

July 22, 1958

F. WEST

2,844,668

PULSE SERIES ANALYZER

Filed Jan. 7, 1955

4 Sheets-Sheet 1

FIG. 1

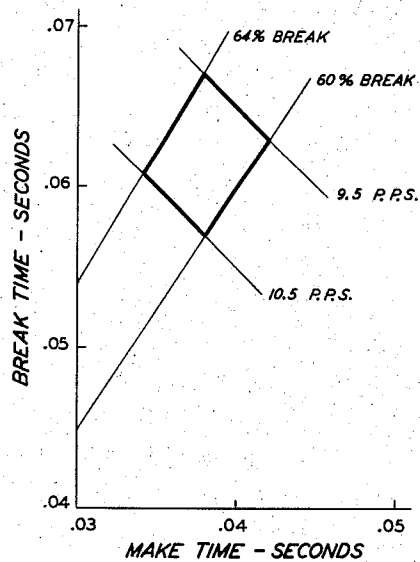


FIG. 1A.

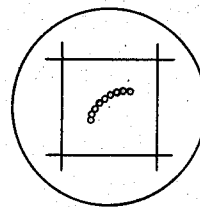
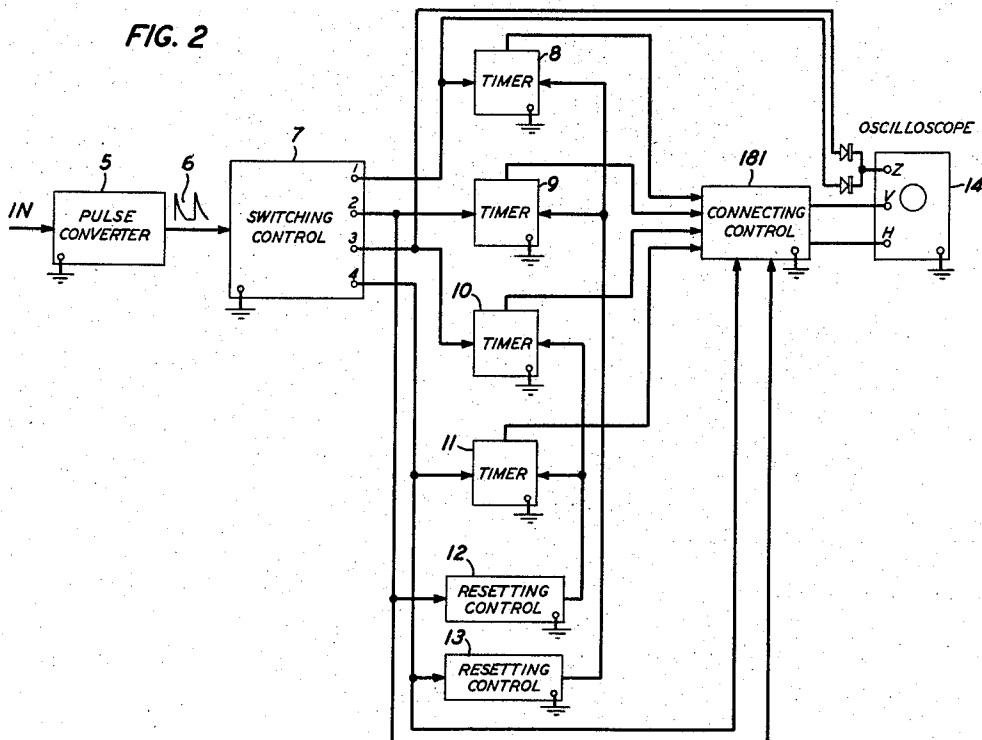


FIG. 2



INVENTOR
F. WEST
BY
g. H. Hupdt.
ATTORNEY

July 22, 1958

F. WEST

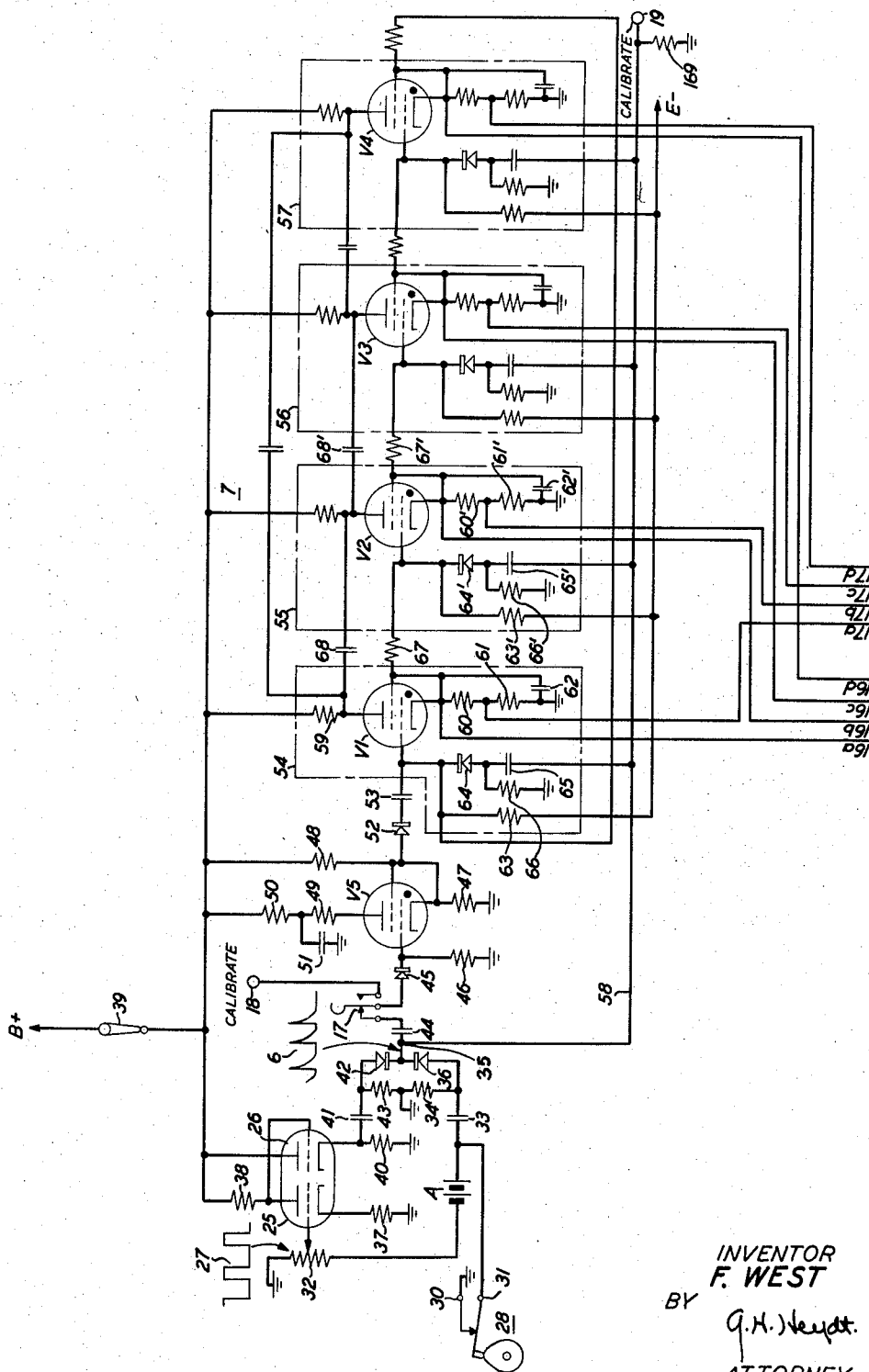
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FIG. 3



INVENTOR
F. WEST
BY
G. H. Heydt.
ATTORNEY

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F. WEST

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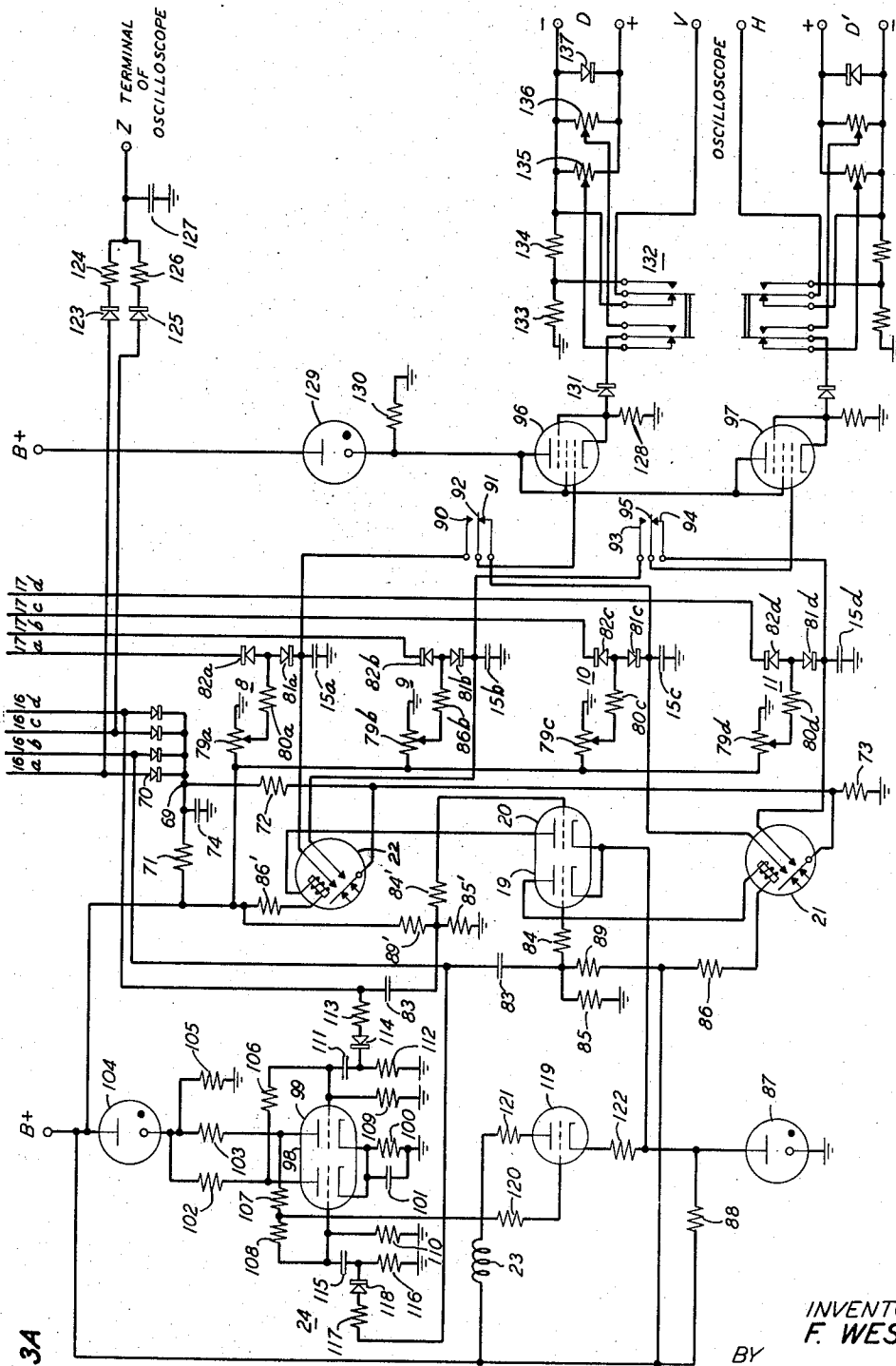


FIG. 3A

INVENTOR
F. WEST
BY
G. H. Hupelt
ATTORNEY

July 22, 1958

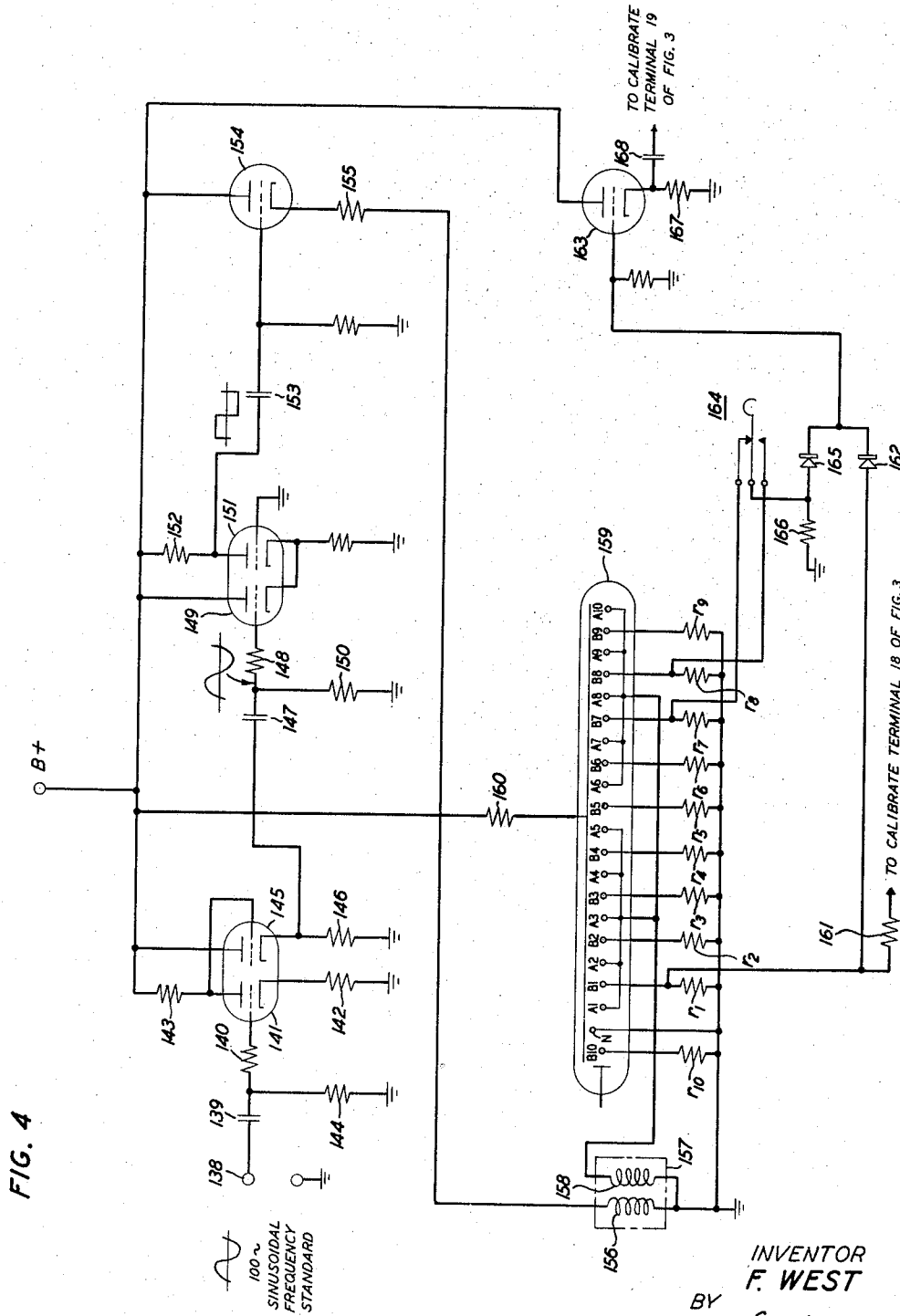
F. WEST

2,844,668

PULSE SERIES ANALYZER

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4 Sheets-Sheet 4



INVENTOR
F. WEST
BY
G. K. Heydt.
ATTORNEY

2,844,668

PULSE SERIES ANALYZER

Fred West, Chatham, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 7, 1955, Serial No. 480,384

7 Claims. (Cl. 179—175.2)

This invention pertains to pulse analysis, and more particularly to display of the duration of each portion of each pulse in a train of pulses.

In automatic telephone systems the actuation of the switching equipment for connecting the calling and called subscribers is produced by a successive series of pulse trains which are characteristic of the called subscriber's telephone number. The pulse generating source is usually a dial which repetitively makes and breaks a set of pulsing contacts as it runs down to starting position from the position to which it was rotated when dialed. The repetitive making and breaking of the pulsing contacts repetitively opens and closes a direct-current circuit, thereby producing a train of voltage pulses which are square in shape. A complete rotation of the dial produces ten pulses. The duration of each pulse equals the duration of one complete operation or cycle of the pulsing contacts, and consists of an interval equal to the time the pulsing contacts are closed ("make time") and an interval equal to the time that the pulsing contacts are opened ("break time"). It is customary to measure and express the dial characteristics in terms of dial speed and percent break. The dial speed is the pulsing rate per second, and is usually averaged over the time for a complete ten-digit rundown of the dial, or ten complete pulses. Percent break is the percent that total break time is of the complete pulse time, and is customarily measured over a ten-pulse interval. Such measurements of dial characteristics would be perfectly adequate if all pulses were uniform, but this may not always be the case. The pulses produced by the pulsing contacts usually differ somewhat from each other in make and break time during a complete dial rundown. The degree of variation is a function of the design of the dial mechanism and the quality of its assembly during manufacture. Some pulses may have overly long break time intervals and others may have overly short break time intervals. Measurements based on totals over a ten-pulse interval would be incapable of indicating that fact. Since the switching equipment responds to individual pulses, and is in no way concerned with average valuations, a switching error may result in the event one or two pulses are distorted beyond the range over which the switching equipment will be responsive. Dials and pulsing contacts should be adjusted so that each pulse has a make and break time within acceptable predetermined limits. To permit such adjustment and to determine whether the dial is operating within its design capabilities, it is necessary to measure the break and make times of each particular pulse in a complete rundown of the dial. A system which will accomplish this also offers the additional advantage of a wider allowable tolerance in pulse characteristics than would at first appear to be acceptable when those characteristics are judged only by average measurements of dial speed and percent break. This will be further explained below.

Patent 2,207,513, issued July 9, 1940 to B. M. Hadfield, describes an apparatus which will measure the make and

break times of each operation of a set of pulsing contacts. It includes stepping switches with multiple wipers, and manual means for checking whether required relative positions of the wipers exist prior to each test. While the patented structure may operate quite well for testing pulsing contacts operating at relatively low speeds, telephone dials adapted for much greater speeds are under development. Equipment for testing such dials must be capable of high speed operation. In addition, new manufacturing methods have increased the rate at which the testing equipment must be repetitively operated. It is a prime requirement that the results from rapidly repeated operations be consistent, to the end that accurate adjustments of pulsing contacts and dials may be made on the production line with a minimum waste of time. Mechanically operated stepping switches have been found too slow to be reliable when testing the faster dials, and in addition, the fact that the wipers of separately actuated stepping switches operate independently of each other has indicated a need for testing equipment wherein all apparatus is kept in proper synchronism by master or central controlling means.

More recently, testing equipment has been developed which enables measurement of the pulse characteristics of any selected one of the pulses in the pulse train produced by a complete rundown of a dial. This is described in the copending application of K. L. Morton, Serial No. 426,448, filed April 29, 1954, and assigned to the assignee of the instant application. That equipment utilizes electronic control means, and is capable of very rapid response. However, the equipment will not provide a display of the variation in characteristics of every pulse in a dial pulse train during a complete rundown of the dial.

An object of the present invention is to provide inherently synchronized means for displaying the make and break time of each pulse in a pulse train as each pulse occurs.

A further object is to provide a rapidly responsive inherently synchronized pulse series analyzer for producing an oscilloscopic display of the time durations of each portion of each pulse in a train of any number of pulses.

A further object is to provide rapidly operative apparatus utilizing a minimum number of components for providing an inherently synchronized display of the make and break times of a set of telephone dial pulsing contacts during rundown of the dial.

An apparatus illustrating certain features of the invention may comprise pulse responsive electronic switching means having separate output terminals at each of which is produced a gating potential of a duration corresponding to the pulse duration to be measured. Each output terminal is connected to a time measuring means and alternate output terminals actuate connecting means and resetting means. The gating potentials actuate the time measuring, connecting and resetting means so that pairs of time measuring means are connected to a displaying means while other pairs are reset subsequent to their disconnection from the displaying means. The operation proceeds continuously, one pair of timing means being actuated while another pair is connected to the displaying means.

An apparatus embodying more specific features of the invention may comprise a continuous ring of pulse responsive bistable devices connected to a common source of control pulses. Each device is pulsed into one of its two stable states, which may be designated the "on" condition, by the pulse which occurs immediately after the preceding device in the ring has been pulsed into its "on" condition; and each device is pulsed into its other stable state, which may be designated the "off" condition, by the pulsing "on" of the succeeding device

in the ring. The control pulses producing this mode of operation occur at intervals equal, respectively, to the make and break times of successive operations of a set of pulsing contacts under test. While each device is on, it actuates a time measuring means that produces a potential of a magnitude proportional to that time interval. The turning "on" of alternate devices in the ring actuates a connecting control which connects the most recently actuated pair of timing means to the proper deflection control terminals of an oscilloscope, producing by "Z" axis control, a spot on the oscilloscope screen having horizontal and vertical positions proportional, respectively, to the make and break times of one cycle of the pulsing contacts. In addition, the previously actuated pair of time measuring means is disconnected from the oscilloscope deflection control terminals and is reset to the zero time condition by a resetting means controlled by the turning "on" of alternate devices in the ring circuit. This process proceeds continuously in response to the application of control pulses to the ring, so that on the oscilloscope screen is produced a pattern of dots representative of the make and break times of each cycle of the pulsing contacts. Measurement of the position of any dot on the screen directly gives the make and break time of the pulsing contact cycle that produced it. Hence, the maximum and minimum make and break times of the contacts for any number of cycles are readily measured. In addition, by placing over the oscilloscope screen a transparent template on which is drawn a maximum tolerance diagram, it can be readily observed whether any cycle of the pulsing contacts is outside the tolerable range.

A complete description of a particular embodiment of the invention is presented in the following portion of this specification, in conjunction with the appended drawings in which:

Fig. 1 is a typical tolerance diagram for a set of pulsing contacts;

Fig. 1A is a view of an oscilloscope screen showing a typical pattern of dots produced thereon, each dot being representative of the break and make times of each cycle of the pulsing contacts;

Fig. 2 is a block diagram showing the manner of interconnection and actuation of the essential components of a particular embodiment of a pulse series analyzer constructed in accordance with the invention;

Figs. 3 and 3A together comprise a circuit diagram of a particular embodiment of a pulse series analyzer constructed in accordance with the invention, and should be placed so that leads 16a to 16d and 17a to 17d terminating at the bottom of Fig. 3 join to the continuation of those leads indicated at the top portion of Fig. 3A; and

Fig. 4 is a circuit diagram of a suitable means for calibrating the embodiment of the invention disclosed in Figs. 3 and 3A.

Referring to Fig. 1, there is shown a graph of the make and break times of various telephone dial pulsing contacts having different speeds and percent breaks. When either the speed or percent break of a set of contacts is constant, the graph for those contacts is a straight line. Most telephone dials are designed for ten pulses per second speed at 62 percent break. If it is ascertained that dial performance will be adequate if the speed is within the range of 9.5 to 10.5 pulses per second and percent break is within the range of 60 to 64 percent, the area included within the lines corresponding to those ranges will enclose all possible combinations of these limits. The size of this area is dependent upon the amount of tolerable variation of the dial performance based on speed and percent break. However, the rectangular area enclosed by the horizontal projections of the upper and lower apices of the area, and the vertical projections of the right and left apices, will define the maximum and minimum acceptable make and break

times of individual pulses. As this area is considerably larger, a test based on the basic requirements of individual pulse make and break times would provide considerably more latitude in selection of acceptable dials.

Referring now to Fig. 2, the pulse train from a set of dial pulsing contacts or any other pulse source is applied to a pulse converter denoted in block 5 which operates on the input pulse train to produce a control pulse train of the type denoted at 6. The control pulses are all of positive polarity and have a sharply rising portion suitable for actuating pulse responsive bistable devices. The intervals between the rising portions of successive control pulses are the same as the durations of the distinct portions of the pulses in the input pulse train which are to be measured. More specifically, suppose the input pulses are square in shape, each square pulse having a first portion of high constant potential and a second portion of low constant potential. If the first portion of each input pulse is produced by a break operation of a set of pulsing contacts, the interval between the first and second control pulses will be of the same duration as the duration of the first break operation. If the second portion of each input pulse is produced by a make operation of a set of pulsing contacts, the interval between the second and third control pulses will be the same as the duration of the first make operation. The same relationship will exist between subsequent control and input pulses, so that successive pairs of control pulses will measure the break and make times of successive operations of the pulsing contacts. Many varieties of pulse-converting circuits may readily be devised which will produce such a control pulse train from virtually any configuration of input pulse train, the basic requirement being preservation of the time intervals between successive portions of each input pulse.

The control pulses 6 are applied to a rapidly responsive electronic switching control designated in block 7. The switching control may have any even number of output terminals of two or more, but in the particular embodiment herein described and for most convenient operation it has four which are denoted 1, 2, 3 and 4. The switching control is an active circuit, and produces a positive gating potential which appears in rotation successively at each output terminal. This gating potential appears at terminal 1 on occurrence of the first of control pulses 6 and remains there until occurrence of the second control pulse, when it is switched to output terminal 2. The same operations occur in response to the third and fourth control pulses, the gating potential thereby reaching output terminal 4. The switching control is a continuous ring circuit, so that on occurrence of the fifth control pulse the gating potential again appears at terminal 1.

Each of output terminals 1, 2, 3 and 4 are coupled to respective timers designated in blocks 8, 9, 10 and 11. These each develop a potential proportional to the duration of a continuous potential applied to them. Thus timer 8 develops a potential of a magnitude proportional to the interval between the first and second control pulses, timer 9 develops a potential of the magnitude proportional to the interval between the second and third control pulses, etc. On occurrence of the fifth control pulse, a potential of a magnitude proportional to the interval between the fifth and sixth control pulses is developed by timer 8, and the entire process repeats in step with the fifth, sixth, seventh and eighth control pulses just as it previously occurred in step with the first, second, third and fourth control pulses. In the case of many types of circuits suitable for use as timers of the kind described, once a timing potential is developed it is necessary to provide additional means for removing it after utilization and prior to development of a later timing potential by the same timer. Failure to do so will result in integration of timing potentials rather than

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development of successive potentials representative of successive individual time intervals.

The resetting controls designated in blocks 12 and 13 accomplish the removal of the timing potential of each timer prior to development of a new timing potential. Resetting control 12 is connected to output terminal 2 of switching control 7, and is momentarily actuated at the instant of development of the gating potential at output terminal 2. Resetting control 12 is also connected to timers 10 and 11, and when actuated resets them to a potential equivalent to zero time. Consequently, timers 10 and 11 are reset at the instant of occurrence of the second, sixth, tenth, etc. control pulses. Resetting control 13 is similarly connected to output terminal 4 of switching control 7, and to timers 8 and 9. It operates in the same manner as resetting control 12, so that timers 8 and 9 are reset at the instant of occurrence of the fourth, eighth, twelfth, etc. control pulses. Consequently, each timer is reset prior to the fourth control pulse succeeding the control pulse that previously actuated it. Since there are four timers, the successive timing potentials developed by each cannot interfere with each other. The first pair of timers, 8 and 9, develop timing potentials proportional, respectively, to the break and make times of the first and all odd input pulses. The second pair of timing gates, 10 and 11, develop timing potentials proportional, respectively, to the break and make times of the second and all even input pulses.

An oscilloscope designated in block 14 is provided for visually displaying the break and make times of each input pulse. To accomplish this successively, in step with each input pulse as it occurs, a connecting control designated in block 181 is provided. This is an electronically operating switching means which connects the vertical and horizontal deflection control terminals V and H of oscilloscope 14 to timers 8 and 9, respectively, at the instant following development of timing potentials by that pair of timers. The connecting control 181 disconnects terminals V and H from timers 8 and 9 and connects those terminals to timers 10 and 11, respectively, at the instant following development of timing potentials by that pair of timers. This switching occurs in response to activation of connecting control 181 by the control pulses from output terminals 2 and 4 of switching control 7. Subsequent to each connection of the V and H terminals to the respective pairs of timers, the normally cut-off oscilloscope spot is turned on by applying control pulses from output terminals 3 and 1 to the intensity control terminal Z of the oscilloscope. This eliminates display on the oscilloscope screen of the build-up of potential by the timers to which it is connected, and shows only a distinct dot on the screen corresponding to each connection of each pair of timers to the oscilloscope.

As a result, on the oscilloscope screen there will successively appear dots of which the vertical and horizontal positions of each is proportional to the break and make times of successive input pulses. The screen may be calibrated by first applying pulses of known make and break times to the switching control 7 and noting the position of the corresponding dots on the oscilloscope screen. A transparent template with a ruled grid may be placed over the screen with the coordinates directly marked in terms of time. When telephone dial pulsing contacts are to be tested, the template may have marked upon it the area bounded by the range of ordinates and abscissae of acceptable pulsing contact break and make times. By dialing zero and letting the dial completely run down, it is easy to observe whether any dots fall outside that area. If so, the dial is unacceptable. This is an ideal arrangement for dial production line testing.

By use of a long persistence phosphor for the oscilloscope screen material, a number of dots may be made simultaneously visible. The degree of dot scattering in-

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dicates the degree of non-uniformity of successive pulses. When it is desired to obtain a record of precise break and make times of each pulse, a simple expedient is to utilize conventional photographic recording means. This will allow exact measurement of the make and break times of each pulse.

By way of example, in Fig. 1A there is shown a typical pattern of dots as they might appear on a long persistence oscilloscope screen. The horizontal and vertical lines, which are preferably scribed on a transparent template, indicate respectively the acceptable limits of pulsing contact break and make times. While the pattern shows a variation in break and make times between the several cycles of the pulsing contacts, all of the dots fall within the delimited area and therefore the dial producing this pattern would be acceptable.

Referring now to Fig. 3, there is shown a ring circuit of four discharge tubes V1, V2, V3 and V4, which are the major elements of a ring circuit of four bistable devices 54, 55, 56 and 57. This ring circuit constitutes the switching control referred to above in block 7 of Fig. 2. An auxiliary discharge tube V5 serves to initiate operation of the ring circuit in a manner hereinafter described. In Fig. 3A, condensers 15a, 15b, 15c and 15d are components of four timers 8, 9, 10 and 11. Triodes 19 and 20 and relays 21 and 22 are the major elements of two resetting controls. Relay Winding 23 and multivibrator circuit 24 are the major components of a connecting control. Triodes 25 and 26 of Fig. 3 and their associated circuits are the major elements of a pulse converter designed to convert the alternating square wave train 27 produced by a set of dialing pulsing contacts 28 to a series of positive control pulses of the type indicated at 6. The input terminals of the complete pulse series analyzer are at 30 and 31, terminal 30 being grounded and terminal 31 being connected to the positive side of a source A of direct-current potential. The negative side of source A is connected to one terminal of a potentiometer 32 which is grounded at its other terminal. The positive side of source A is also connected to the series combination of a condenser 33 and a resistor 34, the free terminal of the resistor being grounded. The junction of condenser 33 and resistor 34 is connected to ring circuit input terminal 35 through a diode 36 poled so as to present low resistance to current flow toward terminal 35. Diode 36 has a reverse resistance of a few megohms, and may conveniently be a crystal rectifier. Condenser 33 and resistor 34 serve as a differentiating circuit, so that the voltage across resistor 34 will be proportional to the time rate of change of the voltage existing between the positive terminal of source A and ground. This voltage will be changing positively when the pulsing contacts 28 change from the closed to the open condition, or break. Hence, each time the pulsing contacts break a positive pulse will appear across resistor 34 and will be conveyed through diode 36 to input terminal 35. When the pulsing contacts close, or make, a negative pulse will be produced across resistor 34. However, due to the blocking effect of diode 36, only a negligible amount of this potential reaches terminal 35.

Potentiometer 32 has its brush connected to the grid of a triode 25. When the pulsing contacts 28 change from the open to the closed condition, or make, the potential between the grid of triode 25 and ground will be decreasing. Triode 25 serves as a polarity inverter, and has a cathode connected to ground through a resistor 37 and a plate connected to the positive side of a source of direct-current potential B+ through a resistor 38 and a switch 39. Switch 39 is closed when the pulse series analyzer is in operation. Since source B+ is used as a power supply for all tubes in the circuit, opening switch 39 restores the entire circuit to its starting condition. Hereinafter in this specification, reference to connection to source B+ will be made without reference to switch 39, it being understood that the switch is included in such connection and is closed. At the plate of triode 25

will appear a polarity-inverted and amplified replica of the potential at its grid. The plate of triode 25 is connected to the grid of a second triode 26 serving as a cathode follower in order to attain a low source impedance for the succeeding circuits. Triodes 25 and 26 may be conveniently contained within a single envelope. The plate of triode 26 is connected to source B+ and the cathode is connected to ground through a resistor 40. Since triode 26 is connected as a cathode follower, there is no polarity change between the alternating-current grid and cathode potentials. Consequently, as the gain is only slightly less than unity, the alternating-current potential at the cathode will be essentially the same as at the grid. The cathode potential will therefore be changing positively whenever the pulsing contacts 28 make. The cathode is connected to terminal 35 through a condenser 41 and a diode 42 poled so as to present low resistance to current flow toward terminal 35. Diode 42 has a reverse resistance of a few megohms, and may conveniently be a crystal rectifier. A resistor 43 is connected between ground and the junction of condenser 41 and diode 42, and serves with condenser 41 as a differentiating circuit. Similar to operation of the differentiating circuit comprising resistor 34 and condenser 33, the combination of this differentiating circuit and the blocking effect of diode 42 will result in a positive pulse at terminal 35 each time the pulsing contacts 28 make. The net potential at terminal 35 will therefore consist of a series of positive pulses which occur successively as the pulsing contacts successively break and make. Since the initial operation of telephone dial pulsing contacts is a break, for a 60-percent-break dial the interval between the first and second pulses at terminal 35 (and between all odd and succeeding even pulses) will be one and one-half times as long as the interval between the second and third pulses (and between all successive even and odd pulses) at that terminal. Wave form 6 has been sketched generally in accordance with this time relationship. In any case, the voltage pulse train 6 produced at terminal 35 will constitute the control pulses referred to above with reference to Fig. 2.

Terminal 35 is connected through the series combination of a condenser 44, a switch 17, and a diode 45 to the control electrode of auxiliary tube V5. Switch 17 is thrown to connect condenser 44 to diode 45, but during calibration it is thrown so they are disconnected and diode 45 is connected to terminal 18. Calibration is described hereinafter. Diode 45 is poled so as to present low resistance to current flow toward the control grid, and has a reverse resistance of a few megohms. It may conveniently be a crystal rectifier.

Condenser 44, diode 45, and auxiliary discharge tube V5 and its associated circuits serve as a novel pulse initiating device for the ring circuit comprising tubes V1—V4 in a manner generally of the type disclosed and claimed in my copending application entitled, "Pulse Initiator," Serial No. 456,572, filed September 16, 1954. In addition, except for some modifications made to adapt the ring circuit to utilization in the instant invention, the novel aspects of the combination of the pulse initiator and the ring circuit are disclosed and claimed in that application. As pointed out therein, tube V1—V5 are gaseous discharge tubes of the type having an anode, cathode, and control electrode. They are rendered conductive, or "fired" by application of a suitable potential to the control electrode and remain fired until reduction of the anode potential below a particular value. Gas-filled tubes of this type are common in the art.

The control electrode of tube V5 is connected to ground through a resistor 46 and the cathode is connected to ground through a resistor 47. Tube V5 preferably has a shield grid to reduce the grid current produced when the tube fires. The shield grid is connected to the cathode, and the cathode is connected to source B+ through a resistor 48. Resistors 47 and 48 serve as

a voltage divider by means of which a small direct-current biasing potential is applied to the cathode of tube V5 to prevent it from firing due to ambient noise or other extraneous voltages. The anode of tube V5 is connected through series connected resistors 49 and 50 to source B+, the junction of those resistors being shunted to ground by a condenser 51. The reason for using this condenser is that when source B+ is connected to the circuit by closing switch 39 a switching transient voltage may be produced. Since tube V5 has only a small applied bias, this might cause it to fire. Condenser 51 serves to delay the application of anode voltage to tube V5 for a sufficient time to permit any switching transients to die out.

On occurrence of the first of control pulses 6 at terminal 35, a positive potential is applied to the control electrode of tube V5 and it fires. Diode 45 serves to insulate the transient voltage caused by the control electrode current of tube V5 (which in the case of a gas-filled discharge tube is primarily a positive ion current) from reaching other parts of the circuit. Condenser 44 provides direct-current isolation.

The cathode of tube V5 is connected through a diode 52 and a condenser 53 in series to the control electrode of tube V1. Diode 52 has a reverse resistance of a few megohms, and may conveniently be a crystal rectifier. When tube V5 fires, a positive voltage pulse is produced at its cathode sufficient to cause tube V1 also to fire. This process occurs so quickly relative to the interval between successive control pulses that for all practical purposes tube V1 is fired at substantially the instant of occurrence of the first control pulse. Condenser 53 charges to the potential of the cathode of tube V5 and thereafter electrically isolates that potential from the control grid of discharge tube V1. Diode 52 prevents positive control pulses reaching the control electrode of tube V1, by another path described below, from being dissipated in cathode resistor 47 of tube V5.

Tube V1 and circuits associated with it comprise the first bistable device 54 in the ring circuit comprising four cascaded bistable devices 54, 55, 56 and 57. Terminal 35 is connected to each of these devices by control pulse conductor 58. Control pulse conductor 58 is connected to a terminal 19 marked "Calibrate." The purpose of this terminal will be explained hereinafter. Resistor 169 provides a ground path for conductor 58. Since all the bistable devices are identical, a description of device 54 will suffice for all. Tube V1 in device 54 has its anode connected through a resistor 59 to source B+, and a cathode connected to ground through the series combination of resistors 60 and 61. Condenser 62 is connected between the cathode and ground and, by tending to maintain the cathode voltage of tube V1 when its plate voltage is lowered, helps to produce rapid extinguishment of tube V1 as described hereinafter. Tube V1 preferably has a shield grid which is connected to the cathode. The control electrode is connected through a resistor 63 to the negative side of a source of direct-current biasing potential E—. The control electrode is also connected to control pulse conductor 58 through the series combination of a diode 64 and a condenser 65. A resistor 66 is connected between ground and the junction of diode 64 and condenser 65. When a control pulse occurs condenser 65 charges over a path from conductor 58, through condenser 65, diode 64, resistor 63, source E—, to ground. When the control pulse ceases condenser 65 discharges over a path through resistor 169, to ground, and through resistor 66. Condenser 63 may be 0.02 microfarad, resistor 66 may be 1 megohm, and resistor 63 may be 10,000 ohms. Consequently the charge circuit time constant for condenser 65 is much smaller than the discharge circuit time constant.

It is a feature of the invention that these charge and discharge circuits constitute chatter pulse discriminatory

means having time constants which are so proportioned that the ring circuit operation is selective as to the rate of pulsing contact chatter. Contact chatter is caused by the damped periodic bouncing of the pulsing contacts against each other following each make and/or break operation. This generates spurious pulses designated "chatter pulses," Chatter pulses occurring at a rate of about 500 per second or faster, which is generally considered to be tolerable providing that only a few such pulses occur, develop a charge on condenser 65 during the interval following the operation of the pulsing contacts which produced the chatter. Provided that only a relatively few chatter pulses occur, the charge so developed will sufficiently leak off through the discharge circuit so that the subsequent control pulse will actuate tube V1. The ring circuit will therefore operate normally. This behavior is due to the fact that the discharge circuit time constant, while large relative to the interval between successive chatter pulses, will be small relative to the interval between the last chatter pulse and the subsequent control pulse. Of course, if too many chatter pulses occur, the interval between the last one and the subsequent control pulse will be too short for the charge accumulated on condenser 65 to substantially leak off through the discharge circuit. The control pulse would then be blocked from reaching the control electrode of tube V1 and so would not fire it. Since the same situation will occur in all the devices in the ring circuit, the ring circuit will remain unresponsive to all control pulses after the first, and only a single spot will appear on the screen of oscilloscope 14, as described below. This spot will lie far outside the normal target area or even off the screen entirely, thereby indicating that the pulsing contacts are defective.

The discharging circuit time constant is also small relative to the interval between successive control pulses, so that the charge which those pulses produce on condenser 65 is dissipated in each of those intervals. Consequently, successive control pulses, and chatter pulses occurring at a rate not greatly faster than the control pulse rate, say in a range of about 20 to 100 pulses per second, will be conveyed to the control electrode of tube V1. Such pulses will be shown on the screen of oscilloscope 14, as described below. Since their duration and speed are far different from that of normal control pulses, the resulting spots on the oscilloscope screen will be outside the normal target area and it will be evident that the pulsing contacts are defective.

The behavior of the ring circuit in response to chatter pulses occurring at a rate in a range intermediate the foregoing rates, or from 100 to 500 pulses per second, is governed by the fact that the discharge circuit time constant is large enough relative to the interval between successive ones of such pulses so that even a relatively few such pulses will leave too little time in the interval between the last such pulse and the subsequent control pulse for condenser 65 to appreciably discharge. Consequently the control pulse will be blocked from the control electrode of tube V1 and the tube will not fire. The ring circuit will therefore remain unresponsive to all control pulses after the first, and only a single spot will appear on the screen of oscilloscope 14, as described below. This spot will lie far outside the normal target area or even off the screen entirely, thereby indicating that the pulsing contacts are defective.

In total, the foregoing chatter pulse discriminatory means enable the invention to show when the pulsing contacts under test are defective from the standpoint of objectionable chatter in addition to when they are defective as to their make or break times.

The cathode of tube V1 is connected to the control electrode of tube V2 through a resistor 67. The anode of tube V1 is connected to the anode of tube V2 by a condenser 68. The output voltage of tube V1 is at its cathode, and the portion of it existing across resistor 61

is conveyed by output lead 17a to timer 8 to be described hereinafter. Due to the coupling of the anode of tube V1 to the anode of tube V2 by condenser 68, and similar coupling of the anodes of tubes V2, V3 and V4, at the instant V1 fires the effective resistance between its plate and source B+ is only about one-fourth of the value of plate resistor 59. The plate resistors of all tubes are effectively in parallel until condenser 68 becomes charged. Consequently, the initial transient current through tube V1 when it fires will be about four times the steady state conduction current, and the cathode potential will be about four times its steady value. This potential may be so large as to adversely affect timer gate 82a connected to output lead 17a. To limit the cathode potential to a preselected value, the cathode is directly connected by lead 16a through a diode 70 to terminal 69 of a voltage limiting circuit. Diode 70 is poled so as to present low resistance to current flowing from the cathode toward terminal 69. The voltage limiting circuit is formed by connecting source B+ to series connected resistors 71, 72 and 73, the free terminal of the latter resistor being grounded. The junction of resistors 71 and 72 serves as the terminal 69, and is connected to ground through a condenser 74. Diode 70 will conduct when the potential at the cathode of tube V1 tends to exceed the potential produced by source B+ at terminal 69, thus limiting the potential of the cathode to the potential at terminal 69.

The operation of the ring circuit will now be described by reference to the operation of bistable devices 54 and 55. Since all the bistable devices are identical, and are identically connected in the complete ring circuit, the components of device 55 and the components connecting it in the ring circuit which correspond to identical components in stage 54 have been denoted with the same reference numerals but with a prime superscript. Bias source E- applies sufficient bias to the control electrode of tube V2 so that it cannot fire in response to any control pulse applied to its control grid from pulse conductor 58 until tube V1 has fired. When V1 is conducting, the potential at its cathode applied to the control electrode of tube V2 so reduces the net bias of V2 that occurrence of the control pulse succeeding the one that caused V1 to fire will cause firing of V2. Diode 64' blocks the cathode potential of V1 from control pulse conductor 58. Resistors 67 and 63' serve as a voltage divider by which a preselected fraction of the cathode potential of V1 is applied to the control electrode of V2. When tube V1 is conducting, its plate potential will be relatively low. If source B+ is 300 volts, the magnitudes of resistors 59, 60 and 61 can be so chosen that the potential at the anode of tube V1 is about 70 volts when it is conducting. The anode potential of tube V2 until it fires will be 300 volts. Condenser 68 will therefore be charged to about 230 volts, with the side connected to the anode of V1 negative with respect to the side connected to the anode of V2. When V2 fires its plate potential will drop sharply to about 70 volts. Since the charge on condenser 68 cannot instantly change, the voltage across it will instantaneously remain the same as before. Both sides of the condenser will therefore drop in potential 230 volts, so that the anode of tube V1 will be momentarily placed at a potential of about -150 volts. This instantly extinguishes tube V1. As a result, the net effect of the control pulse immediately succeeding the control pulse that caused tube V1 to fire is to cause tube V2 to fire and V1 to extinguish.

Since the ring circuit is completely symmetrical, tube V1 fires on the first control pulse and is extinguished by the second control pulse; V2 fires on the second control pulse and is extinguished by the third control pulse; and similarly for tubes V3 and V4. This process continues indefinitely, each tube firing on occurrence of the fourth control pulse succeeding the control pulse that previously fired it. At the four output leads 17a, 17b, 17c and 17d

there will appear in rotation a constant gating potential which exists at output lead 17a for the duration of the first break of pulsing contacts 28, at output lead 17b for the duration of the first make; at output lead 17c for the duration of the second break; at output lead 17d for the duration of the second make; at output lead 17a again for the duration of the third break; at output lead 17b again for the duration of the third make; etc. More concisely, in a ring circuit of n bistable stages, the stage numbered m with respect to the first stage will be fired at the instants of occurrence of the control pulses numbered $[m+n(x-1)]$ with respect to the first control pulse, x being the number of times that the entire ring has been cycled, counting any part of the initial cycle as one, any part of the second traverse as two, etc. It will remain fired until the instant of occurrence of the succeeding control pulse. For example, for the first stage $m=1$. Therefore it fires at the instants of occurrence of control pulses numbered $[1+n(x-1)]$ with respect to the first pulse.

Each of output leads 17a—17d, respectively, actuates timers 8, 9, 10 and 11, being connected thereto by diode gates 82a, 82b, 82c and 82d, respectively. Since the timers and diode gates are identical, a description of timer 8 and gate 82a will suffice for all. The components of the other timers and gates have been given the same reference numerals as the components of timer 8 and gate 82a to which they correspond, but with a suffix letter b , c or d , respectively, for components in timers 9, 10 and 11 and gates 82b, 82c and 82d. Condenser 15a in timer 8 is grounded at one terminal and is connected at its other terminal to source B+ through the series combination of a potentiometer 79a, resistor 80a and diode 81a, the latter poled to present low resistance to current flow toward condenser 15a. Potentiometer 79a provides some degree of control over the voltage applied to the series combination of resistor 80a and condenser 15a. Since the voltage built up on condenser 15a is to be used as a linear measure of time, the time constant of the series RC circuit comprising resistor 80a and condenser 15a must be large compared to the times being measured. For telephone dials, the longest time interval to be measured is of the order of .06 second and the time constant used for measurement was conveniently chosen at two seconds or approximately thirty times the time to be measured. This results, for the relatively short measured period of time, in the resistor 80a maintaining a substantially constant charging current for the condenser 15a, thus making the voltage across the condenser substantially proportional to the time that the charging current is flowing. The nominal values chosen for use in the circuit for resistor 80a and condenser 15a are 10 megohms and 0.2 microfarad, respectively. The resistance of potentiometer 79a must be small relative to that of resistor 80a, and is conveniently chosen at approximately 0.5 megohm with the range of adjustment so limited that the voltage applied to the series combination of resistor 80a and condenser 15a can be varied within approximately the upper 10 percent of the voltage of source B+, which is conveniently chosen at 300 volts. The junction of resistor 80a and diode 81a is connected to output lead 17a through diode gate 82a. Diode gate 82a is poled so as to present low resistance to current flow toward output lead 17a, and provides a conductive shunt path to prevent condenser 15a from charging except when tube V1 is conducting. Before tube V1 is made conductive, current will flow from source B+, through potentiometer 79a, resistor 80a, diode 82a, resistor 61 to ground. The resultant voltage across resistor 61 will be small due to its small resistance in comparison with that of resistor 80a. If resistor 61 is about 2700 ohms the voltage across it will only be of the order of one-quarter volt. Since condenser 15a is initially discharged to a potential of about one-half volt, it will not be charged at all until tube V1 fires. When that occurs, the relatively high potential im-

pressed on output lead 17a will render diode 82a non-conductive, so that condenser 15a will begin charging at that instant. Charging will cease when tube V1 extinguishes, so that across condenser 15a will be developed a voltage proportional to the duration of the first break interval of pulsing contacts 28. Diode 81a prevents this voltage from leaking off. In order to accurately gate the potential on condenser 15a, the resistance of diodes 81a and 82a in the nonconducting direction must be very high. Silicon alloy diodes having a nonconducting resistance of the order of 10^9 ohms have been found to give good gating performance. Similarly, condenser 15b develops a voltage proportional to the duration of the first make interval of the pulsing contacts, condenser 15c develops a voltage proportional to the second break interval, and condenser 15d develops a voltage proportional to the second make interval. To enable these condensers to respond in the same manner to repetitive operations of the pulsing contacts after the second make, it is necessary to discharge the voltage on each of them prior to occurrence of the fourth control pulse succeeding the one that caused development of the existing voltage. This operation is effected by the resetting controls, which will now be described in detail.

Two resetting controls are utilized, one actuated by tube V2 and the other by tube V4. The first resetting control comprises triode 19 and relay 21, and operates to momentarily connect the ungrounded terminals of condensers 15c and 15d to the small positive reference potential existing across resistor 73 at the instant tube V2 fires. The second resetting control comprises triode 20 and relay 22, and operates to momentarily connect the ungrounded terminals of condensers 15a and 15b to the same reference potential at the instant tube V4 fires. Both resetting controls are identical, so that a description of the one comprising triode 19 and relay 21 will also serve for the one comprising triode 20 and relay 22. The circuit components of the latter control corresponding to those in the former have been given the same reference numerals, but with a prime superscript.

The grid of triode 19 is connected to lead 16b through a blocking condenser 83 and a current limiting resistor 84 in series. The plate of triode 19 is connected to source B+ through the winding of relay 21 and a resistor 86 in series. The cathode is connected to the plate of a gas-filled diode 87, the cathode of which is grounded. The plate of diode 87 is connected to source B+ through a resistor 88. Diode 87 serves as a voltage regulator tube, maintaining at its plate a constant positive direct-current biasing potential sufficiently lower than the potential of source B+ so that when utilized as cathode bias for triode 19 the triode operates properly with source B+ used to supply the plate potential. This avoids the need for another source of direct-current potential. The junction of condenser 83 and resistor 84 is also connected to source B+ through a resistor 89, which is shunted to ground by a resistor 85. These resistors serve as a voltage divider for impressing a proper amount of direct-current grid bias potential on the grid of triode 19, so that its quiescent plate current will be very low in the absence of a large positive potential applied to the grid. Relay 21 has an armature which is connected to the ungrounded terminal of resistor 73, and a pair of contacts of which one is connected to the ungrounded terminal of condenser 15c and the other is connected to the ungrounded terminal of condenser 15d. When relay 21 is not actuated the armature is separated from these contacts. However, when tube V2 fires the resultant positive voltage pulse produced across resistor 85 is applied to the grid of triode 19, causing a sudden large rise in plate current. This is sufficient to actuate momentarily relay 21, so that its armature closes to its contacts and thereby causes condensers 15c and 15d to each discharge to the low positive potential existing across resistor 73. Due to the voltage

dividing effect of series connected resistors 71, 72 and 73 connected between source B+ and ground, the voltage across resistor 73 may be made about 0.5 volt. Triodes 19 and 20 are conveniently contained within the same envelope, and may have their cathodes directly connected together with the common point of connection connected to the plate of diode 87.

The voltages developed by the pair of condensers 15a and 15b as a result of the first break and make of pulsing contacts 28 may be simultaneously applied to the vertical and horizontal deflection control terminals, respectively, of an oscilloscope equipped with direct-current amplifiers. The result will be production of a dot on the oscilloscope screen having an ordinate proportional to the break time and an abscissa proportional to the make time of the first complete cycle of operation of the pulsing contacts 28. If then those voltages are replaced by the voltages developed by the voltages developed by the pair of condensers 15c and 15d as a result of the second break and second make of the pulsing contacts, a second dot will be produced on the screen having an ordinate proportional to the break time and an abscissa proportional to the make time of a second complete cycle of operation of the pulsing contacts. This process can be made continuous, producing another dot for each operation of pulsing contacts 28, by successively connecting the vertical and horizontal terminals of the oscilloscope, designated at V and H respectively, to condensers 15a and 15b, then at 15c and 15d, then 15a and 15b again, etc. This switching must occur in step with the charging and discharging of these condensers so that the oscilloscope will be connected to a pair of condensers after they are charged, remain so connected long enough for the dot on the screen to be observed, and then be disconnected from that pair prior to recharging.

The switching of the oscilloscope to the proper pair of condensers at the proper time is accomplished by a connecting control comprising a relay having an operating winding 23 and two sets of contacts. One set comprises fixed contacts 90 and 91 and a movable contact 92 which closes a contact 90 when winding 23 is energized and closes to contact 91 when winding 23 is deenergized. The other set of contacts comprises fixed contacts 93 and 94 and a movable contact 95 which closes to contact 93 when winding 23 is energized and closes a contact 94 when winding 23 is deenergized. Movable contact 92 is connected to the control grid of a pentode 96 serving as part of a voltage detector which actuates the vertical deflection control terminal V of an oscilloscope, and movable contact 95 is connected to the control grid of another pentode 97 serving as part of a voltage detector which actuates the horizontal deflection control terminal H of the oscilloscope. The complete voltage detection circuits are described hereinafter. Contacts 90 and 93 are connected, respectively, to the ungrounded terminals of condensers 15a and 15b. Contacts 91 and 94 are connected respectively to the ungrounded terminals of condensers 15c and 15d. Hence, when winding 23 is energized the oscilloscope is rendered responsive to the voltages of condensers 15a and 15b. When winding 23 is deenergized the oscilloscope is rendered responsive to the voltages of condensers 15c and 15d.

Since the voltages of condensers 15a and 15b are proportional to the break and make times of the first and all other odd numbered cycles of pulsing contacts 28, that pair should be connected to actuate the oscilloscope first. As stated above, those condensers are discharged at the instants of firing of tube V4. The time at which these condensers are fully charged is marked by the occurrence of the second and all even numbered break operations of pulsing contacts 28, which are at the instants of firing of tube V3. To permit sufficient time for retention of the spot on the oscilloscope screen,

and since condensers 15c and 15d are discharged at the instant of occurrence of the control pulses that fire tube V2, the connecting control connects condensers 15a and 15b to the oscilloscope at the instants when tube V2 fires. At those instants condenser 15b will only just have started charging. However, by letting condensers 15a and 15b remain connected to actuate the oscilloscope until occurrence of the control pulse that fires tube V4, both condensers will have become fully charged, and the spot will be properly located on the oscilloscope screen. It will remain there during the interval between firing of tube V3 and firing of tube V4. This is enough time for retention of a bright enough spot for convenient viewing if the oscilloscope screen is of the long persistence type and the Z terminal of the oscilloscope is pulsed positive at the instant tube V3 fires. The oscilloscope brightening circuit which accomplishes this is described in more detail hereinafter.

The instants of firing of tube V4 marks the instants at which condenser 15d will have just started charging and also the instants at which condensers 15a and 15b are discharged. Hence, in the same manner as in the case of condensers 15a and 15b, condensers 15c and 15d are connected to actuate the oscilloscope at the instants of occurrence of the control pulses that fire tube V4.

From the foregoing description it will be apparent that relay winding 23 must be energized at the instant tube V2 fires, remain so until tube V4 fires, deenergize when tube V4 fires, remain so until tube V2 again fires, and then repeat the entire cycle. Since there are intervals when neither of those tubes are conductive, their cathode potentials cannot be directly utilized to actuate relay winding 23. Instead, a bistable trigger circuit 24 is utilized as an electronic switch rapidly responsive to the firing of tubes V2 and V4 to hold over during the intervals when neither of those tubes is conducting. Trigger circuit 24 may be any of well-known variations of the basic Eccles-Jordan type. For definiteness, a particular plate-coupled circuit will be briefly described. This comprises a pair of triodes 98 and 99 which may be contained in a single envelope. The cathodes are connected together and to ground through a bias circuit comprising resistor 100 and condenser 101 in parallel. The plates of triodes 98 and 99 are connected through resistors 102 and 103, respectively, to the cathode of a gas-filled diode 104 having its plate connected to source B+. The cathode of diode 104 is connected to ground through a resistor 105. Diode 104 serves as a voltage reducer, providing at its cathode a positive direct-current potential of the proper magnitude for use as a source of plate potential for triodes 98 and 99. The plate of triode 98 is connected to the grid of triode 99 through a resistor 106, and the plate of triode 99 is connected to the grid of triode 98 through series connected resistors 107 and 108. The grid of triode 99 is connected to ground through a resistor 109 and the grid of triode 98 is connected to ground through a resistor 110. The grid of triode 99 is also connected to ground through the series combination of a condenser 111 and a resistor 112. The junction of condenser 111 and resistor 112 is connected to lead 16d through the series combination of a resistor 113 and a diode 114, the latter poled to present low resistance to current flow away from lead 16d. The grid of triode 98 is also connected to ground through the series combination of a condenser 115 and a resistor 116. The junction of condenser 115 and resistor 116 is connected to lead 16b through the series combination of resistor 117 and diode 118, the latter poled to present low resistance to current flow away from lead 16b.

When tube V2 fires the positive pulse produced at its cathode is conveyed by lead 16b to resistor 117, and thence through diode 118 and condenser 115 to the grid of triode 98. This produces more plate current and a consequent drop in the potential of the plate of triode 98. Through the voltage divider comprising resistors 106 and 109, a portion of this negative potential pulse at the plate

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of triode 98 is applied to the grid of triode 99. If triode 99 was already non-conductive it simply will remain so. If it was conducting, its plate current will be reduced, causing a rise in plate voltage. Via the voltage divider comprising resistors 107, 108 and 110, further positive potential is applied to the grid of triode 98. The process is therefore cumulative, and the circuit will stabilize with triode 98 conducting and triode 99 cut off. When tube V4 fires the same process will occur except that the circuit will stabilize with triode 99 conducting and triode 98 cut off. Diodes 114 and 118 prevent pulses from the trigger circuit returning to the cathode of either tube V2 or V4. Condensers 111 and 115 provide direct-current isolation for the grids of triodes 98 and 99 while transmitting the differentiated voltage surge produced when tube V2 or V4 fires. This enables trigger circuit 24 to switch over almost instantly in response to the firing of each of those tubes. The portion of the plate potential of triode 99 existing across resistors 108 and 110 is applied to the grid of an isolating triode 119 by connecting the grid of triode 119 through a protective resistor 120 to the junction of resistors 107 and 108. The plate of triode 119 is connected to source B+ through a series path including relay winding 23 and resistor 121. The cathode of triode 119 is connected to the plate of diode 87 through a resistor 122. With this arrangement sufficient cathode bias is applied to triode 119 to make possible switching its plate current off and on by means of trigger circuit 24, as will now be described. When triode 99 in trigger circuit 24 is conductive, which will be from the time tube V4 fires until tube V2 fires, its plate potential is low and the resulting potential applied to the grid of triode 119 is small. In this condition the plate current of triode 119 is very small, and relay winding 23 cannot operate contacts 92 and 95. They therefore are closed to contacts 91 and 94, so that condensers 15c and 15d are the ones that actuate the oscilloscope. When triode 99 is cut off, the portion of its high plate potential applied to the grid of triode 119 causes sufficient conduction of triode 119 to energize relay winding 23 and operate relay contacts 92 and 95 to close the contacts 90 and 93. Condensers 15a and 15b then become the ones which actuate the oscilloscope. Because of the isolating effect of triode 119, the operation of trigger circuit 24 is unaffected by the relatively large inductive load presented by relay winding 23. If winding 23 were directly connected in the plate circuit of triode 99, the large inductive load would make for unreliable operation of the trigger circuit.

Without appropriate circuitry, the oscilloscope spot would produce first a vertical and then a horizontal trace ending at the point of interest on the screen corresponding to the measured break and make time of each cycle of the pulsing contacts. The trace produced on the screen for each such cycle would be in the shape of an inverted L. With continuous operation, the presence of an inverted L pattern for each spot would so obscure the screen that observation of the spots would be difficult. To eliminate the lines of these inverted L patterns, the oscilloscope brightness control is set at a point just below visibility and brightening means are provided which impresses a positive voltage pulse on the intensity control terminal Z of the oscilloscope at the instant that each pair of condensers providing the two deflecting voltages are fully charged. The first such instant will be just after condenser 15b has been completely charged and the second just after condenser 15d has been completely charged. The firing of tube V3 denotes the former instant and the firing of tube V1 denotes the latter instant. The brightening means comprises connection of the cathodes of tubes V1 and V3 to the Z terminal of the oscilloscope, through the series connection of diode 123 and resistor 124 in the case of tube V1, and diode 125 and resistor 126 in the case of tube V3. Diodes 123 and 125 are poled to present low resistance to current flow toward the Z terminal, and serve to isolate the cathode potentials of

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tubes V1 and V3 from each other. Resistors 124 and 126 assist in this isolation and further serve to limit the load applied to the cathodes of V1 and V3 by condenser 127. Condenser 127, connected between ground and the Z terminal, forms an RC circuit with the resistive load of the Z terminal, the time constant of which prolongs the application of the brightening pulse and thus provides greater perception time.

The voltage detecting circuits referred to above will now be described. Since both are identical, a description of the circuit connected to the V terminal of the oscilloscope will suffice as a description of the circuit connected to the H terminal. As stated above, movable relay contact 92 is connected to the grid of pentode 96. In this circuit, pentode 96 is triode connected in a cathode follower circuit. In addition to the use of the cathode follower circuit, special attention to tube characteristics and operating point is necessary so that a very high direct-current grid input resistance will be obtained. Due to this very high input impedance of pentode 96 it does not draw appreciable current from condensers 15a or 15c. Pentode 96 is triode connected as a cathode follower in the following manner: The cathode is connected to ground through a resistor 128. The suppressor grid is connected to the cathode. The screen grid is connected to the plate, which is connected to the cathode of a gas-filled diode 129 having its plate connected to source B+. The cathode of diode 129 is connected to ground through a resistor 130. Diode 129 is a voltage regulator tube providing at its cathode a fixed drop in voltage from source B+ to provide the proper direct-current potential to the plate of pentode 96. The output of pentode 96 appears at its cathode, and is a voltage very nearly equal in value to the voltage applied to the grid plus a quiescent voltage which exists when the grid voltage is zero due to the quiescent plate current. While this total cathode voltage could be directly applied to the V terminal of the oscilloscope such an arrangement would have a major disadvantage. The deflection produced on the oscilloscope screen would include a constant component due to the quiescent voltage at the cathode of pentode 96, thereby reducing the range of break time variation that could fit on the oscilloscope screen. For a given range of break time variation, the sensitivity of the oscilloscope, in inches deflection per applied volt, would have to be limited to much less than that required for full scale deflection in order that the deflection resulting from the quiescent voltage at the cathode of pentode 96 would not be off the screen. To permit high sensitivity measurements (and consequently greater accuracy) a voltage balancing and voltage dividing circuit is connected between the cathode of pentode 96 and the V terminal of the oscilloscope. This circuit includes a diode 131 connected between the cathode and the left pole of double-pole double-throw switch 132. Diode 131 is poled to present low resistance to current flow away from the cathode. The right pole of switch 132 is connected to the V terminal of the oscilloscope. Two resistors 133 and 134 are connected in series between ground and the left contact of the right pole of switch 132. The junction of these resistors is connected to the right contact of the right pole of switch 132. The left contact of the left pole of switch 132 is connected to the brush of a potentiometer 135 connected across the terminals of a direct-current source D of relatively low voltage. The negative terminal of source D is connected to the left contact of the right pole of switch 132. The right contact of the left pole of switch 132 is connected to the brush of another potentiometer 136, which also is connected across the terminals of source D. A silicon junction diode 137 serving as a voltage regulator shunts source D, poled so that the potential of source D cannot exceed the Zener voltage of diode 137. A value of 25 to 28 volts for the Zener voltage of diode 137, and a 30-volt source D having an impedance of about 2700 ohms has been found satisfactory.

If resistor 134 has about four times the resistance of

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resistor 133, the sensitivity of the oscilloscope measurement will be about five times greater when the poles of switch 132 are thrown to their left contacts than when thrown to the right contacts. Assume that switch 132 is thrown to the right contacts (low sensitivity position). The portion of the potential at the cathode of pentode 96 which is effective to produce voltage across resistor 133 will depend upon the magnitude of the opposing potential at the brush of potentiometer 136 produced by source D. For example, if the potential at the brush of potentiometer 136 just equals the potential at the cathode of pentode 96, diode 131 will be non-conductive and no voltage will exist across resistor 133. Consequently, there will be no vertical deflection of the spot on the oscilloscope screen. The brush of potentiometer 136 may be adjusted so that when no potential is applied to the grid of pentode 96 the spot on the oscilloscope screen just fails to be deflected. Consequently, any deflection which is produced when timing potential is applied to the grid of pentode 96 from either condenser 15a or 15c will all be due to the timing potential, the effect of the quiescent potential at the cathode having been balanced out. Also, since this opposing potential at the brush of potentiometer 136 is just balanced by the quiescent voltage at the cathode of pentode 96, all of the timing potential will be effective to produce deflection of the spot on the oscilloscope screen.

When switch 132 is thrown to its left contacts (high sensitivity), the brush of potentiometer 135 may be adjusted so it is at a potential greater than the quiescent voltage at the cathode of pentode 96. It may be set so only a residual portion of the potential applied to the grid of pentode 96, exceeding a preselected value, is effective to produce any deflection of the spot on the oscilloscope screen. The break time duration corresponding to that preselected voltage can be included in the screen calibration by a calibration procedure described below. The deflection sensitivity of the oscilloscope can be kept high, and yet the spot indicating the break time will remain on the screen. A highly accurate measurement of the total break time is thereby achieved.

Calibration of the pattern produced on the oscilloscope screen may be accomplished by applying to terminal 35 of the ring circuit, described above with reference to Fig. 3, a train of standard pulses of constant known characteristics, and measuring the position of the resulting spot on the oscilloscope screen. For example, such a pulse train may be selected so the interval between any odd numbered pulse and the succeeding even numbered pulse is 0.06 second and the interval between any even numbered pulse and a succeeding odd numbered pulse is 0.04 second. This is equivalent to the pulse train which would be produced from telephone dial pulsing contacts having a operating speed of ten pulses per second and a percent break of 60 percent. The spot produced on the oscilloscope screen when switch 132 is in its low sensitivity position (right) will have an ordinate relative to the undeflected spot position corresponding to 0.06 second, and an abscissa corresponding to 0.04 second. Measuring these distances will provide the calibration for the entire screen. This calibration procedure applies when switch 132 is in the low sensitivity position because then no part of the timing potential is balanced out and the deflected and undeflected spots will both be on the screen. The screen should first be so calibrated. In addition, the oscilloscope positioning controls may be adjusted so that this 60-percent-break, 40-percent-make, spot is located at a desired point on the oscilloscope screen.

When switch 132 is in the high sensitivity position (left), potentiometer 135 may be adjusted so that the 60-percent-break calibrating spot is in the same position on the oscilloscope screen as it was when switch 132 was in the low sensitivity position. However, since a part of

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the timing potential is being balanced out, the distance of this spot from the original undeflected position will not directly give the screen calibration. Instead, calibration is accomplished by marking on a transparent template placed over the screen the position of the spot so produced, and then replacing the 60-percent-break standard pulse train with a 70-percent-break pulse train, also occurring at a rate of ten pulses per second. The interval between odd and even pulses will then be 0.07 second, and between even and odd pulses will be 0.03 second. A new spot will be produced on the screen, and it will be displaced to the left and upward from the former spot. The displacement to the left will correspond to 0.01 second make time, and so gives the calibration of the abscissae of the screen. The displacement upward corresponds to 0.01 second break time, giving the calibration of the ordinates of the screen.

A ruled grid on a transparent template passed over the screen may have each ordinate and abscissa marked in terms of break and make time for both the low and high sensitivity positions of switch 132, and may have two of the diagrams of maximum acceptable pulse characteristics outlined on it, one for each time scale. When actually testing a set of dial pulsing contacts the test can first be conducted with switch 132 in the low sensitivity position. If the spots form a close group within the acceptable diagram area the switch may be thrown to the high sensitivity position and the test repeated on the magnified scale for more precise indication.

While various types of sources of standardized pulse trains are known, the circuit of a particularly convenient one is depicted in Fig. 4. A 100-cycle per second sinusoidal frequency standard is used as a source of signal voltage applied between ground and input terminal 138 of the pulse source. Input terminal 138 is connected through a blocking condenser 139 and a grid current limiting resistance 140 to the grid of a triode 141 used as an amplifier. Triode 141 has a cathode which is grounded through a resistor 142, and a plate connected to source B+ through a resistor 143. A resistor 144 connected between ground and the junction of condenser 139 and resistor 140 serves as a ground return for the grid of triode 141. At the plate will appear an amplified replica of the signal applied at terminal 138. The plate is connected to the grid of a triode 145 used as a cathode follower. Triode 145 may be conveniently contained in the same envelope with triode 141. The plate of triode 145 is connected to source B+, and the cathode is grounded through a resistor 146. The output of triode 145 appears at its cathode, and is an amplified replica of the signal applied at terminal 138. The cathode is connected through a blocking condenser 147 and grid current limiting resistor 148 in series to the grid of a triode 149. A resistor 150 is connected between ground and the junction of condenser 147 and resistor 148 to provide a ground return path for the grid of triode 149. The plate of triode 149 is connected to source B+, and the cathode is connected to ground through a cathode resistor. Triode 149 cooperates with another triode 151, which may be contained in the same envelope with it, to form a "slicer" circuit for converting a sinusoidal input signal to a substantially square wave output signal. The cathode of triode 151 is connected to the cathode of triode 149 and the plate is connected through a resistor 152 to source B+. The grid of triode 151 is grounded. On each positive half cycle of the sinusoidal voltage applied to the grid of triode 149, that triode will draw a large plate current. This produces sufficient voltage at the cathode so that triode 151 is biased to cut off early in the half cycle. Early in each negative half cycle of the sinusoidal voltage applied to the grid of triode 149, that tube is driven near to cut off, reducing the cathode voltage to a level at which the resulting plate current of triode 151 is at saturation.

Consequently, at the plate of triode 151 will exist a substantially square wave voltage each complete cycle of which occurs in 0.01 second. The grid of triode 149 is driven positive during part of each positive half cycle of the voltage applied to the grid, so that grid current will flow. Resistor 148 limits the amount of such current, and the low internal impedance of the cathode follower comprising triode 145 prevents excessive loss of voltage at the grid of triode 149 during conduction. The plate of triode 151 is connected through a blocking condenser 153 to the grid of a triode 154 serving as a cathode follower to provide low source impedance for the succeeding circuit, which draws considerable current. The plate of triode 154 is connected to source B+, and the cathode is connected to ground through series connected resistor 155 and primary winding 156 of transformer 157. The grid of triode 154 is returned to ground through a grid leak resistor. Secondary winding 158 of transformer 157 is grounded at one terminal and is connected at its other terminal to each of ten input cathodes A1, A2, A3 . . . A10 of a multicathode cold discharge gaseous stepping tube 159 of the type disclosed and claimed in Patent 2,575,370, issued November 20, 1951 to M. A. Townsend. For a complete description of tube 159 reference should be made to that patent. The tube utilized in the instant application is of the same type but includes an initiating cathode N close enough to the plate so that it will fire as soon as plate potential is applied to tube 159. The function of transformer 157 is to provide efficient coupling and to eliminate the direct-current component of the potential at the cathode of triode 154. This simplifies operation of stepping tube 159, by making ground the reference potential for all cathodes. The plate of stepping tube 159 is connected to source B+ through a resistor 160. Tube 159 has ten output cathodes B1, B2 . . . B10, each of which is connected to ground through separate resistors $r_1, r_2 \dots r_{10}$. Initiating cathode N is connected directly to ground. As soon as source B+ is connected to the plate, discharge is initiated to cathode N. The first output cathode B1 may be connected through a current limiting resistor 161 to the "Calibrate" terminal 18 of the ring circuit in Fig. 3. Switch 17 is thrown to disconnect condenser 44 from diode 45 and connect diode 45 to terminal 18. On the occurrence of the first negative pulse applied to input cathodes A1 through A10, the potential between the plate and cathode A1 will exceed the potential between the plate and initiating cathode N, and discharge will therefore transfer from cathode N to adjacent input cathode A1. On occurrence of the succeeding positive pulse the input cathodes become more positive than the output cathodes, and the discharge will therefore step from input cathode A1 to adjacent output cathode B1. The succeeding negative pulse makes the input cathodes more negative than the output cathodes and the discharge steps from output cathode B1 to input cathode A2. The tube 159 is actually constructed with its cathodes arranged in a continuous circle or ring, so that this stepping process continues indefinitely. Since each complete cycle of the applied square wave voltage requires 0.01 second, discharge will step from any output cathode to the succeeding output cathode in 0.01 second.

When discharge first reaches output cathode B1, the resultant positive voltage produced across resistor r_1 will be conveyed through resistor 161 to terminal 18 of Fig. 3 and through diode 45 and resistor 46 to ground. Tube V5 will, therefore, fire and initiate operation of the ring circuit of Fig. 3 as described above. Consequently, operation of the ring circuit is initiated when discharge first appears at cathode B1 in tube 159 in the calibrating circuit. This will be true even if perchance cathode B1 is not the first output cathode to fire, since the ring circuit cannot begin operating until initiating tube V5 has been fired.

The interval for discharge in tube 159 to transfer from cathode B1 to cathode B7 is 0.06 second, and the interval for discharge to return from cathode B7 to B1 is 0.04 second. Also, the interval for discharge to transfer from cathode B1 to cathode B8 is 0.07 second, and the interval for discharge to return from cathode B8 to cathode B1 is 0.03 second. Cathode B1 is connected through a diode 162 to the grid of a triode 163 serving as a cathode follower. Cathodes B7 and B8 are connected to separate terminals of a switch 164 having a pole which may be thrown to contact either of these terminals. The pole of switch 164 is connected through a diode 165 to the grid of triode 163. Diodes 162 and 165 are both poled so as to present low resistance to current flow toward the grid of triode 163. A resistor 166 connected between ground and the pole of switch 164 serves to provide the same total output load for output cathodes B7 and B8 as resistors 161 and 46 (Fig. 3) in series provide for cathode B1. The grid of triode 163 returns to ground through a grid leak resistor. The plate of triode 163 is connected to source B+, and the cathode is grounded through a resistor 167. The output of triode 163 appears at its cathode, which may be connected through a condenser 168 to "Calibrate" terminal 19 of Fig. 3. Condenser 168 may have a capacitance such that it and resistor 169 (Fig. 3) serve as a differentiating circuit. When the pole of switch 164 contacts its upper terminal, across resistor 169 will be produced a series of pulses constituting a 60-percent-break, 40-percent-make, pulse train. When the pole of switch 164 contacts its lower terminal, across resistor 169 will be produced a series of pulses constituting a 70-percent-break, 30-percent-make, pulse train. In both cases the time for one complete cycle of break and make pulses will be one-tenth second. These are the standard pulse trains required for calibration of the oscilloscope screen as described above, and are impressed directly on pulse conductor 58 in Fig. 3.

When a source of uniform pulses is used to calibrate the oscilloscope screen, only a single spot should appear. However, due to slight variations in the capacitances of condenser 15a, 15b, 15c and 15d and in the values of resistors 80a, 80b, 80c and 80d, for the same applied voltage for the same time interval slightly different voltages may be developed on the condensers. To equalize the charging conditions, potentiometers 79a, 79b, 79c and 79d may be adjusted so that only a single spot appears on the screen for a given calibrating pulse train. These potentiometers therefore serve as spot resolution controls.

While four bistable devices were used in the stepping ring circuit, the complete pulse series analyzer may be adapted to utilize a stepping ring having any even number of four or more bistable devices. If six were used, the time for observing any spot would be increased by the time required for firing two additional devices. Hence, proper choice of the number of bistable devices enables easy viewing of the spots produced by even very rapidly occurring pulses. Although gaseous discharge tubes were used as the elements of the bistable devices, the same operating characteristics could have been attained by using bistable multivibrators comprising two high vacuum tubes of which only one is connected to the timing and gating circuits. These types of modifications of the invention will be readily apparent to those skilled in the art.

What is claimed is:

1. A system for measuring the intervals between successive ones of a series of control pulses, comprising switching means to which said pulses are applied, said switching means having a plurality of output terminals, said switching means adapted to respond to said pulses to produce a series of gating potentials in sequence at said output terminals for intervals corresponding to the intervals between successive ones of said control pulses, a plurality of timer means connected respectively to said output terminals, each of said timer means adapted to produce a timing potential proportional to the duration of the gating

potential at the output terminal to which such timer means is connected, an oscilloscope, and a connecting control for selectively connecting pairs of said timer means to said oscilloscope at the instants of occurrence of preselected ones of said gating potentials.

2. An analyzer of a series of spaced pulses having successive break and make time intervals, comprising the combination of a pulsed switching means adapted to operate in step with occurrence of each of said pulses, a timing means connected to said pulsed switching means adapted to develop a first potential of a magnitude corresponding to the break time of a pulse, an alternate timing means connected to and operable by said pulsed switching means to develop a second potential of a magnitude corresponding to the succeeding make time of said pulse, an oscilloscope, a connecting control connected to said timing means and to said oscilloscope, means further connecting said connecting control to said pulsed switching means whereby the former is under control of the latter means to apply said two potentials substantially simultaneously to said oscilloscope, and resetting means connected to said pulsed switching means and to said timing means for discharging said potentials subsequent to their application to said oscilloscope.

3. An analyzer of a series of spaced pulses, comprising pulse converting means for deriving from said spaced pulses a series of control pulses of brief duration and of uniform polarity, successive ones of said control pulses being separated by intervals equal to the intervals between successive portions of said spaced pulses, a ring circuit of a plurality of bistable devices, means connecting said ring circuit to said converting means, said converting means adapted to simultaneously apply each of said control pulses to each of said bistable devices, said ring circuit so constructed and arranged that each of said devices produces a gating potential during the interval from occurrence of a selected one of said control pulses to occurrence of the immediately succeeding control pulse, a timer means for each of said devices, gating means respectively connecting said devices to their timer means and adapted to permit any one of said timer means to operate only during the interval that the device to which such timer means is connected is producing said gating potential, each of said timer means adapted when operated to produce a timing potential of a magnitude proportional to the time during which it is operated, voltage detecting means, connecting means controlled by said ring circuit to successively connect said voltage detecting means to preselected groups of said timer means, and resetting means controlled by said ring circuit to successively dissipate said timing potentials of each of said groups of timer means subsequent to connection of each of such group to said voltage detecting means.

4. A system responsive to a series of applied control pulses, comprising a ring circuit of n bistable devices each having an output terminal, said ring circuit adapted to produce at the m th of said output terminals a series of gating potentials each of which exists from the instant of occurrence of the $[m+n(x-1)]$ th of said control pulses until the instant of occurrence of the immediately succeeding one of said control pulses, x being the number of times that said ring circuit has been cycled, a plurality of timer circuits each of which includes a condenser, a plurality of voltage gates respectively connecting said timer circuits with said output terminals, each of said voltage gates adapted to normally prevent each of said timer circuits from charging its condenser, each of said voltage gates adapted to respond to said gating potentials to cause each of said timer circuits to charge its condenser during the interval that said gating potential exists at the one of said output terminals to which that timer circuit is connected, voltage detecting means, a connecting control connected to selected ones of said output terminals and to said voltage detecting means, said connecting control adapted to respond to the existence of

said gating potentials at said selected ones of said output terminals to successively and individually connect preselected groups of said condensers to said voltage detecting means, and resetting means connected to said selected ones of said output terminals and to said preselected groups of said condensers, said resetting means adapted to successively discharge each of said preselected groups of condensers after their connection to said voltage detecting means.

5. In combination, a ring circuit of bistable devices adapted to be connected to a source of control pulses of common polarity, each of said devices constructed and arranged to change from a first to a second stable state in response to a control pulse occurring after the preceding device in said ring has so changed in response to the preceding pulse, each of said devices further constructed and arranged to change from said second stable state to said first stable state in response to the change of the succeeding one of said devices in said ring circuit from said first to said second stable state, a plurality of voltage gates respectively connected to said devices, a plurality of capacitive charging circuits of long time constant relative to the longest interval between successive ones of said pulses respectively connected to said voltage gates, each of said voltage gates adapted to permit the capacitive charging circuit to which it is connected to develop a charge only when the one of said devices to which such voltage gate is connected is in its second stable state, connecting means including a relay having a plurality of input contacts and a plurality of output contacts, means connecting said input contacts respectively to said capacitive charging circuits, voltage detecting means connected to said output contacts, relay actuating means connected to said relay and to selected ones of said devices, said relay actuating means adapted to respond to the states of said selected devices to cause said relay to successively connect predetermined groups of said input contacts to said output contacts, whereby predetermined groups of said capacitive charging circuits are successively connected to said voltage detecting means, a plurality of resetting controls including a plurality of clearing relays, means connecting said resetting controls to particular ones of said devices, said clearing relays respectively connected to said predetermined groups of said capacitive charging circuits, and each of said clearing relays adapted to discharge the charges of its group of capacitive charging circuits subsequent to connection of that group to said voltage detecting means.

6. In combination, a ring circuit of the type comprising a plurality of pulse responsive bistable devices so interconnected as to be individually actuated in succession in response to occurrence of successive pulses in a series of pulses applied to said ring circuit, each of said devices having an on and an off condition, each of said devices responsive to said pulses to assume its on condition at the instant of occurrence of the pulse occurring immediately after the preceding device in said ring circuit has assumed its on condition, each of said devices adapted to resume its off condition in response to the assumption of the on condition by the succeeding device in the ring, a plurality of timer means respectively connected to said plurality of devices, each timer means adapted to be actuated by its device to produce a timing potential of a magnitude proportional to the duration of the on condition of its device, a connecting control connected to alternate ones of said devices, an oscilloscope, said connecting control adapted to respond to the assuming of the on condition of said alternate ones of said devices to successively connect the two most recently actuated timer means to said oscilloscope, and resetting means connected to alternate ones of said devices, said resetting means adapted to respond to the assuming of the on condition of said alternate ones of said devices to successively discharge the timing potentials of the two timer means most recently connected to said oscilloscope.

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7. In combination, a ring circuit of the type comprising a plurality of pulse responsive bistable devices so interconnected as to be individually actuated in succession in response to occurrence of successive pulses in a plural series of pulses having different pulse repetition rates applied to said ring circuit, each of said devices having an on and an off condition, each of said devices responsive to said pulses to assume its on condition at the instant of occurrence of the pulse occurring immediately after the preceding device in said ring circuit has assumed its on condition, each of said devices adapted to resume its off condition in response to the assumption of the on condition by the succeeding device in the ring, a plurality of chatter pulse discriminatory means respectively connected to each of said devices and through which said pulses must pass to reach said devices, said discriminatory means having a charge time constant which is small relative to the interval between successive ones of the pulses in the one of said series having the highest pulse repetition rate, said discriminatory means having a discharge time constant which is small relative to the interval between successive ones of the pulses in the one of said series having the slowest pulse repetition rate and which is large relative to the interval between successive ones of the pulses in those of said series having pulse repetition rates which are at least an integral multiple of the repeti-

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tion rate of the one of said series having the slowest pulse repetition rate, a plurality of timer means respectively connected to said plurality of devices, each timer means adapted to be actuated by its device to produce a timing potential of a magnitude proportional to the duration of the on condition of its device, a connecting control connected to alternate ones of said devices, an oscilloscope, said connecting control adapted to respond to the assuming of the on condition of said alternate ones of said devices to successively connect the two most recently actuated timer means to said oscilloscope, and resetting means connected to alternate ones of said devices, said resetting means adapted to respond to the assuming of the on condition of the alternate ones of said devices to successively discharge the timing potentials of the two timer means most recently connected to said oscilloscope.

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