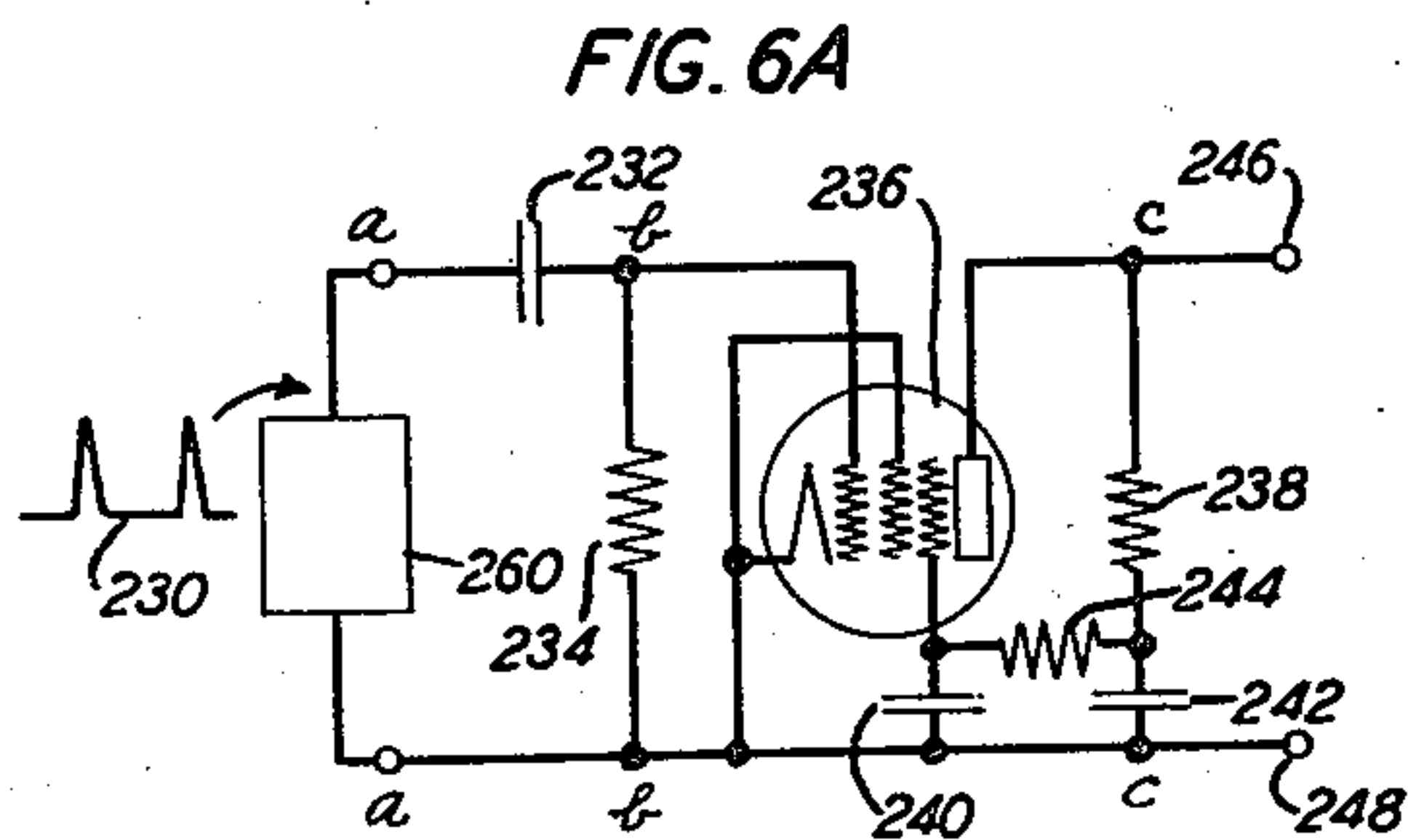
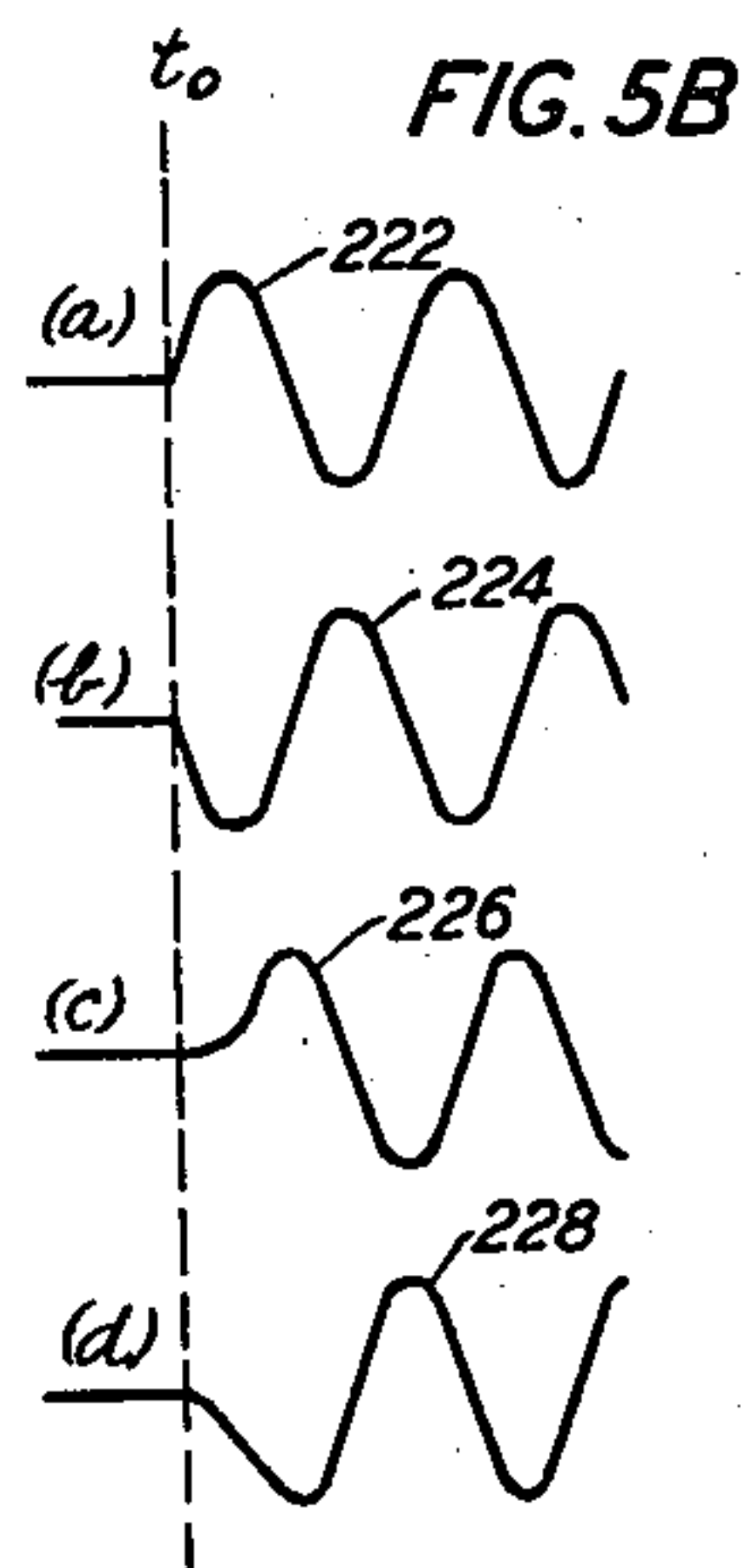
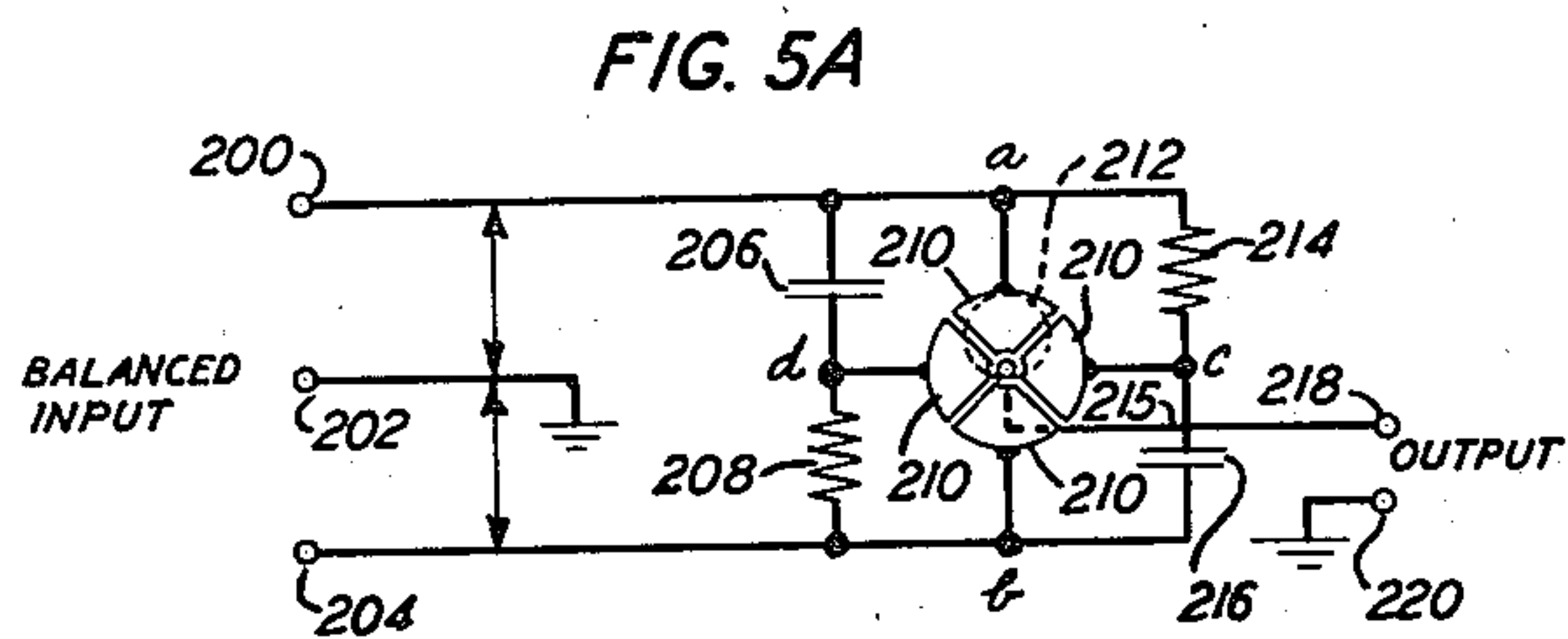
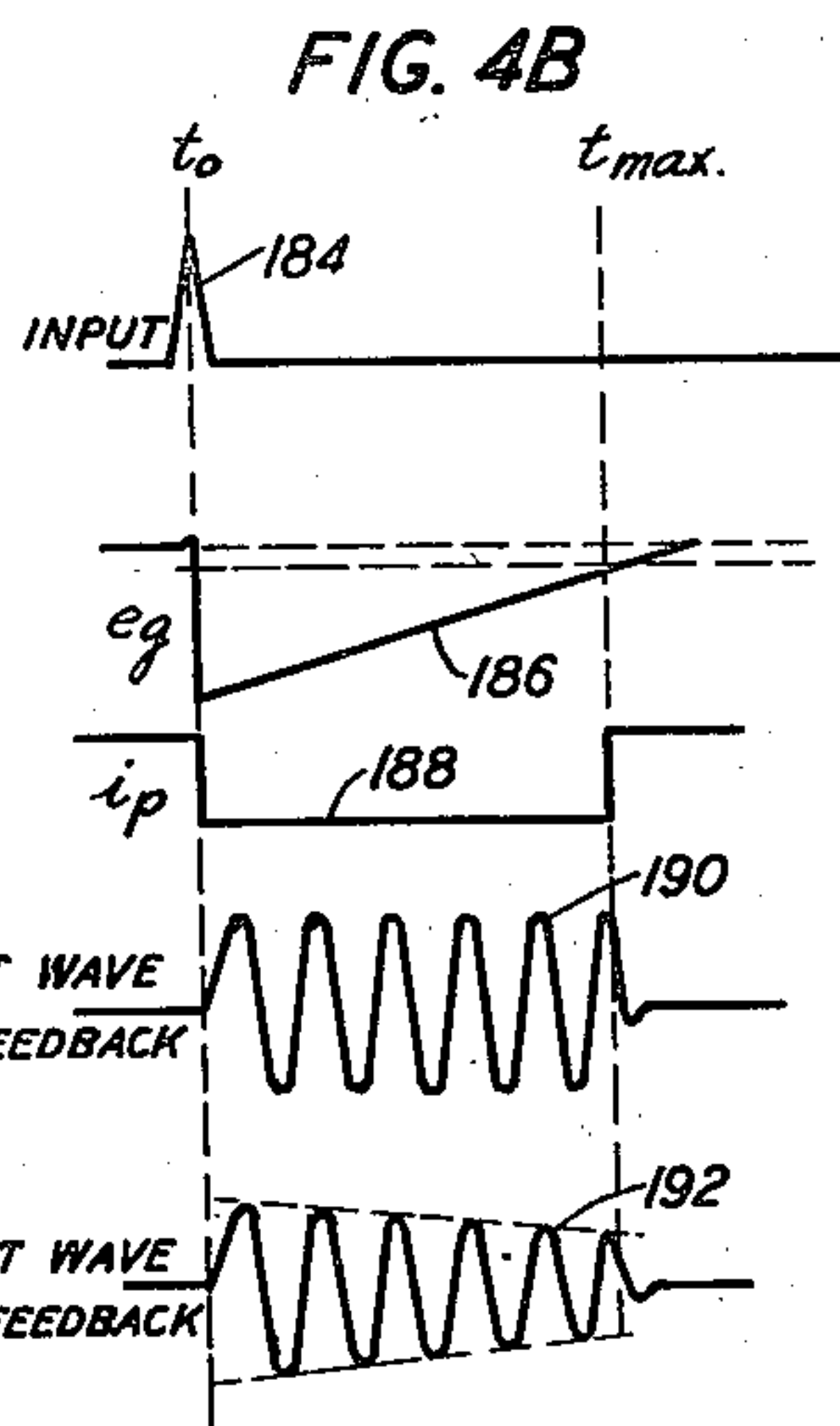
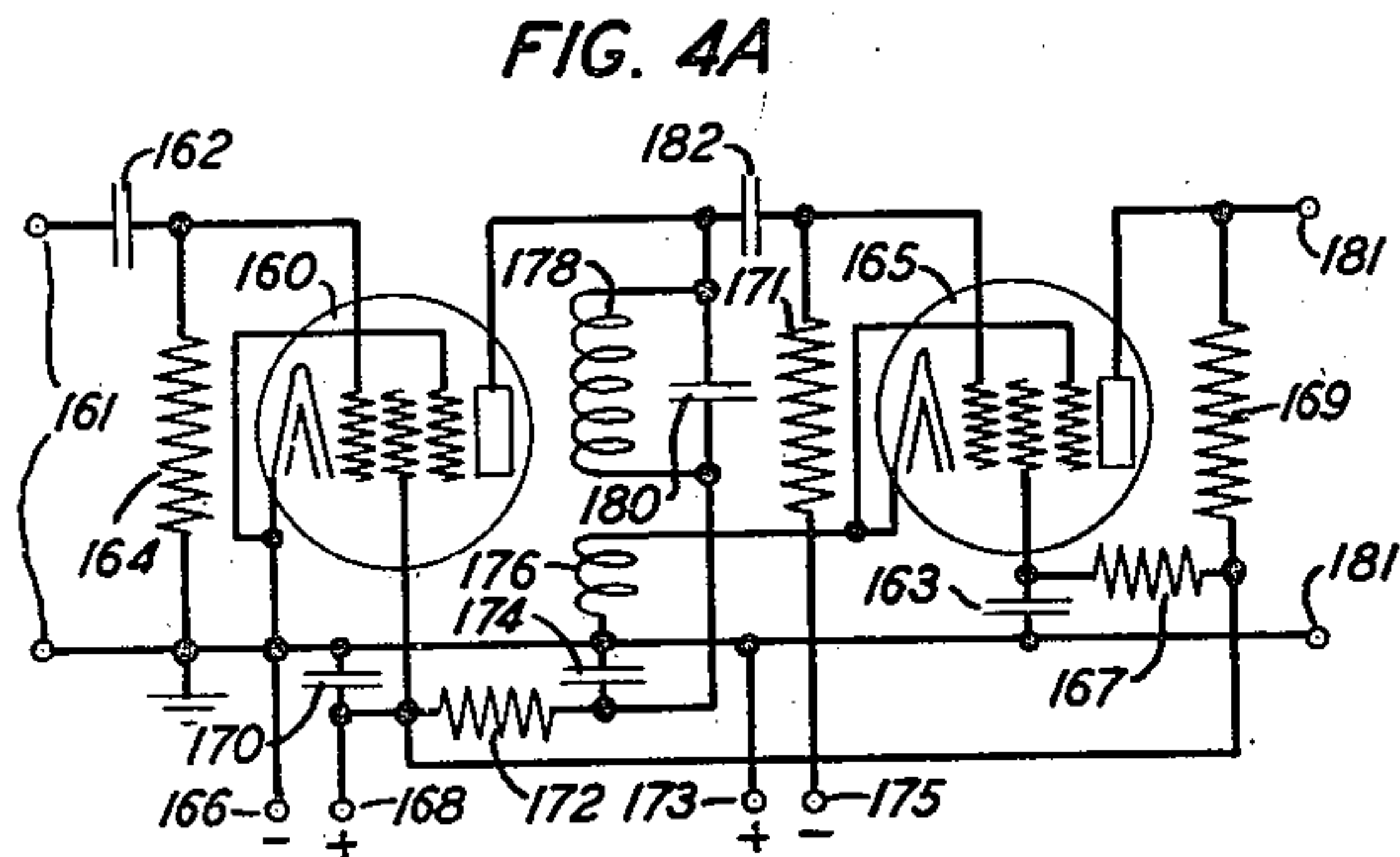
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APERIODIC PULSE TIMING SYSTEM

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4 Sheets-Sheet 3



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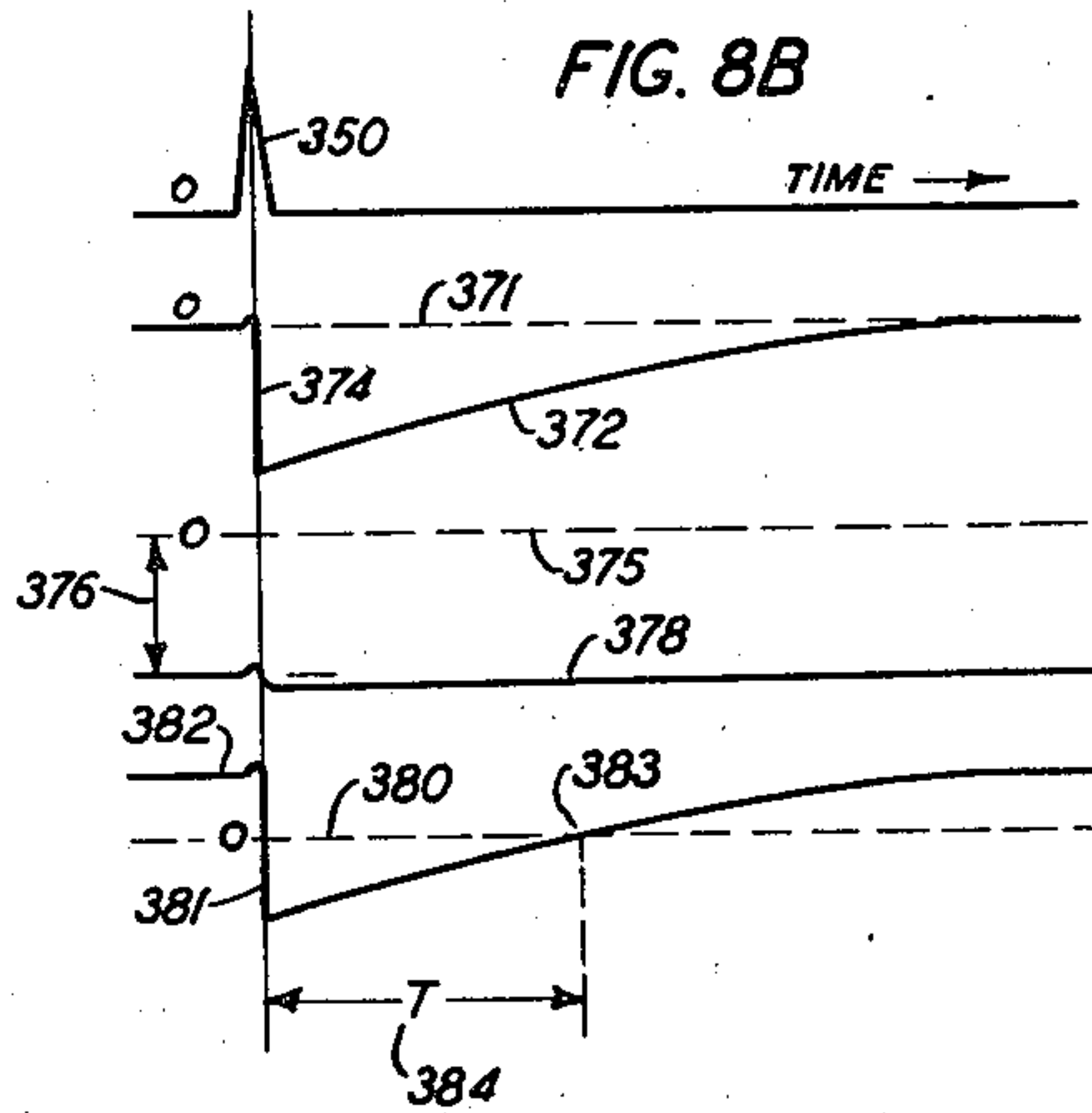
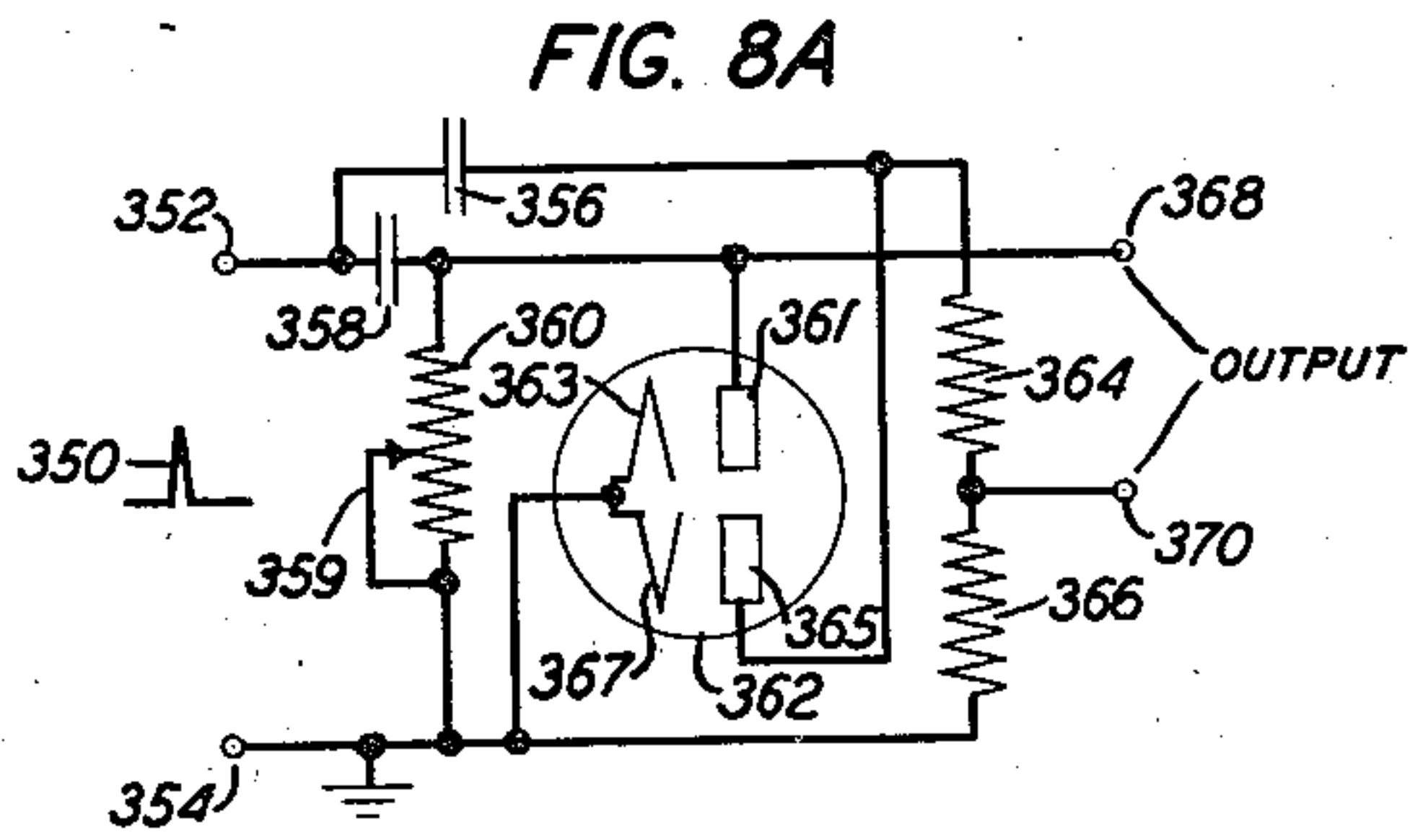
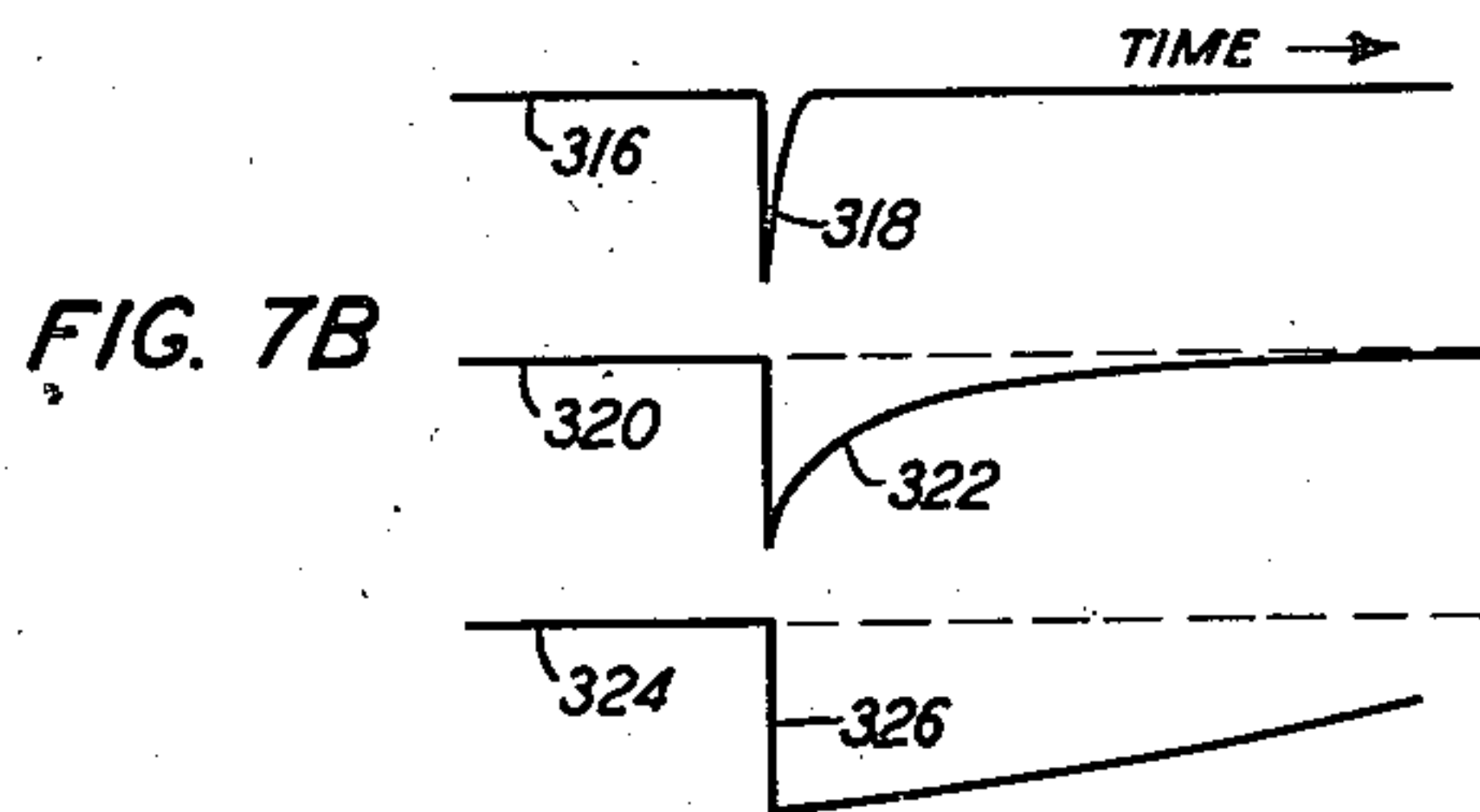
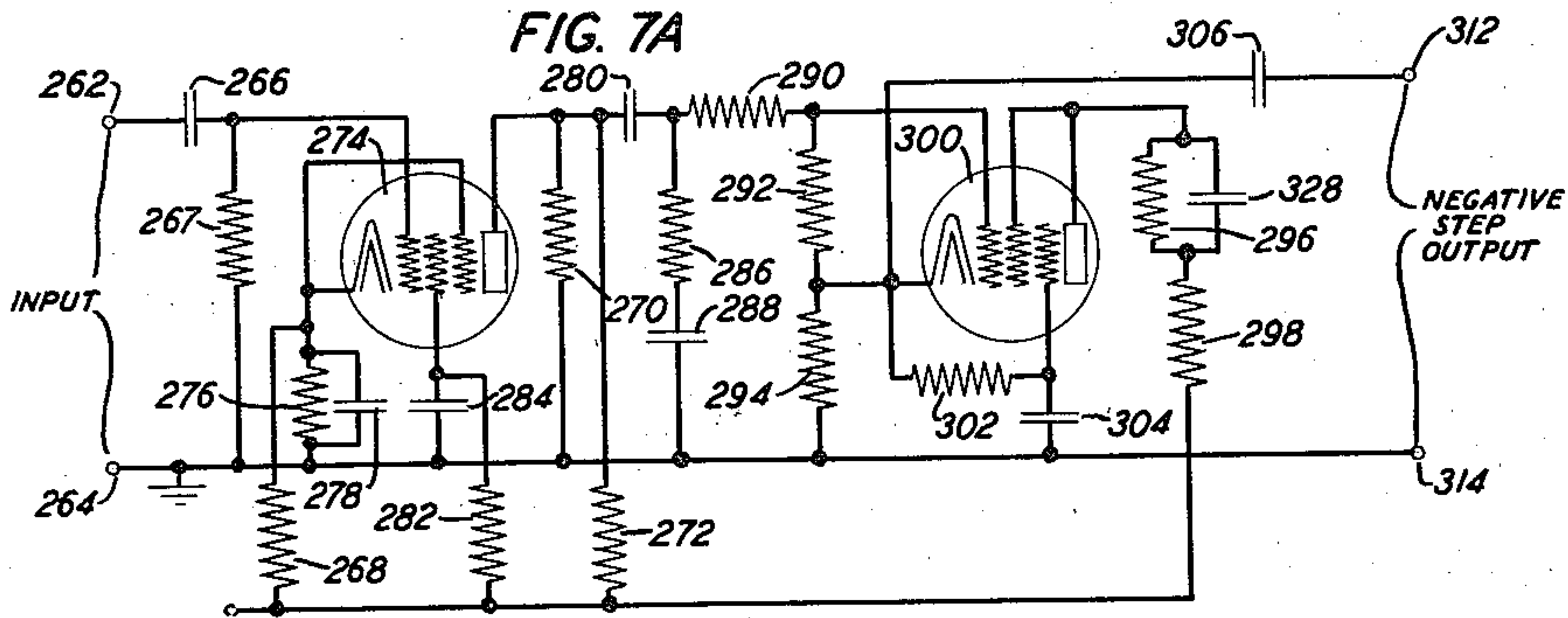
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APERIODIC PULSE TIMING SYSTEM

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4 Sheets-Sheet 4



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APERIODIC PULSE TIMING SYSTEM

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Application October 19, 1942, Serial No. 462,525

10 Claims. (Cl. 250—1.66)

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This invention relates to timing arrangements and more particularly to arrangements for precisely determining the reflection time of pulses in pulse reflection radio object locating systems. It is directed particularly to arrangements, commonly known as ranging units, which readily adapt themselves for use in that type of pulse reflection radio object locating system in which it may be desired to emit exploratory pulses at irregular or changing periodicities as distinguished from the more usual types of pulse reflection systems which employ a fixed or invariable and accurately determined pulsing rate. The arrangements of the invention can of course be employed in periodic as well as aperiodic systems.

Pulse reflection radio object locating systems are well known, in which pulses are emitted at regular accurately determined intervals from a highly directive antenna system, the antenna system being directed to explore an area so that the emitted energy will impinge upon objects, particularly ships, aircraft, obstacles, and the like, within the area and be reflected back to the point of observation, whereupon they are received and by determining the interval between the emission of pulses and the receipt of reflections thereof from a particular object the distance of the object from the observation point may be determined. It has been the customary practice to emit the exploratory pulses at regular accurately determined time intervals, the time intervals exceeding the time required for the reflections to return from objects at the maximum distance to be determined by the system, so that all reflections of interest will be received before the next succeeding pulse is emitted.

Such systems are usually open to the objections that their accuracy is impaired if the pulsing rate departs from its normal rate, that if it is desired to employ a number of such systems within a relatively limited area interference may be encountered, and that when used for military purposes the enemy may readily "jam" or cause interference with the indications obtained by them by directing pulses of the fixed periodicity toward the exploratory systems.

To avoid the above-mentioned difficulties the present invention provides systems in which the intervals between successive emitted pulses may, if desired, be varied within wide limits and at random without in the least diminishing the accuracy of the range or distance indications provided by the system. This is effected by employing, as a timing device, a resonant device, the device being shock-excited into vibration, or

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oscillation, by the same control impulse which simultaneously, or after a small time delay, causes the emission of an exploratory energy impulse from the directive transmitting antenna of the system. The ranging units of the invention then employ the regularly spaced oscillations of the resonant device as timing units and provide means for determining precisely the time, in terms of these oscillations, required for an emitted pulse to travel to a particular object and to be reflected back to the point of observation.

Naturally the timing oscillations must persist for a time interval equal to that required for reflections to be received from an object at the maximum range to be measured. Also a very short time interval for quenching the resonant device, i. e., for restoring it to a passive state, is required before the next successive shock-excitation is applied. These factors prescribe a maximum recurrence rate for the emission of exploratory pulses and any lesser rate down to that which will just produce satisfactory indications on the indicating mechanism employed can be used. Between the above-indicated limits the pulsing rate may be varied at will and if desired in any irregular or random manner without impairing the accuracy of the range indications.

Obviously, therefore, with systems employing the principles of this invention, no precise control of the pulsing rate of the transmitter is necessary, adjacent friendly systems may select pulsing rates which will produce a minimum of interference with each other and jamming by hostile pulsing systems can be rendered very difficult by employing a random variation of the pulsing rate.

An object of the invention is, therefore, to provide ranging units and methods for use with pulse-reflection object locating systems, which will provide precise range indications and at the same time permit substantial variations in the rate at which exploratory pulses are emitted.

A further object is to provide ranging units suitable for use in pulse-reflection object locating systems of variable pulsing rates.

Another object is to provide convenient means for readily minimizing interference between pulse-reflection object locating systems employed in a common area and to render it difficult for hostile systems in the area to jam such systems.

Other objects will become apparent during the course of the following description and in the appended claims.

The principles and features of the invention will be more readily understood from the follow-

ing detailed description of preferred forms of ranging units and apparatus therefor illustrated in the accompanying drawings, in which:

Fig. 1 shows in block-schematic diagram form a pulse-reflection type object locating system employing a ranging unit for determining the distance to objects from which reflections are received;

Fig. 2A illustrates, in block-schematic diagram form, one type of ranging unit of the invention;

Fig. 2B illustrates for a cycle of operation the wave forms and the time relations between them of the energy as it passes through the component apparatus elements of the unit of Fig. 2A;

Fig. 3A illustrates, in block-schematic diagram form, a second type of ranging unit of the invention;

Fig. 3B illustrates for a cycle of operations the wave forms and the time relations between them of the energy as it passes through the component apparatus elements of the unit of Fig. 3A;

Fig. 4A shows in electrical schematic form, a simple "start-stop" circuit, with cathode feedback and an LC oscillatory circuit associated therewith suitable for producing the shock-excited oscillatory waves employed for timing in systems of the invention;

Fig. 4B illustrates the wave forms and the time relations between them of the energy as it passes through the circuit of Fig. 4A;

Fig. 5A illustrates in electrical schematic diagram form a preferred type of phase shifter for use in ranging units of the invention;

Fig. 5B illustrates the relative phases of the energy on the four quadrant stators of the phase shifter of Fig. 5A;

Fig. 6A illustrates in electrical schematic diagram form a simple circuit for generating a "square-topped" pulse for use as a "pedestal" selector or unblocking pulse in units of the invention;

Fig. 6B illustrates the wave forms and the time relations between them of the energy at various points in the circuit of Fig. 6A;

Fig. 7A shows in schematic diagram form a suitable step generating circuit for systems of the invention;

Fig. 7B illustrates the formation of the step voltage in the circuit of Fig. 7A;

Fig. 8A shows in schematic diagram form a timing circuit providing an unblocking impulse for systems of the invention; and

Fig. 8B illustrates the operation of the circuit of Fig. 8A.

In more detail in the pulse-reflection object locating system of Fig. 1, adjustable oscillator 10 provides, for example, a sine wave, the frequency of which may be varied over a wide range, the highest frequency being such that a single cycle is completed within a time interval slightly greater than that required for a radio wave to travel twice the distance to an object at the maximum range of the system.

Energy from oscillator 10 is applied to pulse generator 14, the pulses of which energize transmitting oscillator 16. Pulse generator 14 provides a sharp squared-top positive pulse at a particular point of each cycle of the sine wave supplied to it. These pulses are preferably of from 1 to 5 microseconds in duration and key the transmitting oscillator 16 which, thereupon, furnishes like pulses of high power to antenna 18, the latter serving to radiate corresponding pulses 19 of radio wave energy. Antenna 18 is usually directive so that the direction in which it is pointed

for maximum amplitude of reflection from a particular object will serve to indicate the direction of the object.

Reflections 33 of the emitted pulses 19 are received on antenna 32 which is preferably sufficiently directive to discriminate effectively against the direct transmission of energy from antenna 18. Alternatively, a single antenna can be employed for both transmitting and receiving, and a suitable duplexing arrangement is then employed to isolate the transmitter and receiver of the system from each other in accordance with principles well known in the art. The reflections 33 are detected and amplified in receiver 30 and when switch 13 is closed they are applied to the vertical deflecting plates of cathode ray oscilloscope 28.

The sine wave provided by oscillator 10 is also applied to a second pulse generator 20 which provides a positive pulse for each cycle of the sine wave substantially as does the pulse generator 14. Pulse generators 14 and 20 may preferably be of the non-linear inductance type well known to the art as exemplified, for example, in United States Patent 2,117,752, issued May 17, 1938, to L. R. Wrathall.

The pulses of generator 20 are supplied to range unit 22 and to full scale sweep circuit 26 as indicated. Sweep circuit 26 is preferably of the conventional saw-tooth wave type, its wave being synchronized with, or keyed by, the pulses provided to it as above described, and serves to deflect the ray across the scale at a uniform rate such that it reaches full scale deflection at the maximum time to be measured. When it is employed and receiver switch 13 is closed, all reflected pulses appear as vertical deflections distributed along the horizontal sweep at distances from the left proportional to the distances to their respective reflecting objects. A calibrated scale can be associated with the cathode ray screen to facilitate estimates of the distances of objects from which reflections are received.

Ranging unit 22 provides a range mark which is precisely timed and adjustable in time with respect to the pulse reaching it from generator 20. Preferred forms which ranging unit 22 may take and their principles of operation are illustrated in Figs. 2A, 2B, 3A and 3B and will be described in detail hereunder.

The precisely timed range mark provided by ranging unit 22 is, when switch 11 is closed, also supplied to the vertical deflecting plates of cathode ray oscilloscope 28. The reflection time or distance of any reflected pulse received by the system may be determined by adjusting ranging unit 22 to align the precisely timed range mark with the received pulse whereupon the adjustment of the ranging unit 22 required is a measure of the time or distance.

By means of switch 25 either full scale sweep circuit 26 or precision sweep circuit 24 may be connected to the horizontal deflecting plates of cathode ray oscilloscope 28.

When the precision sweep circuit 24 is employed, a small portion of the total range on each side of and including the precisely timed range mark of ranging unit 22 is selected and expanded to substantially cover the entire width of the target of the oscilloscope 28 so that ranges of particular interest centered about the range mark may be examined in detail and the range mark may be more accurately aligned with a particular received reflected pulse.

In Fig. 2A there is shown in schematic block

diagram form within the rectangle 38, one preferred embodiment of a unit which can be employed as the ranging unit 22 of Fig. 1. Unit 38 is connected to the output of a starting impulse source 21 which can, for example, be the pulse generator 20 of Fig. 1. In the description of the circuit of Fig. 2A, frequent reference will be made to the curves of Fig. 2B which indicate the forms taken by the energy at various points in passing through the circuit of Fig. 2A.

The starting impulse source 21 provides a series of pulses 72, as indicated in curve *a* of Fig. 2B. The time interval between the successive pulses 72 exceeds the maximum time to be measured, designated t_{max} in Fig. 2B, sufficiently to permit at least adequate time for quenching the circuit so that it will be restored to a quiescent state before the next starting impulse occurs at time t'_0 .

Apparatus unit 40 is, as labeled, an oscillation starter and quenching time circuit and may have timing wave 74 as shown in curve *b* of Fig. 2B, although a wave approximating as closely as practicable the more abruptly changing wave 76 is preferable if it can be conveniently realized. Apparatus unit 40 will be referred to as a "start-stop" circuit because its effect upon the precise oscillator 42 and the low frequency oscillator 64, respectively, is that of starting and stopping the oscillations. A preferred and simple form of start-stop circuit associated with an oscillator is shown in detail in Fig. 4A and will be described at length in connection with that figure, hereinafter.

The precise oscillator 42 can, for example, preferably consist of a stable, or stabilized, LC circuit comprising a coil and condenser connected in parallel. The precision of time measurement is, as will presently become apparent, dependent upon the accuracy of the oscillator frequency and consequently a dependable oscillator with stable frequency is required.

An LC circuit may be started oscillating by a sudden discontinuity or impulse in the current flowing in the coil. This results instantaneously in a damped train of waves, the degree of damping depending primarily upon the "Q," or electrical efficiency, of the LC circuit.

With many coils and condensers readily available and well-known in the art, damping is not a severe limitation for the majority of applications since it has no effect upon the precision of the measurements but only moderately limits the maximum range in time between t_0 and t_{max} which can be employed. However, the limiting effect of damping can be entirely eliminated by the addition of positive feedback as indicated in Fig. 2A where the output of the oscillator 42 passes through amplifier 46 and a portion of the amplifier output is returned to the oscillator through feedback circuit 44.

The resulting wave train 78 of curve *c*, Fig. 2B, is consequently shown without appreciable damping. It is, furthermore, shown with very few cycles to avoid undue confusion in the illustration, though it is to be understood that in actual practice for high precision systems, the precise oscillator will provide a very large number of cycles during the time interval between t_0 and t_{max} . For high precision, LC circuits having free oscillation frequencies of 100,000 or more cycles per second can readily be used.

The oscillation, of course, starts at the time t_0 and proceeds until the time t_{max} when it is quenched by restoration of the circuit to its quiescent state by the "start-stop" circuit a pre-

ferred embodiment of which will as above-mentioned be described in detail below, in connection with Fig. 4A.

In place of an LC circuit, a quartz crystal, a magnetostrictive oscillator or any of numerous other forms of stable and efficient oscillators well known to the art and susceptible to shock-excitation and rapid quenching may obviously be employed to provide a suitable timing wave.

The main portion of the output of amplifier 46 is passed through the continuous phase shifter 48 which may be similar to the types described in United States Patents 2,004,613, issued June 11, 1935, to L. A. Meacham, and 2,147,728 issued February 21, 1939, to W. T. Wintringham.

Phase shifter 48 is continuously adjustable throughout a full 360 degrees and will provide any desired discrete phase shift such as that indicated by wave 80 of curve *d*, Fig. 2B (or any other phase relation with respect to the waves or curve *c*, Fig. 2B).

The phase shifter circuit must be designed to be capable of a quick rise to a stable "steady state" condition. A form particularly well suited for the purposes of this invention, is shown in detail in Fig. 5A and will be discussed at length hereinafter.

A control crank 52 on a shaft 50 provides for manual adjustment of the phase shift of phase shifter 48. The right end of shaft 50 is coupled by gears 54 to the shaft of a second adjustable phase shifter 68, for reasons which will presently become apparent.

The output of phase shifter 48 passes through pulse generator 58 and generates, as indicated by curve *e* of Fig. 2B, a series of sharp pulses, the positive pulses being designated by the numeral 82 and the negative pulses being designated by the numeral 84. These pulses are precisely spaced in time as they are derived from the sine wave output of the phase shifter 48 and can be made to move to any position within the limits of t_0 and t_{max} by adjusting the phase shifter.

Any one of these pulses may be used as a fiducial mark, and a problem involved in the design of suitable ranging units of the invention is the segregation of one of these pulses from all the rest. This segregation may be accomplished in several ways, one of which will be described in connection with Fig. 2A and another in connection with Fig. 3A of the accompanying drawings.

In the arrangement of Fig. 2A, the process of segregating one of the precision pulses from the rest is accomplished by employing the oscillator starter and quenching timer 40, previously mentioned, to operate, simultaneously with oscillator 42, a second shock excited but low frequency oscillator 64, the output of which latter oscillator is a simple sine wave 86 of curve *g* of Fig. 2B. The output of oscillator 64 is amplified by amplifier 66 and then passed through phase shifter 68 to pedestal generator 70 where it triggers the generation of a pedestal pulse 90 shown in curve *j* of Fig. 2B.

By the adjustment of phase shifter 68, the wave 88 of curve *i* of Fig. 2B is adjusted in phase with respect to curve 86 of curve *g* of Fig. 2B and thus the pedestal 90 can be moved smoothly over the complete range from the time t_0 to t_{max} .

As noted above, phase shifter 68 is geared to phase shifter 48, the gear ratio being such that the phase shifter 48 turns faster than the phase shifter 68 in proportion to the ratio of the respective frequencies of the waves passing through

them. By this arrangement one of the precision pulses of pulse generator 58 is centered on the pedestal 90 of pedestal generator 70 and may be adjusted to any position within the complete range. This is illustrated by the addition, as curve k_1 , of the curves e and j of Fig. 2B which results in one pulse 92 being placed upon the pedestal 90 and thus projecting higher than any of the others whereby it can readily be separated, for example, by passing the combination through a properly biased vacuum tube amplifier, the result being the selection of a single pulse 94 as shown in curve k of Fig. 2B. This resulting isolated precision pulse can, as previously mentioned, be caused to occur at any time between t_0 and $t_{\max}$ by appropriately adjusting the geared phase shifters 48 and 68.

The selected pulse may be employed directly as a fiducial mark or it may be applied to a separate fiducial mark generator 60 to produce some special form of fiducial mark such as the step 96 of curve l of Fig. 2B. A preferred form of circuit for generator 60 is shown in schematic diagram form in Fig. 7A and will be described in detail in connection with that figure.

In Fig. 3A, a second preferred embodiment, or form, which the ranging unit 22 of Fig. 1 may take for the purposes of this invention, is indicated in schematic block diagram form within rectangle 101 and is actuated as for the arrangement of Fig. 2A by impulses from a starting impulse source 21, precisely as for the arrangement of Fig. 2A. In Fig. 3B wave form curves illustrating the sequence of events in passing through the units of the arrangement of Fig. 3A are given.

In the arrangement of Fig. 3A, a starting and stopping timer circuit 100 is employed and may be similar to timer 40 of Fig. 2A. On the left side of the circuit, a precise oscillator 102, an amplifier 106, a feedback circuit 104, a continuous phase shifter 108, a pulse generator 118 and a fiducial mark generator 120 are provided as for the arrangement of Fig. 2A and for substantially identical respective purposes.

On the right side of the circuit of Fig. 3A, however, the pedestal pulse is triggered by a resistance capacitance delay device 122, the characteristic of which for a particular adjustment is indicated by wave 144 of curve f of Fig. 3B. The slope of curve 144 can be adjusted by changing either the capacity or the resistance of the circuit 122. A preferred form for circuit 122 is shown in schematic diagram form in Fig. 8A and described in detail hereunder in connection with that figure.

When the start-stop circuit 100 starts the precise oscillator 102, it also starts the timing condenser 358 of Fig. 8A in circuit 122 discharging through the timing resistance 360 of Fig. 8A in circuit 122 and when the potential across the condenser is reduced to a certain predetermined fraction of its initial potential, it causes a pedestal to be generated by the pedestal generator 124 as will be described in detail hereinunder. The time required to discharge to this point is directly proportional to the product of the above-mentioned resistance and capacity. Varying either of these, therefore, shifts the position of the pedestal linearly in time so that either one can be geared to the phase shifter 108 through shaft 116, gears 114 and shaft 110 so that the pedestal 146 of curve g of Fig. 3B may be made to occur simultaneously with any one of the precisely timed pulses 136 of curve h . The resistance variation obtainable in standard apparatus

parts makes the resistor the more suitable element to vary in present applications. Details of circuit 122 will be readily understood from the detailed description of Fig. 8A given hereunder.

The precisely timed pulses from generator 118 and the pedestal pulse from generator 124 are combined, as for the system of Fig. 2A, and passed through the fiducial mark generator 120, which can be of the same type as generator 60 of Fig. 2A.

In an object locating system such as that illustrated in Fig. 1 to which the principles discussed above are to be directly applied, distances are determined by measuring echo travel time. The "on" time $t_{\max}$ of the stable oscillator is related to the maximum distance $D_{\max}$, to which measurements are to be made, by the following formula:

$$t_{\max} = \frac{2D_{\max}}{C} \quad (1)$$

where

C =velocity of propagation of radio waves=327,799,000 yards per second.

The precision of distance measurement is related to the frequency of the precise high frequency oscillators and the precision of the phase shifter by the following formula:

$$f = \frac{C\Delta\theta}{4\pi\delta} \quad (2)$$

where

f =frequency of stable oscillator in cycles per second,

$\Delta\theta$ =smallest dependable phase measurement in radians.

δ =smallest distance measurement desired.

The distance d covered by one turn of the phase shifter is then

$$d = \frac{C}{2f} \quad (3)$$

As previously noted, the combination of a simple start-stop circuit and high frequency precision LC oscillator suitable for use in ranging units of the invention is shown in schematic diagram form in Fig. 4A and in Fig. 4B wave forms illustrative of the operation of the circuit of Fig. 4A are given.

The circuit of Fig. 4A operates from a positive pulse applied to the input terminals 161 and provides instantaneous starting and rapid quenching. With an experimental circuit of this type, it was found possible to quench a 100 kilocycle oscillation in approximately 1 cycle, or 10 microseconds.

Oscillation is started by the input pulse applied to terminals 161 cutting off the plate current of the vacuum tube 160 by imposing the initial negative potential across condenser 162 on the first or control grid of the tube, i. e., the grid nearest the cathode, and is quenched again when the grid potential leaks off condenser 162 through resistance 164 to permit the potential on this grid to return to the cut-off point. The "on" time is proportional to the product RC_1 , where R is the resistance 164 and C_1 is condenser 162, and the frequency of oscillation is dependent upon the inductance L of coil 178 and the capacity C_2 of condenser 180. Feedback is provided through coil 176, which inductively couples the cathode of the following tube 165 with the coil 178 of the LC circuit in the plate circuit of the tube 160. The potential source to supply plate

voltage is connected across terminals 166 and 168. Condensers 170 and 174 prevent interaction of the screen or intermediate grid and plate impulses of tube 160, and resistance 172 affords a control of the amplitude of oscillation. Condenser 182 prevents direct current of the plate potential supply source of tube 160 from appearing on the first or control grid of tube 165, i. e. the grid nearest the cathode. Tube 165 and its associated circuit elements 163, 167, 169, 171 comprise an amplifier of conventional design. The first or control grid of tube 165 is biased sufficiently negative by battery connection to terminals 173 and 175 to assure that the voltage swings appearing on it from coil 178 will never drive it positive into the conductive region.

In Fig. 4B, the input pulse 184 is, as previously stated, positive and occurs across input terminals 161 at the starting time t_0 . The grid voltage e_g occurring on the first grid of tube 160 is indicated by wave 186, representing the charging time of condenser 162 through resistance 164, and is next shown. Curve 188 indicates the sudden drop in plate current I_p to substantially zero when the starting impulse 184 is applied at the time t_0 and the recovery to normal value of plate circuit current at the time t_{max} when the curve 186 relating to the first or control grid voltage of tube 160 reaches a predetermined critical value.

The output wave with feedback is indicated by curve 190 and the effect of damping, which effect is eliminated by the use of feedback, is indicated by comparison of the undamped curve 190 with the damped curve 192 which would obtain with no feedback.

In Fig. 5A, a continuous phase shifter circuit of the general type described in the above-mentioned patents, 2,004,613, to L. A. Meacham and 2,147,728 to W. T. Wintringham, is indicated. For this particular use, however, the phase shifter circuit must be designed to be capable of a quick rise to a "steady state" condition.

The particular circuit shown in Fig. 5A employs a quadrant-plate type of condenser having a single set of eccentrically mounted circular rotor plates 212 and four sets of stator plates of quadrant shape, the four sets of quadrant stator plates each being designated by the numeral 210. The set of rotor plates 212 is connected to terminal 218 by conductor 215. Input terminals 200 and 204 are balanced to ground on terminal 202 as indicated and capacities 206 and 216 and resistances 208 and 214 serve to provide potentials in proper quadrature relationship at points c and d which are connected to stator plates 210. Curves 222, 224, 226 and 228 of Fig. 5B show the relative phases on the four sets of stator quadrant plates 210 and illustrate the absence of a transient effect upon the sudden application of an input voltage.

In Fig. 6A a circuit suitable for use as a pedestal generator in the arrangements of Figs. 2A and 3A is illustrated and comprises a series condenser 232 in the input lead, a shunt resistance 234 across the input grid circuit of pentode vacuum tube 236 and a screen grid potential supply circuit comprising resistance 244 and condenser 240, and a plate lead resistor 238 and supply capacity 242. A pulse 230 furnished by a source 260 to input terminals a as indicated by curve a of Fig. 6B results in a voltage wave 252 as shown in curve b of Fig. 6B across resistance 234 in the control grid circuit of pentode 236. This results in the generation across terminals 246 and 248 of a square pulse 254 as shown in curve c of Fig. 6B.

In Fig. 7A the circuit of a preferred form of step generator is shown in schematic diagram form. This circuit is designed to respond to a sharp precisely timed pulse, such as pulse 94 or 150 provided by the ranging circuits of Figs. 2A and 3A respectively, as described in detail above, here represented by pulse 318 of Fig. 7B, and provides a step-shaped pulse such as is represented by curve 324 of Fig. 7B, a portion of which curve, more particularly the "step" 326, is precisely placed and sharply defined so that alignment with respect to a received reflected pulse in a pulse reflection object locating system may be readily effected with a high degree of precision. Pulse 318 is inverted and may be conveniently derived from pulse 94 or 150 above-mentioned, by drawing energy from a "cathode follower" circuit in a manner well known and frequently employed in the art.

In Fig. 7A terminals 262, 264 connect to the series condenser 266 and the shunt resistance 267, the time constant of which provides a broadening effect 322 upon pulse 318, similar to that illustrated in curve 320 of Fig. 7B. This results from the fact that the voltage across resistance 267 appears in the control grid-cathode circuit of pentode 274. Curve 320 is the voltage appearing in the plate circuit of pentode 274 and is in turn impressed upon the control grid-cathode circuit of pentode 300 and the broadening process is repeated so that in the plate circuit of pentode 300 the desired step-shaped pulse represented by curve 324 of Fig. 7B is obtained. The step output whose form is as shown in curve 324 above-mentioned may be obtained across the terminals 312, 314.

In Fig. 8A a preferred embodiment of the RC delay circuit 122 of Fig. 3A is shown in schematic diagram form. A sharp pulse such as 350 is impressed upon the input terminals 352, 354. The operation of the circuit is as follows:

Vacuum tube 362 contains two diode rectifiers through which condensers 356 and 358 are charged to the peak potential of pulse 350. The discharge path for condenser 356 is given a fixed long time constant by making resistances 364 and 366 large. The time constant should be long enough that an inappreciable loss of charge occurs during one normal operational cycle. Curve 378 of Fig. 8B illustrates this effect, the amplitude 376 from zero line 375 being substantially equal to that of the original pulse 350.

The discharge path for condenser 358 however is through variable resistance or potentiometer 360 having a control member 359 so the rate of discharge is adjustable. Curve 372 shows the rate of discharge for one particular setting of resistor 360 and illustrates its return to the zero line 371 in a relatively shorter time. On the output, terminal 368 is normally positive relative to 370 until pulse 350 occurs whence the potential of 368 drops to a negative value relative to terminal 370 as indicated in curve 382 the proportionality of potentials above and below the zero line 380 being determined by resistors 364 and 366. For the particular setting of variable resistance 360 the output potential passes through zero line 380 in time T (384). For any other setting of resistance 360 the time of passing through zero would be different as it is directly proportional to resistance 360 and capacitance 358.

From the above it is clear that the output voltage across terminals 368, 370 passes through zero when condenser 358 discharges through the effective portion of potentiometer 360 to half

value and that the time interval between the impressing of pulse 350 upon the input terminals 352, 354 and recovery to zero is directly proportional to the product of the capacity of condenser 358 and the portion of potentiometer 360, which is effective in the circuit. The control of the potentiometer 360 can therefore be connected through shafts 116 and 110 and gears 114 to phase shifter 108 of Fig. 3A and the pedestal pulse 146 of curve *g* of Fig. 3B may be synchronized with any particular one of the precisely timed pulses 136, such as 148, for example, so that it may operate the fiducial mark generator 120 as described above.

The above embodiments illustrate preferred applications of the principles of the invention. They are, however, representative only and numerous similar and equivalent arrangements may readily be devised by those skilled in the art in the light of the teachings of this specification. The scope of the invention is defined in the following claims.

What is claimed is:

1. In a pulse reflection distance determining system, a timing arrangement comprising the combination of an oscillatory device adapted for shock excitation and substantial instantaneous quenching and providing a high frequency electrical wave upon excitation, a first electrical circuit cooperatively coupled with said oscillatory device to provide shock excitation of said device at instants intimately associated with the beginnings of the time interval to be measured and allowing said excitation to continue throughout intervals exceeding the longest time intervals to be measured and to quench said device following each excitation after an interval which also exceeds the longest time intervals to be measured but is less than the interval between successive shock excitations, a second electrical circuit cooperatively coupled with the oscillatory device to produce a sharp positive pulse at a predetermined point in each cycle of the wave generated by the oscillatory device, an output device normally unresponsive to the pulses generated by said second circuit, a third electrical circuit cooperatively connected with said first and said second circuits and said output device, said third circuit providing said output device with a positive impulse which when combined with a particular positive pulse from said second circuit renders said output device responsive to pass said particular pulse only, and adjustable electrical timing devices in said second and said third circuits respectively, said timing devices being mechanically interconnected for simultaneous adjustment whereby the impulse of said third circuit can be adjusted to be coincident in time with any one of the pulses generated in said second circuit.

2. In a time interval measuring system, the combination of a high frequency oscillatory device adapted to be electrically shock excited into oscillation and rapidly quenched, and a control pulse operated electrical timing circuit cooperatively connected to said device, said circuit including a timing portion having a time constant substantially exceeding in duration the period of the control pulse, said circuit providing to said device an electrical shock excitation upon the receipt of an electrical control pulse by said circuit, said circuit automatically quenching said oscillatory device by electrically short-circuiting the same at a predetermined time interval thereafter.

3. In a time interval measuring system, the combination of a high frequency oscillation gen-

erator adapted to be shock excited into oscillation and rapidly quenched, said generator providing upon excitation an oscillatory electrical wave of a substantially constant high frequency, a continuously adjustable phase shifting electrical network electrically connected to the electrical output circuit of said oscillation generator, a pulse generator electrically connected to the output of said adjustable phase shifting network and adapted to produce a sharp impulse at a particular point of each cycle of the high frequency wave, a first electrical circuit connected to said pulse generator and normally non-responsive to the pulses therefrom, a second electrical circuit connected to said first circuit and providing impulses which render said first circuit responsive to pulses from said pulse generator, said second circuit including an adjustable electrical timing circuit controlling the timing of the impulses of said second circuit, and a mechanical linkage coupling the adjustment mechanisms of said phase shifter and said electrical timing circuit whereby particular pulses of said pulse generator will be translated through said first circuit and may be employed to produce fiducial marks of accurately known time relation with respect to the instant of shock excitation of said high frequency generator, said combination further including a start-stop circuit responsive to electrical pulses and electrically connected to said high frequency generator and said second circuit to shock excite said high frequency generator and to quench it after a predetermined interval and to energize said second circuit to initiate the formation process of an impulse by said second circuit.

4. In a time interval measuring system, the combination of a high frequency oscillation circuit adapted for shock excitation and substantially instantaneous quenching, means for shock exciting said oscillation circuit, a continuously adjustable phase shifting circuit connected to the output of said oscillation circuit, a pulse generator connected to the output of said phase shifting circuit, means for segregating a particular one of the pulses generated by said pulse generator, and means for instantaneously quenching said oscillation circuit to restore it to a quiescent state.

5. The combination of claim 4, said pulse selecting means including a timing circuit continuously adjustable over the interval of oscillation of the oscillation circuit, and a mechanical linkage coupling said adjustable timing circuit with the adjustable phase shifting circuit of claim 4 whereby the segregation of a pulse can be effected at any point of time within the interval of oscillation of the oscillation circuit.

6. In a pulse reflection object locating system a timing circuit for facilitating the determination of the reflection time of pulses, comprising an oscillatory low-loss tuned circuit, a control circuit adapted and connected to suddenly vary the current flow through said oscillatory circuit to produce free oscillation thereof, a circuit connected to said oscillatory circuit, providing precisely timed pulses from the oscillatory wave resulting from the free oscillation of said tuned circuit, an auxiliary circuit providing a pedestal pulse at a subharmonic frequency of the free period of oscillation of said tuned circuit, a phase shifter in the circuit of the precisely timed impulses, a second phase shifter in the auxiliary circuit providing the pedestal pulse, reduction gears coupling said two phase shifters whereby

the pedestal pulse is shifted in phase only in proportion to the inverse of the harmonic ratio with respect to the phase shift imparted to said precisely timed pulses and a particular one of the series of precisely timed pulses is selected as a fiducial mark by combining the particular precise pulse with the pedestal pulse and passing the combined wave through a vacuum tube amplifier biased to exclude pulses which have not been combined with the pedestal.

7. In a distance measuring system of the type in which energy pulses are aperiodically emitted, reflections thereof are received, and the time interval between the emission of pulses and the receipt of reflections of said pulses from a particular object is determined by synchronizing therewith auxiliary pulses derived from the control source of the emitted pulses the synchronization being effected by appropriately shifting the time base of the said auxiliary pulses, the method of obtaining auxiliary pulses of like aperiodicity and of increasing the accuracy with which the time base adjustment of the auxiliary pulses can be determined which comprises deriving from the control source of the emitted pulses a like series of pulses, shock exciting thereby into free oscillation, a precision low-loss oscillatory device, the free oscillation period of which is extremely short with respect to the average interval between the pulses derived from the control source, obtaining simultaneously a relatively low frequency cyclic wave having a period of substantially the same order as the average interpulse period of the pulses of said control source, simultaneously shifting the phases of the wave from the shock excited high frequency source and the low frequency source, the phase shift imparted to the first said wave being always greater than that imparted to the second said wave by the ratio of their respective periodicities, deriving from the high frequency oscillation a series of precisely timed sharp pulses, deriving from the low frequency cyclic wave a pedestal pulse at a particular selectable point in said low frequency wave, the width of the pedestal pulse being less than the separation between consecutive high frequency pulses obtained from said high frequency oscillation source, combining the high frequency pulses with the pedestal pulse, selecting only that high frequency pulse which is coexistent in time with the pedestal pulse and employing the pulse so selected as a fiducial mark or timing pulse, and quenching both the said high frequency oscillatory device and said low frequency cyclic wave to reestablish a quiescent state, prior to the occurrence of the next successive pulse derived from the control source.

8. In a pulse-reflection object locating system of the type in which pulses of wave energy are emitted from an observation point to impinge upon objects within a particular region, reflections of said pulses from objects within said region are received at said observation point, and the distances from said point to the objects from which reflections are received are determined by measuring the time intervals required for pulses to be transmitted to and reflected back from said objects, respectively, the measurements being effected by synchronizing with the reflected pulses, auxiliary pulses derived in known time relation with respect to the emitted pulses and delayed in time until the said synchronous relation with particular received reflected pulses has been established, the method of deriving accurately timed and readily controllable auxiliary

timing pulses which comprises shock exciting into free oscillation in known time relation with respect to the emitted pulse a high frequency low-loss oscillator, deriving a first sine wave therefrom, simultaneously shock exciting into free oscillation, a lower frequency low-loss oscillator having a period approximately commensurable with the average interpulse interval between transmitted pulses and deriving a second sine wave therefrom, shifting the phases of said first and said second sine waves respectively, constraining the phase shift of said first wave to vary with that of said second wave in proportion to the frequency ratio of said high to said lower frequency waves, deriving a series of sharp pulses from said phase-shifted high frequency sine wave, deriving a pedestal pulse from said phase-shifted lower frequency wave, combining the said sharp pulses and the said pedestal pulse, selecting the sharp pulse which coincides in time with said pedestal pulse and adjusting the said phase shifts until the selected sharp pulse coincides in time with a particular received reflected pulse and quenching both said oscillators prior to the emission of the next successive pulse, whereby the reflection time interval for said particular received reflected pulse can be accurately determined.

9. In a pulse-reflection type of object detecting system, which includes a source of energy pulses, the pulses from said source occurring aperiodically, the interval between any two successive pulses being in excess of a predetermined minimum time interval, a timing circuit providing an auxiliary pulse occurring an accurately determinable adjustable time interval after each pulse from said source, said timing circuit comprising a high frequency low-loss oscillatory device capable of shock-excitation into free oscillation and rapid quenching, an exciting and quenching circuit interconnected between said source of energy pulses and said oscillatory device, said last stated circuit shock exciting said oscillatory device upon the receipt of an impulse from said source and quenching it within the said predetermined minimum time interval, a low frequency low-loss oscillatory device capable of shock excitation into free oscillation and rapid quenching the period of oscillation of said latter device being of the same order of magnitude as said predetermined minimum time interval, the said exciting and quenching circuit being interconnected between said source of energy pulses and said low frequency oscillatory device, said last stated circuit shock exciting said last stated device upon receipt of an impulse from said source and quenching it within said predetermined minimum time interval, said oscillatory devices providing, when oscillating, high frequency and low frequency sine waves, respectively, a first accurately calibrated continuously adjustable phase shifter connected to the output of said high frequency oscillatory device, a second like phase shifter connected to the output of said low frequency oscillatory device, a mechanical linkage coupling the adjustment mechanisms of said two phase shifters, said linkage reducing the adjustment imparted to the mechanism of the said second phase shifter by the frequency ratio of the high to the low frequency in actuating the adjustment mechanism of the said first phase shifter, a pulse generator operated by the high frequency wave output of said first phase shifter producing a series of sharp accurately timed pulses, a pedestal generator

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operated by the low frequency wave output of said second phase shifter producing a pedestal pulse at a predetermined location with respect to said phase shifted low frequency wave and a fiducial mark generator operated by the combined outputs of said pulse generator and said pedestal generator to produce a precisely timed fiducial mark or impulse.

10. A circuit for accurately timing the receipt of reflections of aperiodically recurrent emitted energy pulses comprising a high frequency low-loss oscillatory sine wave generator, a start-stop device operatively connecting to said generator to instantaneously excite said generator into oscillation and to quench its oscillations abruptly at the end of a predetermined time interval, said time interval being at least equal to the maximum reflection time to be measured, a continuously adjustable phase shifter operatively connecting to the output of said sine wave generator, a pulse generator operatively connected to the output of said phase shifter, a pedestal pulse generator, a control circuit for said last-mentioned generator adjustable to operate said pedestal pulse generator at any time within the start-

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stop interval defined by said start-stop circuit and operatively connecting thereto, a coupling mechanism coupling the adjustment mechanism of said last stated control circuit with the adjustment mechanism of said continuously adjustable phase shifter, the coupling mechanism constraining adjustment of said pedestal pulse to correspond in time delay with the phase adjustment of said sine wave by said phase shifter and a fiducial mark generator operatively connected with the combined outputs of said pulse and said pedestal generators to produce a fiducial mark precisely timed with respect to the beginning of the interval of operation of said start-stop circuit.

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