Jan. 18, 1955 K. W. PFLEGER 2,700,133

MEASUREMENT OF RELATIVE DELAY OF WAVE ENVELOPES

Filed April 25, 1951 9 Sheets-Sheet 1

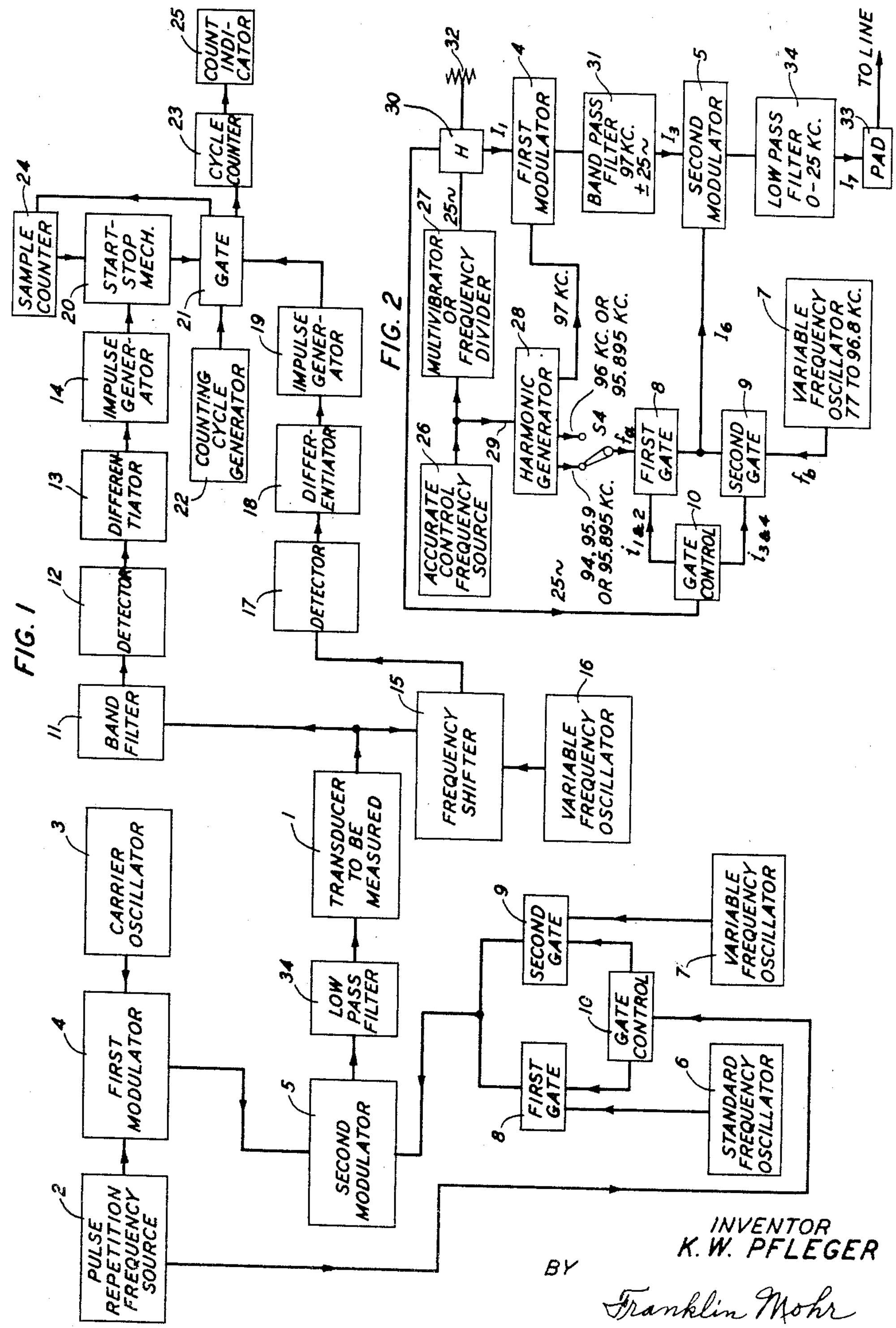

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FIG. 3

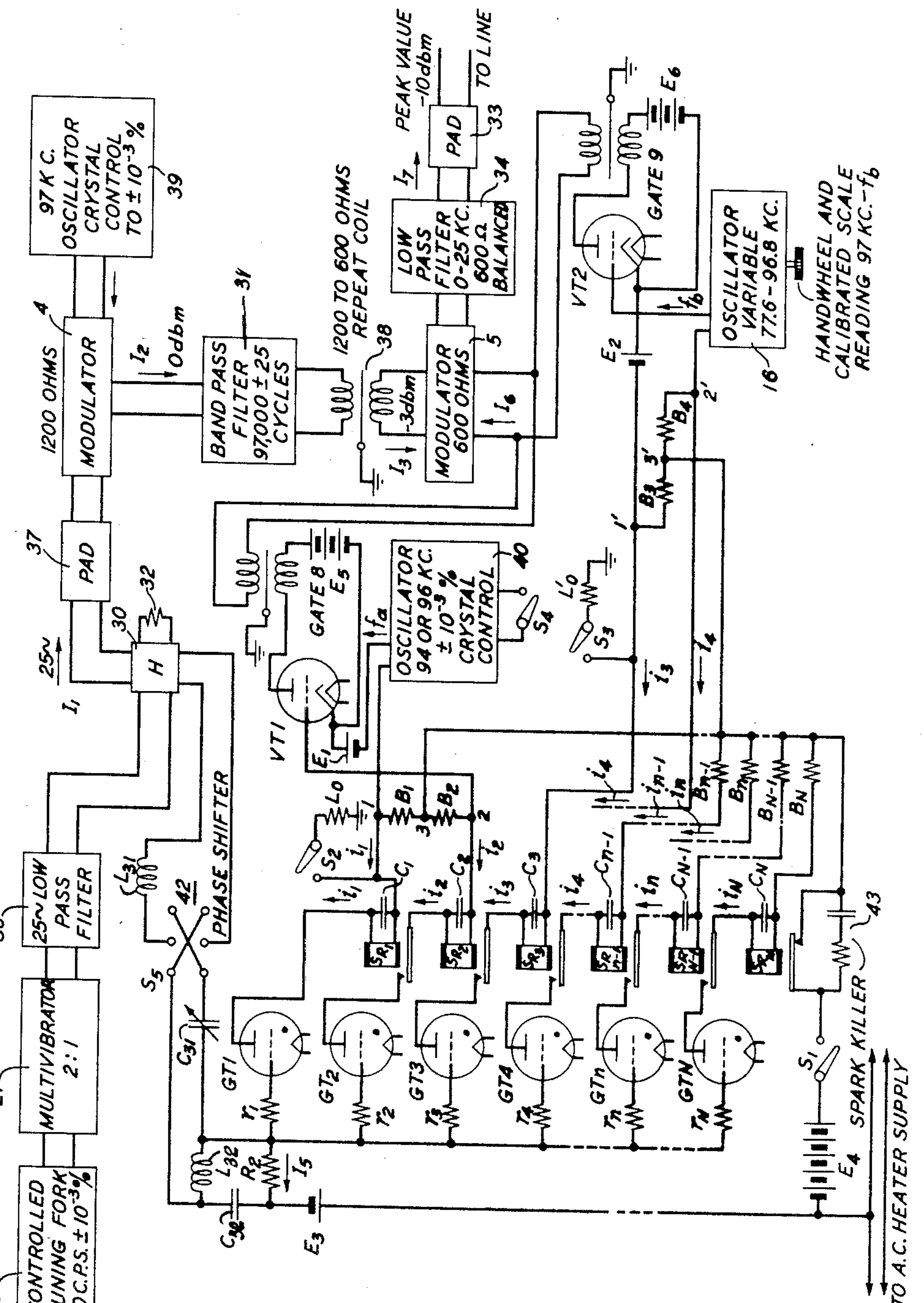

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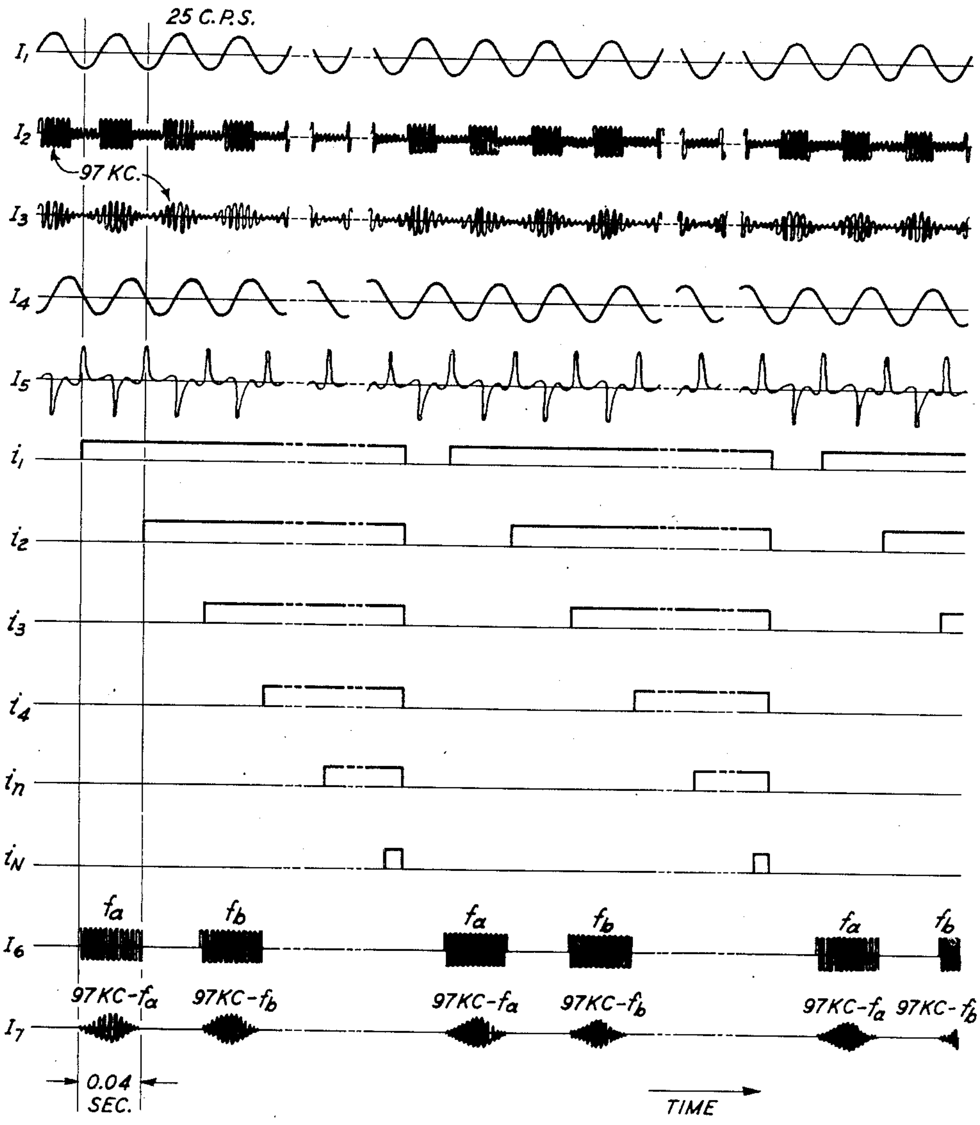
FIG. 4



OSCILLOGRAMS (NEGLECTING DELAY IN FILTERS)

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FIG. 5

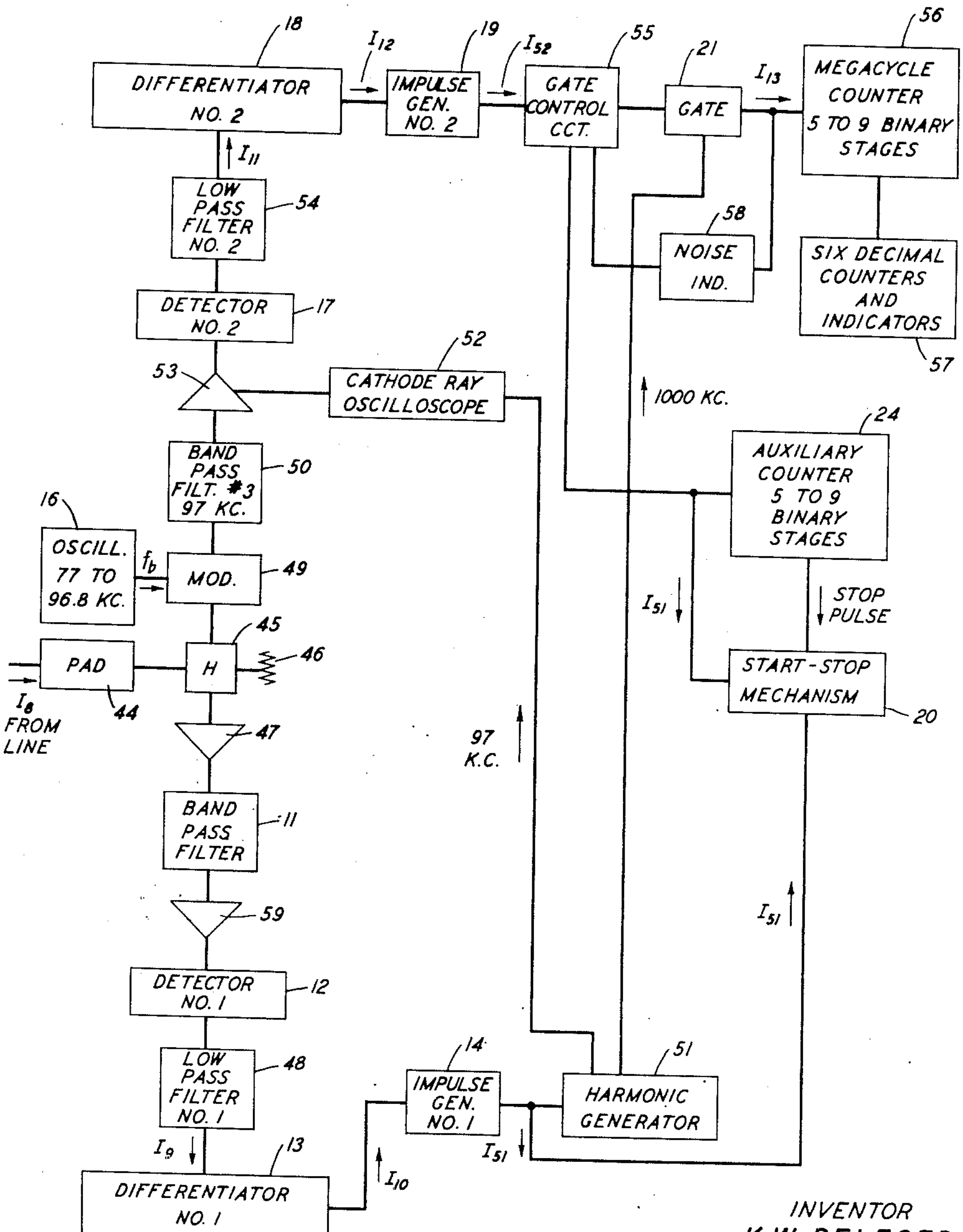

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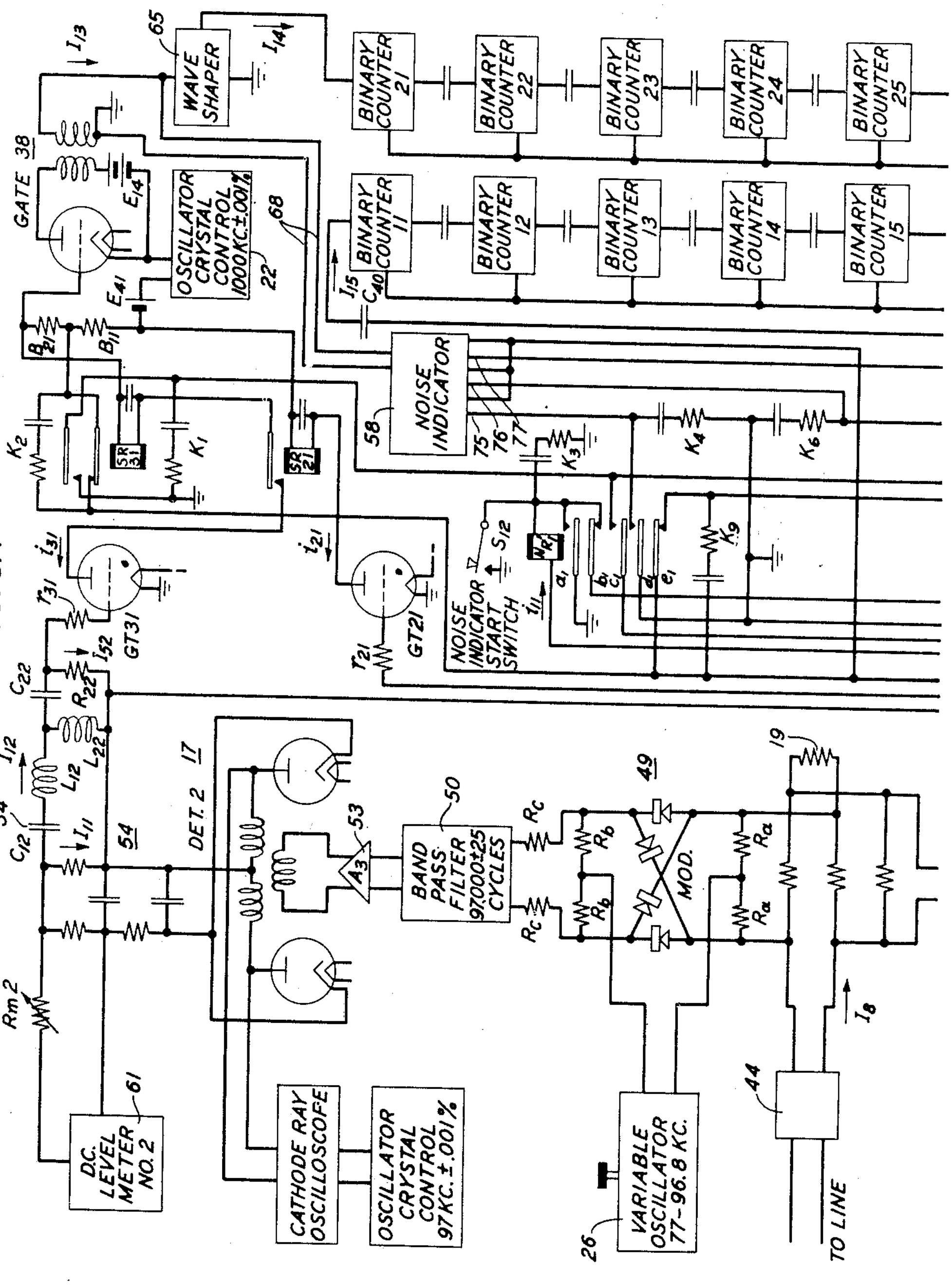
FIG. 6A



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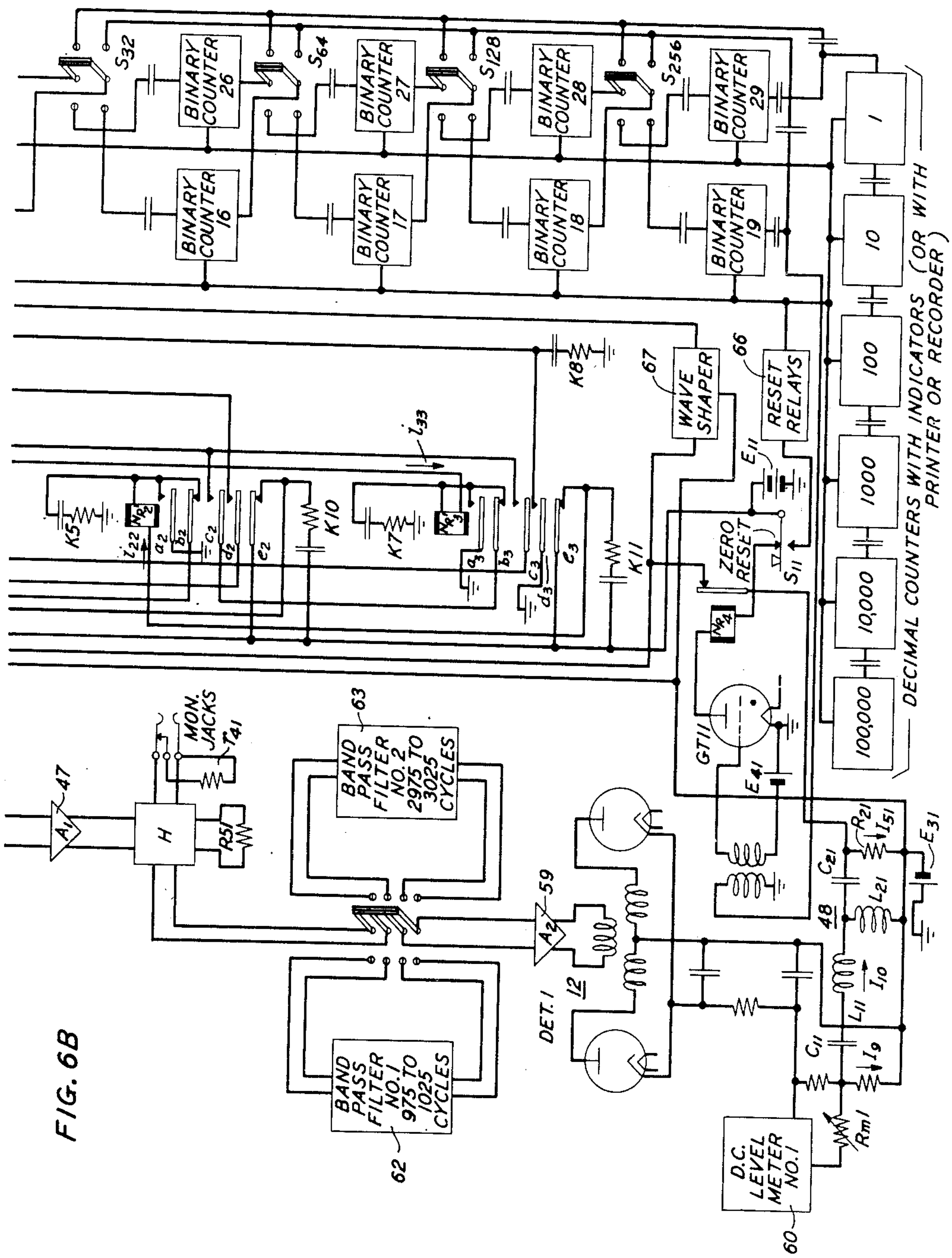

FIG. 6B

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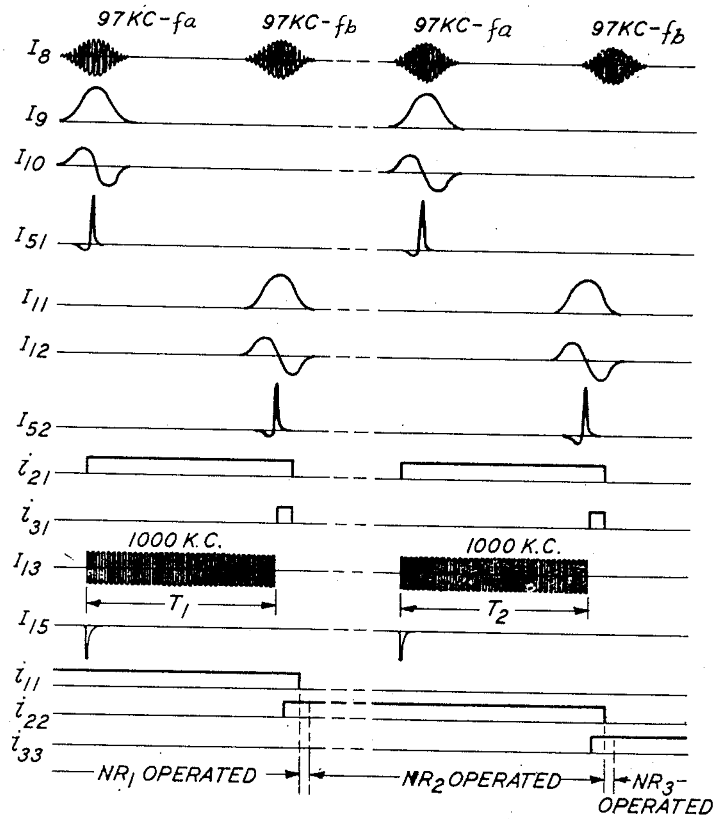
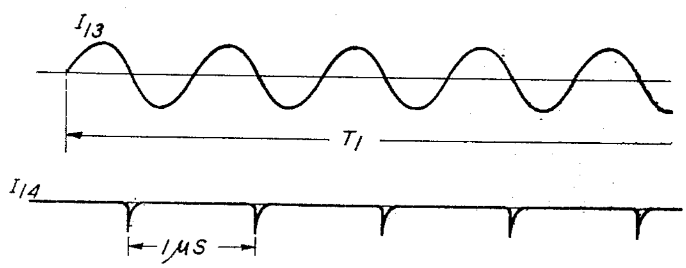
FIG. 7



OSCILLOGRAMS (NEGLECTING DELAY IN FILTERS)
TIME →

FIG. 8



ENLARGED OSCILLOGRAMS
TIME →

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FIG. 9

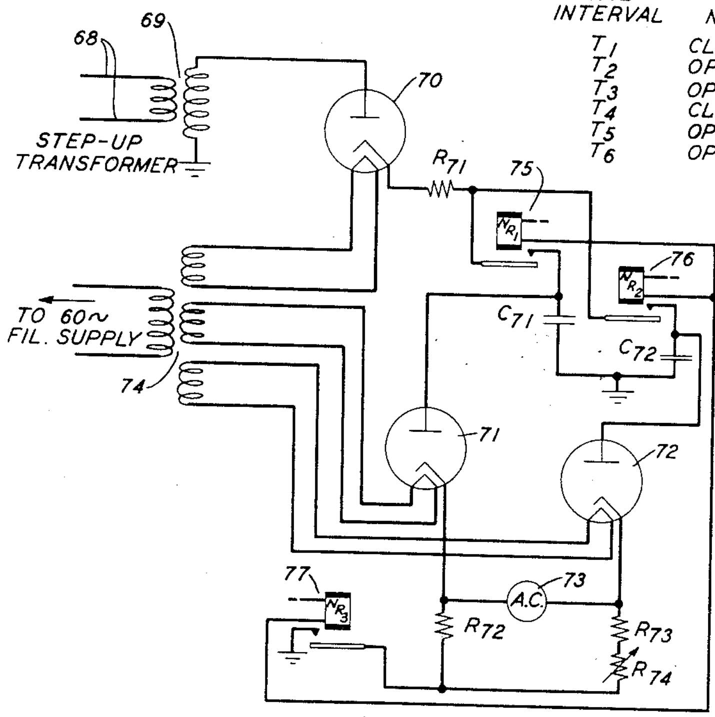


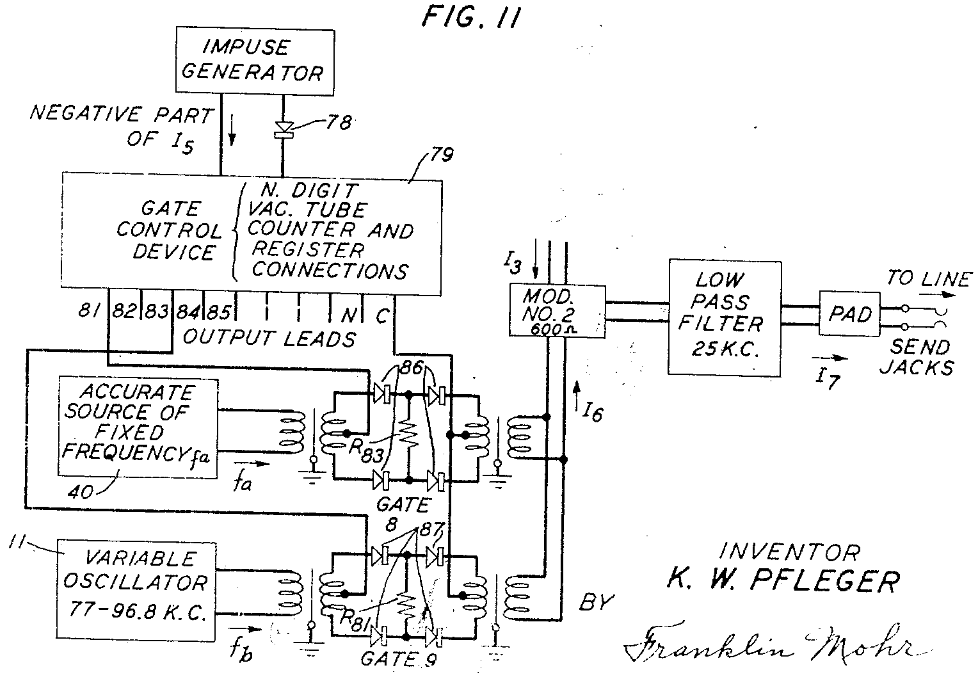
FIG. 10

SEQUENCE OF RELAY OPERATION

TIME INTERVAL	NR1	NR2	NR3
T_1	CLOSED	OPEN	OPEN
T_2	OPEN	CLOSED	OPEN
T_3	OPEN	OPEN	CLOSED
T_4	CLOSED	OPEN	OPEN
T_5	OPEN	CLOSED	OPEN
T_6	OPEN	OPEN	CLOSED

etc.

FIG. 11



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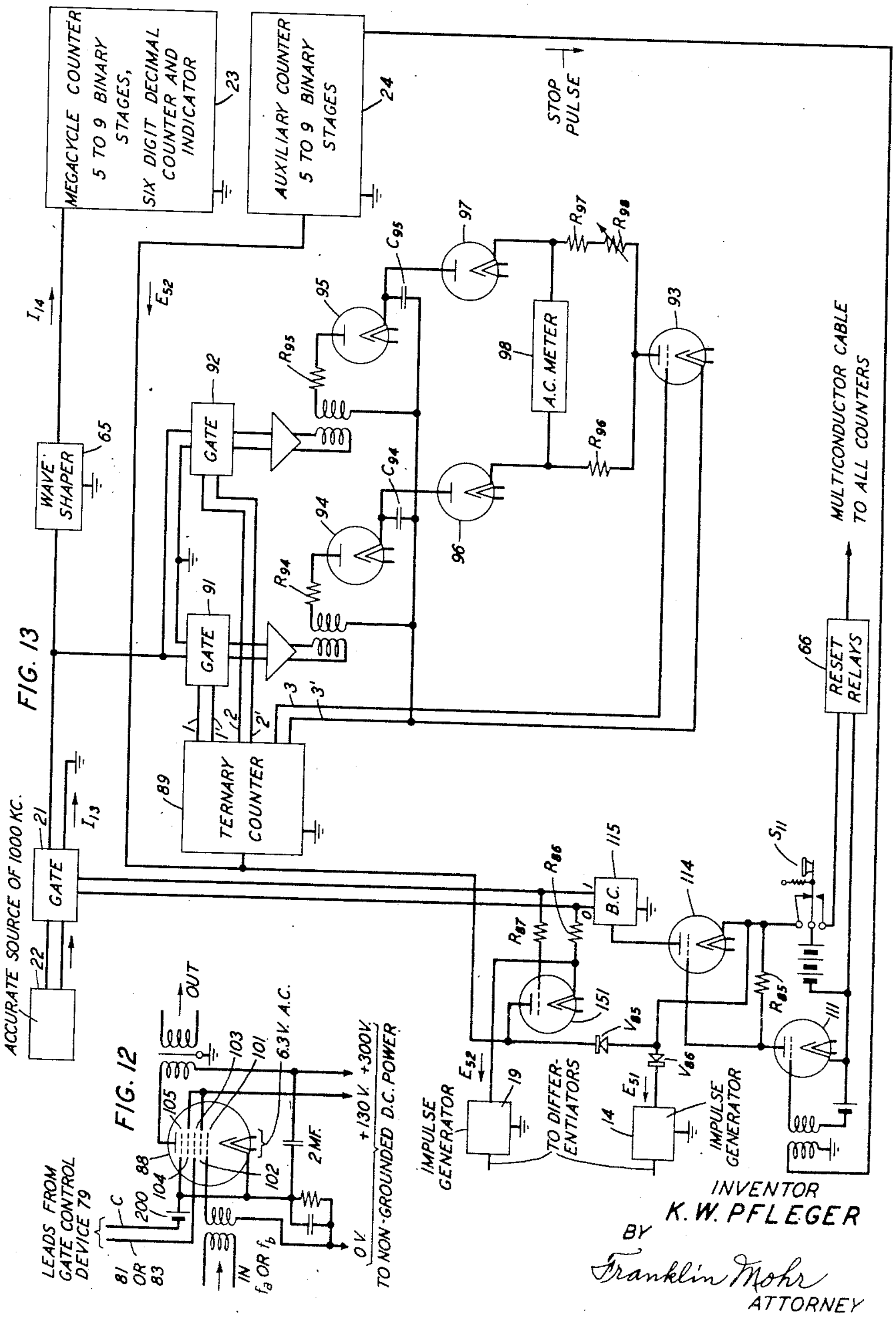
MEASUREMENT OF RELATIVE DELAY OF WAVE ENVELOPES

Filed April 25, 1951

9 Sheets-Sheet 9



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United States Patent Office

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MEASUREMENT OF RELATIVE DELAY OF WAVE ENVELOPES

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Application April 25, 1951, Serial No. 222,832

6 Claims. (Cl. 324—57)

This invention relates to electrical measuring apparatus and methods and more particularly to apparatus for measuring envelope delay distortion and relative delay time in the transmission of waves or signals over an extended transmission system as a function of frequency.

The invention is applicable to systems in which the sending end and receiving end are separated any given distance and does not require a return transmission path to the sending end, except as may be necessary for intercommunication between personnel at the sending and receiving terminals, which intercommunication may be carried out over any available return line, for example, by telegraph or telephone.

A feature of the invention is the sending of test signals alternately at a standard reference frequency and at a variable measuring frequency.

Another feature is automatic clocking of the interval between the arrival of successive test signals at the receiving terminal.

A further feature is a display of the relative delay time at the receiving terminal.

In the figures:

Fig. 1 is a single-line schematic diagram of an illustrative system embodying the invention;

Fig. 2 is a single-line schematic diagram of an illustrative sending device;

Fig. 3 is a double-line schematic diagram of an illustrative sender in greater detail than shown in Fig. 2;

Fig. 4 is a group of illustrative oscillograms of currents in various circuit branches of the systems of Figs. 2 and 3;

Fig. 5 is a single-line schematic diagram of an illustrative receiving device;

Fig. 6 is a double-line schematic diagram of an illustrative receiver in greater detail than shown in Fig. 5;

Fig. 7 is a group of illustrative oscillograms of currents in various circuit branches of the systems of Figs. 6 and 7;

Fig. 8 is a group of enlarged oscillograms of currents in certain circuit branches in the systems of Figs. 6 and 7;

Fig. 9 is a schematic diagram of a noise indicator;

Fig. 10 is a tabulation of a sequence of relay operations involved in the operation of the noise indicator of Fig. 9;

Fig. 11 is a schematic diagram of an alternative gating system for use at a sending terminal;

Fig. 12 is a schematic diagram of a gate control circuit employing a pentagrid vacuum tube; and

Fig. 13 is a schematic diagram of a portion of an alternative receiving arrangement.

General method and apparatus

In accordance with the invention, the method of measuring envelope delay distortion as applied over a straightaway circuit or line, comprises (*a*) sending periodically onto the line to be measured a pulse of reference frequency tone and a pulse of comparison or measuring frequency tone, one after the other, preferably with restricted sidebands, (*b*) counting the time elapsing between arrivals of particular amplitudes of these pulses' envelopes at the receiving end, and (*c*) averaging the results of a multiplicity of such counts when it is desired to reduce fortuitous effects such as caused by noise. The averaged count may be automatically indicated; and successive indications, each taken with a different measuring frequency and using the same time interval between sent tones, give substantially the envelope delay distortion vs. frequency characteristic except for a constant delay which is usually unimportant. If the absolute delay is desired, it can be obtained when measuring is done on a loop rather than on a straightaway basis.

A variety of methods are known for the independent transmission of the reference and variable frequency signals. Of these, one in which time division is used is preferred, since it has the advantages of requiring only one circuit and of eliminating modulation difficulties between the two tones although at the expense of some storage mechanism at the receiver.

Usually two-way communication will be desirable between persons at each end of the line under test, and can be carried on over the same line during intervals between measurements. When the line does not transmit in both directions some auxiliary form of communication, for example, a telegraph or telephone circuit, may be used to convey intelligence back and forth from sender to receiver.

Usually the narrower the range to which sidebands of the measuring (variable) frequency signal are restricted the better, as the delay measured is then more nearly the same as the theoretical value, $d\beta/d\omega$, except that the received envelope wave is then so gradual in slope that it is very difficult to measure time accurately to a particular point on the wave. As a compromise in a telephoto circuit, e. g., it is practical to receive a signal spectrum about 50 cycles wide from the line having sidebands each 25 cycles wide. The sent wave's envelope is rounded, closely approximating the function $c(1+\cos 50\pi)$ where c is a constant and t has values from $-.02$ to $+.02$. Outside this range of t the envelope is zero until time for the next mark. This gives rise to a wide band of frequencies but the energy outside the 50 cycle band is small. Due to the cut-off of the receiving band-pass filter, the received envelope departs somewhat from that of the sent wave.

The sidebands of the reference frequency signal need not be restricted to such a narrow band as 50 cycles, because it is not necessary that its delay approximate $d\beta/d\omega$. Any delay value is satisfactory for the reference pulse so long as it is constant. However, the greater the restriction of band width, the easier it becomes to use measuring frequencies close to the reference frequency without erroneous operation of selective receiving circuits due to overlapping of frequency spectra of these tones. By using wide sidebands for the reference tone and by giving it a steep wave front the need for much amplification of the reference wave at the receiving end diminishes, as discussed below. Of course, the frequency spectrum of the reference tone should not contain much energy in the frequency range used for the measuring tone, and consequently it is then difficult to measure delay distortion very close to the reference frequency. The use of two reference frequencies is then generally necessary in order to obtain a complete delay distortion characteristic over all parts of the desired frequency range. Although the illustrative examples disclosed hereinafter do not use wide sidebands, this possibility is available in case one wishes to trade cost and weight of apparatus for the slight inconvenience of using two reference frequencies.

In the event that a 50 cycle band width is used for both the reference and measuring frequency marks, one may use measuring frequencies as close as about 100 cycles to any reference frequency. Furthermore, by using two different reference frequencies successively it is possible to obtain the delay distortion anywhere in the pass band of the line, when the delay distortion characteristic obtained with one reference frequency is modified by a suitable constant so that one continuous characteristic results when both are plotted on the same graph.

In the counting mechanism, to measure the time interval between the arrivals of particular amplitudes of the reference and measuring tones, measuring preferably is done between peak values of the detected envelope waves of these tones because small amounts of level variation or selective attenuation on the line do not appreciably affect the mechanism's ability to discern the instants of maximum current. These instants are easily recognizable after passing the detected envelopes over a differentiating circuit because the latter's output wave passes through zero at each maximum of the received wave, and the rapid change in sign of the differentiator's output is suitable for the precise operation of trigger circuits for starting or stopping an electronic counter.

In order to insure still more reliable operation of trigger circuits the transitions in the differentiator's output wave may be greatly amplified, as is accomplished partly by non-linear coils which generate a sharp impulse of high voltage, and partly by linear amplification.

Separate amplifiers and differentiators may be used for the two detected signals, although some saving in cost may result from a reduction in such apparatus, such as by the use of wider sidebands for the reference frequency signal as explained above.

Although an electronic counter measures delay precisely in one observation, the value may be influenced by interfering effects such as caused by noise. Therefore it is generally advantageous to design the counter so that it makes a number of delay measurements and indicates the average value.

Outline of illustrative system

Fig. 1 is a simplified schematic diagram of an illustrative system having the basic elements required in the practice of the invention. Sinusoidally-enveloped pulses of a suitable high-frequency carrier are produced at accurately timed intervals at the sending end of the transducer **1** to be measured, such as a line by means of a pulse repetition frequency source **2** of frequency such as 25 cycles reacting with a carrier oscillator **3**, of frequency such as 97,000 cycles, in a first modulator **4**. The resulting modulated wave is impressed upon a second modulator **5** along with selected and timed pulses of standard and variable comparison frequency oscillations of uniform duration from oscillators **6** and **7** respectively. The pulses of standard frequency are under the control of a first gate **8** and those of the variable frequency under the control of a second gate **9**, both gates being operated by a gate control device **10** which in turn is under the control of the low frequency source **2**. The device **10**, upon being manually started by the operator, first opens gate **8** to pass one pulse of standard frequency, then closes gate **8** for a selected number of pulse intervals, generally only one pulse interval, as in the illustrative system, then opens gate **9** and pass one pulse of comparison frequency, closes gate **9** and holds both gates closed for a selected number (one or more) of pulse intervals and repeats this series of operations until shut down. The modulator **5** shifts the standard and variable comparison pulses downward in frequency to the desired values of frequency with which the transducer **1** is to be tested, for example, the standard pulses may be shifted to 3,000 cycles and the variable frequency pulses to the range 200 to 20,000 cycles, a low pass filter **34** being inserted between the modulator **5** and the transducer **1**. At the receiving end of the line a band filter **11** selects the 3,000 cycle pulse which is thereupon translated into a sharp impulse by means of a detector **12**, a differentiator **13** and an impulse generator **14**. To handle the pulses of variable frequency efficiently it is usually preferable to shift them to a common frequency band as by means of a frequency shifter **15** controlled by a variable frequency oscillator **16**. The common frequency may advantageously be placed at 97,000 cycles in the illustrative example. The 97,000 cycle resulting pulse is translated into a sharp impulse by means of a detector **17**, a differentiator **18** and an impulse generator **19**. The first impulse upon the generator **14** is used to actuate a start-stop mechanism **20** which in turn actuates a gate device **21** which connects a standard counting cycle generator **22** to a cycle counter **23** which counts cycles from the generator **22** as long as the gate **21** remains open. The next impulse, which comes from generator **19**, shuts off the counting cycle generator, and, registers a count of one on a sample counter **24**. When the last sample has been received and its number of cycles counted, the sample counter **24** stops the counting process by actuating the start-stop mechanism **20** to close the gate **21**. The total count is shown on the count indicator **25**, and is an automatically averaged value of all sample counts, as explained more fully hereinafter.

Sending apparatus

The purpose of the sender is to transmit to the sending end of the line under test successive modulated spurts of reference and variable comparison frequency separated by fixed time intervals of zero current as shown by the oscillogram of current I_7 in Fig. 4. The reference frequency as illustrated is (97 kc.$-f_a$) where f_a may have any convenient number of fixed values, and the variable frequency is (97 kc.$-f_b$) in the example shown. These two voice frequencies are the result of heterodyning in the example hereinafter described. The envelope wave of these spurts is substantially sinusoidal as explained below, and resembles a 25 cycle wave in the system. The duration of each spurt is .04 second when the modulating wave is 25 cycles. The time elapsing between the peak value of the reference tone and the peak value of the next following spurt of variable frequency tone is assumed to be fixed, at .08 second. Therefore there is zero output during .04 second of this interval. This interval may be made greater if desired depending upon whether the envelope delay in the line is appreciably greater at the reference frequency than at any variable frequency used, it being necessary that these pulses shall not overlap at the receiving end of the line.

The choice of the time elapsing between the peak value of the variable frequency tone and the peak of the next succeeding reference frequency spurt depends upon the amount of delay distortion to be measured, since it is necessary that the spurt of variable frequency tone shall not overlap or run into the spurt of reference frequency tone at the receiving end of the line. It is evident that the duration of the zero current interval following a pulse of variable frequency at the sender output should about equal the maximum value of delay distortion to be measured.

Illustrative spurts or pulses are shown in Fig. 4 as current I_7 and in order to obtain current I_7, the sending device may be shown schematically by the single line diagram in the upper portion of Fig. 2.

In Fig. 2, a source **26** of accurate frequency provides the input wave of a multivibrator or frequency divider **27** whose output is the first modulating frequency, for example, 25 cycles per second in the case of certain telephotograph circuits.

The 25 cycle wave passes over a hybrid coil **30** and one output thereof is connected to one input of the first modulator **4**. The other input of this modulator is an accurate high frequency, for example 97 kilocycles obtained either as a harmonic of the accurate source **26** through the connection **29** as shown (or from the frequency divider **27**). The value 97 kilocycles is assumed for illustrative purposes. A narrow band-pass filter **31** is shown at the output of the first modulator **4**. The sidebands passed by this filter are narrow so that the current I_3 at its output has only three frequencies: 96.975, 97.0 and 97.025 kilocycles. The amplitudes of 25 cycles per second and 97 kilocycles applied to modulator **4** preferably are adjusted so that I_3 is 100 per cent modulated as shown in the oscillogram of Fig. 4. If the control source **26** is a 50 cycle per second tuning fork the connection **29** may be used, 97 kilocycles being the 1940th harmonic of 50 cycles per second. This may require several stages of harmonic generation. If the control frequency is 1 kilocycle, only the 97th harmonic is required.

The harmonic generator **28** may provide also any desired number of accurate high frequencies near 97 kilocycles such as values shown in Fig. 2 at two other outputs of the generator, and discussed more fully below. The particular high frequency desired may be selected by means of a switch S4 and is the frequency referred to hereinabove as f_a. A rectangular spurt of frequency f_a is passed by the first gate **8** starting and ending when the envelope of I_3 has zero value as shown in the oscillogram of I_6. A rectangular spurt of .04 second duration of frequency f_b from the variable high frequency oscillator **7** is passed by the second gate **9**, .04 second later than the spurt of f_a as shown in the oscillogram of I_6. The gates **8**, **9** and the gate control **10** are described more fully below, and are synchronized by a current of 25 cycles from the other output of the hybrid coil **30**. A balancing network **32** for the hybrid coil **30** is indicated schematically, and a pad **33** is shown connected between a low pass filter **34** and the line to be tested.

The currents I_3 and I_6 enter the second modulator **5** and the lower sideband in the output is selected by the low pass filter **34**, the current I_7 being obtained. When current I_6 has long continued zero value I_7 also is zero because the current I_3 does not appreciably pass over the modulator **5**, which is preferably balanced for this purpose, and the low pass filter **34** cuts off well below 96.975 kilocycles.

Fig. 3 shows an illustrative sender in greater detail with an arrangement of gates and gate control circuits using gas tubes and relays.

In Fig. 3 the sources of f_a and 97 kilocycles are shown as precise oscillators, though in many practical applications it may be preferable to use the harmonic generation indicated in Fig. 2. Except for the individual oscillators shown in Fig. 3, the operation of this arrangement is substantially the same as for Fig. 2, but more details are given.

The source **26** is replaced by a controlled tuning fork **35** which may have a frequency of 50 cycles per second with a precision of, for example, ± one one-thousandth of one per cent. The multivibrator **27** may have a frequency dividing ratio of 2:1, giving an output of 25 cycles, which is preferably passed through a low pass filter **36**. A pad **37** is shown between the hybrid coil **30** and the modulator **4**. The harmonic generator **28** is not needed and is omitted. A repeating coil **38** may be used between the filter **31** and the modulator **5** for matching impedances. The 97 kilocycles output provided by the harmonic generator **28** in Fig. 2 is supplied instead by an oscillator **39**, which may be crystal controlled to the same precision as the tuning fork **35**. The 94 kilocycles or 96 kilocycles output provided by harmonic generator **28** in Fig. 2 is supplied instead by an oscillator **40** which may also be crystal controlled to the same precision.

The peaked wave form of current I_5 described below and shown in the oscillograms in Fig. 4 would be particularly useful for activating a harmonic generator, although none is shown in Fig. 3. The **25** cycle low pass filter **36** shown at the multivibrator output in Fig. 3 may be desirable to insure a suitable approximately sinusoidal wave form in the generator of I_5 described below, the design of which is based on current I_4 being sinusoidal.

In Fig. 3 provision is made for a zero current interval of any desired multiple of .04 second following the sent variable frequency pulse in current I_7. This zero current interval governs the value of N, the number of gas tubes in a series, G. T. 1 to G. T. N, shown at the left of Fig. 3. The operation of these tubes is described below from which it is apparent that the greatest delay distortion which can be measured with the arrangement shown is about .04 (N–3) second and the time elapsing between the peak value of the sent variable frequency tone and the peak of the next succeeding sent reference frequency spurt is .04 (N–2) second. The period of repetition of the sent signal is .04N second.

While large values of N enable one to measure great amounts of delay distortion, it should be noted that the time consumed in the automatic counter and averaging device is also proportional to N. In order to speed up the testing of short lines and to provide equipment for measuring long ones, it is advisable to make N variable.

Means for varying N are not shown in Fig. 3 but can be included by means of keys (not shown) so that N may be made to vary effectively from 4 to any desired larger value, the minimum number of gas tubes required in measuring small distortions generally being 4.

The upper path from the hybrid coil **30** conducts the 25 cycle current I_1 through the resistance pad **37**, for the purpose of adjusting the level, to the modulator **4**. The current I_2 at the modulator output is substantially 25 cycle carrier telegraph reversals, and need not have a sinusoidal envelope. The amount of carrier leak from the modulator is to be adjusted so that the wave I_3 as seen at the band-pass filter **31** output is 100 per cent modulated. A cathode ray oscilloscope (not shown) is desirable to check the wave form of I_3 and I_7. It may be a small portable oscilloscope.

The current I_6 at the other input of the modulator **5** of Fig. 3 is substantially the same as in Fig. 4 and results from operation of gates **8** and **9** of either figure to pass rectangular spurts of fixed or variable frequency, f_a or f_b, respectively, each of .04 second duration, and timed so as to occur just when the spurt of (97 kilocycles—f_a) or (97 kilocycles—f_b) is desired in output current I_7. (In this statement the delay of low pass filter **34** has been neglected as it may be very small.) The method for operating the gates is described below.

The filter **34** at the output of the modulator **5** should be balanced and should preferably have negligible delay distortion in the measuring frequency range of the set, say 200 to 20,000 cycles per second. If difficulty is experienced in obtaining negligible delay distortion, the cut-off frequency of the filter **34** may be raised to 70 or 80 kilocycles, or more. The purpose of the pad **33** between the filter **34** and the line is to control the level of current entering the line or transducer to be measured, and to obtain a suitable terminating impedance at the sending end thereof.

The spurts of f_a and f_b should be substantially equal in amplitude. In order to make this adjustment one may observe I_6 on the oscilloscope while adjusting the volume controls (not shown) of the oscillators **40** and **11**. Another method is to observe the level at the output of the pad **41** first with gate **8** open and gate **9** closed and second with gate **8** closed and gate **9** opened. Switches for manually controlling opening and closing of these gates are provided and described below.

The variable oscillator **16** provides a continuously adjustable frequency over the range say 77 to 96.8 kilocycles so that the value of 97 kc.—f_b appearing at the input of the line ranges from 200 to 20,000 cycles per second.

In order to control the opening and closing of gates **8** and **9**, the accurate 25 cycle frequency from the lower output of the hybrid coil **30** is passed through an adjustable phase shifter **42** consisting of an inductance L_{31}, variable condenser C_{31} and a reversing switch S_5.

The current I_4 should pass through zero very close to the zero values of the envelope of I_3, because switching is then desired controlled by sharp pulses in current I_5 produced by a non-linear coil L_{32} of a network L_{32}, C_{32}, R_2. The requirement is that the voltage generated across resistance R_2 shall build up rapidly reaching 8 volts or more within about 2 microseconds. If this cannot be done satisfactorily with the coil L_{32} alone, it can be done using a multistage amplifier limiter instead, provided the grid bias does not vary. The reason for this requirement is that the switching of the gates must be done at precise instants. L_{31} and C_{31} should have high reactances at 25 cycles per second in order to prevent the discharge from C_{32} from being dissipated too much in the 25 cycle source. The exact values of C_{31} and L_{31} may be readily found by trial. The hybrid coil **30** may be of inequality ratio since only about +20 dbm. (decibels above milliwatt) would be required for I_1. The coil L_{32} may be of the type described by Peterson, Manley and Wrathall in "Magnetic Generation of a Group of Harmonics," Bell System Techanical Journal, vol. XVI, page 437, 1937.

Illustrative values for L_{31} and C_{31} are from 6 to 12 henries and from 2 to 8 mf. respectively. The final setting for this phase shifter depends mainly on the delay in the filter **31**. The phase shifter gives a range of nearly a quarter cycle for each position of switch S_5. Additional phase shift range can be obtained if necessary by shunting reactance directly across the lower output of the hybrid coil **30**.

Successive positive peaks in current I_5 generate sufficient voltage across resistance R_2 to fire gas tubes G. T. **1** to G. T. N, inclusive, when plate voltage is connected. Protective resistors r_1 to r_N, inclusive, are shown in series with the grids so that there is no appreciable current drawn thereby. It is possible that these resistors in some cases may not be needed. The gas tubes have their respective anode circuits operatively connected to individual relays SR_1 to SR_N inclusive.

Switches S_1 and S_5 are normally closed and S_2 and S_3 are normally open. Before closing S_1 all relays SR_1 to SR_N, inclusive, are released and gas tubes not firing. The normal grid biases E_1 and E_2 of gates **8** and **9** are sufficient to prevent transmission of oscillators' outputs through the gates. After closure of S_1 the first positive pulse in I_5 causes gas tube **1** to fire and current i_1 begins, causing a direct current voltage drop across a resistor B_1 which counteracts part of the negative grid bias and puts gate **8** in a transmitting state, so that frequency f_a is transmitted by gate **8**. The rise of i_1 operates slowly the relay SR_1, (SR_1 must be slow enough not to operate before the first positive pulse of I_5 has died out or SR_2 may operate prematurely), and connects battery E_4 to the plate of G. T. **2** which fires on the next positive pulse of I_5. Then the current i_2 begins. The voltage drop across a resistor B_2 is equal and opposite to that caused by i_1 across B_1. The result is immediate closure of gate **8** since the grid bias is then equal to the full value of E_1.

When i_2 begins, relay SR_2 operates slowly (for a similar reason to SR_1) and connects battery E_4 to the plate of G. T. 3 which fires on the next positive pulse of I_5. The rise of current i_3 opens gate **9** because of the voltage drop across a resistance B_3, and slowly operates relay SR_3 to put plate battery on G. T. 4.

The next positive pulse of I_5 causes G. T. 4 to fire. The rise of i_4 closes gate **9** because of the voltage drop across B_4, and slowly operates relay SR_4. Succeeding positive pulses of I_5 operate the other gas tubes in this series one at a time in a similar manner, but their protective load resistors B_{n-1}, B_n, . . . B_{N-1}, and B_N do not operate any gates. When the last gas tube, G. T. N, has been fired, its plate circuit relay SR_N opens contact to extinguish all gas tubes. Relay SR_N should be slightly slow in releasing so that it does not release until all gas tubes are completely extinguished. It is clear that the number of gas tubes in this series determines how long it takes before all are extinguished and the circuit ready to begin over again the procedure of opening and closing the two gates successively.

The currents i_1, i_2, i_3 and i_4 should reach steady state value without overshoot almost instantly once the correspondingly numbered gas tube has fired. Therefore small condensers, c_1, c_2, c_3, and c_4, et cetera, are shunted around the respective relay windings. This also tends to slow down the relays' operation as desired. Values of these condensers are readily found by trial after observing the gas tube currents with an oscilloscope.

When high values are used for resistors B_1, B_2, B_3, . . . B_N, the currents i_1, i_2, i_3 . . . i_N may be small and the gas tubes may be miniature. On the other hand these resistors should not be too high or vacuum tubes V. T. **1** and V. T. **2** of gates **8** and **9** respectively, will have their cathodes far removed from ground and might become noisy. Suitable values are readily found by trial. The oscillators of frequencies f_a and f_b may be connected either directly to the grid bias battery as in the case of oscillator **40**, or directly to the grid as in the case of oscillator **16**. Trial should readily reveal which location is preferable from the noise standpoint, and then both oscillators can be connected in the preferred manner to their respective gates.

A spark killer **43** may be connected across contacts of relay SR_N to reduce contact deterioration, but should be designed so that the gas tubes go out quickly. Otherwise spurious gate openings may occur if the decays of the plate currents are unequal.

On opening S_5 and S_1 all the relays release. Then one may close S_1 and S_2 if one desires gate **8** to be open for a longer time. By closing S_1 and S_3 gate **9** is made open. On opening first one gate and then the other in this manner one may observe the effect on level in I_6 or I_7 due to adjusting the power outputs of oscillators of frequencies f_a or f_b as previously mentioned. Resistors L_0 and L'_0 may be provided to give the same resistance as a gas tube when firing.

The advantage of the electronic gates is that commutation occurs very rapidly and without the usual troubles found in mechanical distributors such as brush chatter or variation in contact resistance.

The filter **31** attenuates greatly any sideband frequencies in I_3 which are more than 25 cycles from 97 kilocycles.

One may tolerate some minor departure in the loss characteristic of the filter **31** from perfect symmetry about 97 kilocycles as well as some small inaccuracy in the setting of the phase shifter **42**, so long as the spurts of tone of reference and variable frequency in I_7 have the same well rounded envelope shape, which should be satisfactory for measuring envelope delay even if not perfectly sinusoidal.

Direct current sources E_1, E_2, E_3, E_4, E_5 and E_6 are shown as batteries. Obviously one may use another form of direct current potential source but the requirement is that certain of them should be entirely separate. Thus if E_3 and E_4 have their common side grounded, no ground should be on the other direct current sources.

If trouble with noise in V. T. **1** and V. T. **2** is experienced, a separate heater supply may be necessary so that they are not heated from the same source as the gas tubes.

Receiving apparatus

In order to carry out the function of the receiving device as stated above, the apparatus shown by the single line schematic of Fig. 5 may be provided.

The current I_8 shown in the oscillograms of Fig. 7, received from the line closely resembles I_7 of Fig. 4, except for such difference between arrival of spurts of reference frequency (97 kilocycles—f_a) and variable frequency (97 kilocycles—f_b) as is caused by envelope delay distortion of the line.

The current I_8 after traversing a pad **44** divides at a hybrid coil **45** with balancing network **46** into two paths. The reference frequency passes through a buffer amplifier **47** and the band-pass filter **11** and enters detector **12** (DET. 1) through a buffer amplifier **59**. The carrier frequency is eliminated by a low pass filter **48** (L. P. F. 1). The resulting direct current wave I_9 is shown in the oscillograms in Fig. 7 as a rounded "E" signal. It is not quite sinusoidal due to band width limitation in the receiving narrow band-pass filter **11**. Both reference and variable frequency spurts from the upper output of hybrid coil **45** enter a signal shifter comprising a modulater **49** (MOD), a variable oscillator **16** and a 97 kilocycle band-pass filter **50** (B. P. F. 3). The variable oscillator is set to give the frequency f_b so that pulses of frequencies (97 kilocycles—f_b) on entering the modulator **49** are shifted to 97 kilocycles and pass through B. P. F. 3. The 97 kilocycle output of a harmonic generator **51** further mentioned below and a cathode ray oscilloscope **52** (C. R. O.) are useful in checking the frequency of the shifter's output. Pulses of frequency (97 kilocycles—f_a) are shifted by the modulator **49** but then lie outside the pass band of B. P. F. 3. The output of this band-pass filter is next amplified in amplifier **53** and detected in detector **17** (DET. 2). The carrier frequency is eliminated by a low pass filter **54** (L. P. F. 2) and the current I_{11} is obtained similar to I_9 except for a delay.

Both I_9 and I_{11} are next differentiated in differentiators **13** and **18** respectively to yield waves I_{10} and I_{12}. These waves pass through zero at instants corresponding to maxima of I_9 and I_{11} respectively.

The waves I_{10} and I_{12} act upon impulse generators **14** and **19** respectively, which preferably employ non-linear coils to produce the impulses I_{51} and I_{52} respectively having sharp positive peaks building up at a fast rate so that prompt and definite action of the connected circuits results. These circuits comprise a gate control circuit **55**, the gate **21**, a megacycle counter **56** having a plurality of binary stages, and a set of decimal counters **57** with indicators.

Once a start button (S_{11} to be described hereinafter with reference to Fig. 6) has been pressed which automatically resets all counters on zero, the positive pulses of I_{51} open the gate **21** and the positive pulses of I_{52} close the gate. A megacycle current I_{13}, produced by the harmonic generator **51** activated by periodically repeated pulses of I_{51}, flows through the gate **21** during an interval of time T equal to the interval between the occurence of a positive pulse in I_{51} and the next succeeding positive pulse in I_{52}.

Each time a pair of these pulses occurs a spurt of megacycle current of duration T enters the binary megacycle counter **56**. This counter and the connected decimal counter **57** operate as described below to indicate the average value of T in microseconds on a digital register, which may be luminous and may show six digits, more or less, as desired, or may be arranged through known printing mechanisms to record figures, or upon a paper tape.

Sample counter **24** sends a negative pulse into the start and stop mechanism **20** which stops all counting when sufficient repetitions of the interval T have been measured and averaged, as described below.

In prior art systems employing a dynamometer, the operator of the delay measuring set can tell when excessive noise is present by unsteadiness of the dynamometer reading as explained. In the case of random noise he must watch the dynamometer deflection a while and estimate an average reading. In the case of single frequency noise he can change the variable carrier frequency slightly and eliminate the effect. In the set herein described, the presence of noise may vary the location of peak values of I_9 and I_{11} which tends to make unequal the successive intervals of megacycle current such as T. This inequality can be detected by a noise indicator **58** which operates under control of the gate control circuit **55** as described below. The meter of the noise indicator may be calibrated to indicate the number of repetitions of the interval T which ought to be averaged in the case of random noise. Then the operator can see how to set switches in the binary counters which govern the number of repetitions of the measurement of T as described hereinafter. The presence of a single frequency noise usually causes the noise indicator meter to deflect. Its effect should be eliminated by varying the carrier frequency until the noise does not pass the narrow band receiving filter as discussed more fully below.

In Fig. 6, the harmonic generator of Fig. 5 is replaced by separate precise oscillators which need not be used in practice if the harmonic generator is cheaper, lighter or otherwise preferable.

The pad 44 is provided for coarse adjustment of received current, since it is desirable to maintain fairly constant levels into the modulator **49** and the amplifier 47. Pad 44 also provides a suitable terminating impedance for the transducer under test. Very constant levels should be maintained in the two detectors as by means of slide-wire potentiometers (not shown) located within power amplifiers **59** and **53**, and a pair of sensitive and sluggish direct current level meters **60** and **61** may be held by these manual controls to constant deflections in order to reduce phase variations caused by non-linearity in the detectors **12** and **17**. The former detects the reference frequency tone while the latter detects the variable frequency tone after it is shifted in frequency to 97 kilocycles by the variable frequency oscillator and modulator in the previously discussed manner. The detected pulses I_9 and I_{11} are also shown qualitatively in the sketch of oscillograms on Fig. 7 and resemble the modulating wave form described above except for slight distortion due to line and filters which is unimportant because it is practically unchanged over the range of testing frequencies.

The narrow band-pass filter **50** of approximately 50 cycle width is used in the signal shifter to reduce the line noise and other disturbances if present.

The band-pass filters **62** and **63** for two reference frequencies are also of about 50 cycle width when the sent pulses of reference frequency are thus restricted in frequency spectrum as this favors measuring fairly close to the reference frequency without appreciable error.

The low-pass filters **48** and **54** immediately following the respective detectors **12** and **17** consist of series resistors and shunt condensers because inductances at high levels are apt to be non-linear and to cause varying effects as the level changes slightly. These filters suppress the carriers. No wave shaping is required of these filters due to the wave shaping action of the sending band-pass filters.

Currents I_{10} and I_{12} are substantially proportional to the slopes of currents I_9 and I_{11} respectively due to the differentiating effect of series condensers C_{11} and C_{12}, which respectively perform the functions of the differentiators **13** and **18** of Fig. 5.

Coils L_{21} and L_{22} are non-linear and operate similarly to L_2 of Fig. 3, to produce sharp wave fronts in currents I_{51} and I_{52} so that the voltages across resistors R_{21} and R_{22} rise from 0 to 8 volts in about 2 microseconds. The optimum values for circuit elements connecting to these non-linear coils may be found by trial.

Inductances L_{11} and L_{12} help to suppress the carriers and prevent discharge of condensers C_{21} and C_{22} toward the source. These inductances should be substantially linear. Each may consist of one or more retard coils. The inductance of such coils should be determined experimentally to obtain the desired maximum amplitudes for I_{10} and I_{12} with a minimum of input power and without excessive transients. Initial fluctuations during the build up of I_{10} and I_{12} are not wanted as they may cause unwanted pulses in I_{51} and I_{52} ahead of the desired times which might give false operation of gas tubes.

A zero reset switch S_{11} is provided and when this has been closed momentarily, gas tube G. T. **11** is not firing and a neutral relay NR_4 is released so that a pulse of I_{51} is transmitted over the contact of NR_4 and resistor r_{21} to the grid of gas tube G. T. **21** which fires to open the vacuum tube gate 38 in the manner previously described in connection with gates in Fig. 3.

The next succeeding pulse in I_{52} is transmitted over resistor r_{31} to the grid of gas tube G. T. **31** which fires to close the gate. Accordingly the megacycle current I_{13} which passes the gate has the duration T_1. This is equal to the time interval elapsing between the sharp rises of the respective pulses in I_{51} and I_{52} provided currents i_{21} and i_{31} rises abruptly with equal slopes to full value when the respective gas tubes fire.

Resistors r_{21} and r_{31} should be designed similarly to r_1 to r_N of Fig. 3.

A relay SR_{31} is necessary in series with the plate of gas tube G. T. **31** which operates to cut off its plate voltage from source E_{11} and extinguishes both gas tubes very soon after gate closure.

A relay, SR_{21}, having substantially identical winding impedance to that of SR_{31}, is provided in the plate circuit of gas tube G. T. **21** so that both plate circuits have substantially identical transient responses. The windings of SR_{21} and SR_{31} may be shunted by small condensers so as to obtain the nearest approach to rectangular on and off switching of the gate. The contacts of relay SR_{21} are open at the firing instant of gas tube G. T. **21** to make sure that tube G. T. **21** fires before tube G. T. **31**, but close shortly thereafter to permit firing of gas tube G. T. **31** on the next pulse of I_{52}.

The megacycle pulses in I_{13} are shown again to an enlarged scale in Fig. 8. They may be passed through a wave shaper **65** to produce negative pulses of the same fundamental periodicity, as shown in the oscillogram of I_{14}. Such pulses are suitable for operating binary counters B. C. **21**, B. C. **22**, et cetera. In some cases, the shaper **65** is not needed, the binary counter operating satisfactorily without the shaper. The shaper may be made of either tube circuits or varistor circuits, or a copper oxide varistor with a direct current bias may be used to pass short pulses of only one polarity.

The counting mechanism, described below keeps adding up the number of megacycle pulses it receives not only during time interval T_1 but also during T_2 and succeeding time intervals measured until a predetermined number of such intervals have passed whereupon a pulse is received by the grid of gas tube G. T. **11** from an auxiliary series of binary counters, B. C. **11**, B. C. **12**, et cetera, which count the number of positive spikes in I_{51}. This pulse fires the gas tube G. T. **11** and its plate current operates the relay NR_4 to stop further spikes in I_{51} from acting on the counters, at which time the counter indication becomes stationary and may be read and recorded by the operator. Operation of NR_4 should not occur until at least .04 (N−1) second has elapsed following the final spike in I_{51}, and must be complete before .04N second has elapsed, in order to allow the gate to remain open for the longest necessary value of T and to make sure it does not open after the last value of T. Therefore relay NR_4 should be slow acting and its slowness should be adjustable if N is varied.

The restoring of all counter circuits to the zero condition is accomplished by pressing the reset key S_{11} which operates reset relays **66** to make suitable voltage changes in the power supply of the counter stages, as discussed below.

The circuits of relays NR_1^1, NR_2^1, and NR_3^1 are provided for the purpose of driving a noise indicator as described below. This indicator detects variations in lengths of successive spurts of the current I_{13}. When these variations are excessive, the number of samples of the time intervals T_1, T_2, T_3, et cetera, averaged by the megacycle counter should be increased as described more fully below.

The number of samples averaged is controlled by a set of switches S_{32}, S_{64}, S_{128}, and S_{256}. When all these switches are closed to the left, 512 samples are averaged. When one of these switches is closed to the right and the others are closed to the left, the number of samples averaged is the same as the subscript on the designation of the switch which is closed to the right.

The time which is required for the counter to average a given number of samples is about equal to that number multiplied by .04N second.

A wave shaper **67** is also shown for the current pulses I_{15} used to drive the auxiliary counter. Pulses in I_{51} when inverted may be suitable for driving this counter. Therefore the wave shaper **67** may be nothing but an inverter, for the purpose of changing positive pulses into negative pulses similar to I_{14}.

In case the sent reference tone is given wider sidebands, band-pass filters **62** and **63** should be just wide enough to pass them. A tenfold increase in these sidebands permits the received reference signal to build up about ten times as fast and changes the shape of I_9 from sinusoidal to nearly rectangular. The differentiated current I_{10} then consists of positive and negative spikes. By making use of one or the other of these spikes to fire G. T. **21** and to operate the auxiliary counter, one can omit L_{11}, L_{21} and condenser C_{21} and probably decrease the size of amplifier **59** and detector **12**. The values for R_{21} and for the low pass filter **48** would be changed, the resistors being much smaller as they need not dissipate as much heat.

Electronic counters trigger circuits, gates, et cetera, have been used for other purposes. Consequently no detailed explanation of these elements is considered necessary. Electronic counters are described by C. B. Leslie, "Megacycle Stepping Counter," Proceedings Institute Radio Engineers, volume 36, No. 8, August, 1948, pages 1030 to 1034.

Counting mechanism

It is assumed in the system illustrated that during a time interval T ranging in duration from about 40,000 to 40,000 (N–1) microseconds, a precisely one megacycle current flows from the oscillator **22**, Fig. 1, suitable for operating an electronic pulse counter. The time interval and the one megacycle current flow are repeated periodically, each such interval being separated by a short time of zero current. Due to small amounts of line noise not under control, slight fortuitous variations exist in the value T from one repetition to the next. In order to reduce the effect of these, and to obtain a better value of T, it is desirable to add and average a number of separate measurements of T. In accordance with the invention, apparatus is provided to automatically indicate the result in microseconds.

Let 2^n denote the approximate number of repetitions of T which should be averaged in order to reduce the fortuitous effects to a negligible amount, the value for n being calculable for any small amount of noise as explained below. The megacycle pulses of I_{14} in Fig. 6 are made to operate first on a binary electronic counter comprising n pairs of (or n double) tubes. The output of the binary counter is connected to a six stage decimal counter. The latter counter regiscters a digit about once in each 2^n microseconds. The final reading of the decimal counter is the desired average value of T.

Averaging of a plurality of measurements of T is effected automatically by adjustment of a scale factor associated with the counting mechanism. An average being by definition the sum of m readings divided by m and the sum is equal to m times the average. For example, if the sum of eight readings is 1,600,000, the average is 200,000. Hence, if the counter counts once for every eight cycles of the megacycle current, the result of impressing 1,600,000 cycles upon the counter is an indicated count of 200,000 which gives the average directly expressed. Also, if there are a total of 6,400,000 cycles impressed upon the counter in the course of 32 readings, average reading again 200,000, the counter may be arranged to count once for every 32 cycles, giving an indicated count of 200,000, thus once more directly indicating the average. By using such a scheme, the average value as indicated is independent of the number of samples averaged.

It is evident that when $n=5$ there are 32 samples of T averaged and since samples of T occur every .2 second when N=5 the running time is 6.4 seconds. It has been determined by computation that in the case of a telephotograph line on which there is a normal or average amount of random noise here assumed to be like thermal noise, the measuring error represented by the average of 32 values of T has a standard deviation of 8.2 microseconds, which should usually be satisfactory precision in measuring telephotograph circuits. Such a normal or average amount of thermal noise is sometimes referred to as a thermal noise level of 35 dba. with telephoto weighting at the zero level point of a telephotograph line. The unit used in expressing the noise level is adjusted decibels, abbreviated dba., and refers to the reading of a noise measuring set such as the Western Electric Company's No. 2 type noise measuring set described in Bell Laboratories Record, March, 1936, volume 14, page 233, when used with an appropriate equalizer designed to weigh the disturbing effect of noise currents of different frequencies and durations upon a telephotograph circuit, the noise measurement being made at the zero level point of the line.

Experience with telephotograph operation has indicated that the highest tolerable limit of thermal noise is reached at 45 dba. or 10 decibels above the normal or average condition. When the noise is at the highest tolerable limit, the number of values of T which must be averaged to obtain the same standard deviation of error is ten times as great, or 320. In the binary scale the lowest sufficient value of n is 9, requiring the averaging of 512 values of T, since with n equal to 8, only 256 values of T would be averaged. Accordingly the binary counter needs to have 9 double tubes or stages such as B. C. **21** to B. C. **29** in Fig. 6, so that n may be varied by desired amounts between 5 and 9, using switches S_{32}, S_{64}, S_{128}, and S_{256} as described above.

Noise indicator

Noise on the line may reduce the accuracy of the timing of an interval by distorting, lengthening, or shortening of the pulses of I_8 of Fig. 7, which in turn affects the shape of the detected pulses, I_9 and I_{11}, and displaces the zero points of I_{10} and I_{12}, and hence affects the spacing between the impulses I_{51} and I_{52}. The net result is that either too many or too few cycles of the standard frequency are included in the intervals T_1, T_2, et cetera, of I_{13}. The accuracy in the presence of line noise may be improved by including a large number of intervals in the cycle count. The more the effect of line noise, the more intervals should be included. As the effect of line noise is random, it is very likely to make itself evident by making adjacent intervals unequal. The more noise, the more inequality is likely to be found.

Although one may compute the number of values of T which should be averaged when the line noise has a certain value, it is advantageous to have a meter which indicates this automatically.

In Fig. 6 it is shown that the output of the vacuum tube gate **38** is tapped by a branch circuit delivering megacycle power to the noise indicator **58** shown simply by a box in this figure but shown more in detail in Fig. 9. Therein leads **68** and a step-up transformer **69** impress a high megacycle voltage upon a rectifier **70** which may charge either condenser C_{71} or C_{72} over a high resistance R_{71}. Therefore the charge on either condenser is proportional substantially to the charging time which is the same as the duration of a spurt of megacycle current such as T_1 or T_2, et cetera.

As shown by the table of Fig. 10, a neutral relay NR_1 has closed contacts during time interval T_1, corresponding to the spurt of megacycle current T_1 in the oscillogram of Fig. 7. The condenser C_{71} is charged during this time T_1. The contacts of two other relays NR_2 and NR_3 are then open as shown in the table. Shortly thereafter the contacts of NR_1 open and this is followed by closure of contacts of relay NR_2 so that during time interval T_2 the condenser C_{72} is charged. After the end of interval T_2 the contacts of NR_2 open. Shortly after this the contacts of relay NR_3 close which permits both condensers to discharge simultaneously to ground through a pair of rectifiers **71** and **72** and resistors R_{72}, R_{73} and R_{74}. The resistance R_{74} is adjusted so that the alternating current meter reads zero when the two condenser discharges are equal as when noise is absent. Then subsequent inequality of duration of two adjacent spurts of megacycle current will cause unequal charges upon condensers C_{71} and C_{72}, and during discharge will produce meter torque about in proportion to the difference between the durations of T_1 and T_2. The meter should be sluggish as of the thermocouple type and may be calibrated in terms of the exponent n required to satisfactorily average out the effect of the noise. (It would also be possible to operate switches S_{32}, S_{64}, S_{128}, and S_{256} automatically from the meter with the help of marginal relays, not shown.) Condenser discharge cannot occur until relay NR_3 closes contacts because neither tube **71** nor **72** will conduct current from filament to plate. The tubes **70**, **71**, **72** are served by a filament supply transformer **74**.

In order to insure closing or opening of contacts of relays NR_1, NR_2, and NR_3 to completely include all of the respective time intervals indicated in Fig. 10, various means can be used to activate the relay windings. One method is next described which uses three auxiliary neutral relays NR_1^1, NR_2^1, and NR_3^1 shown in Fig. 6.

Before the power supply E_{11} in Fig. 6 is turned on, relays NR_1^1, NR_2^1, and NR_3^1 are not operated and all their moving tongues are in the down position. After E_{11} is functioning, the operator starts the noise indicator by momentarily closing a start switch S_{12} which permits current to flow from E_{11} over a tongue e_2 of relay NR_2^1 through the winding of relay NR_1^1 to switch S_{12} and there to ground. This relay then operates and current continues to flow in its winding to ground by way of tongue a_1 after the start switch is no longer closed.

The operator may next press the zero reset switch S_{11} and the counting mechanism starts. During the entire first pulse of megacycle current in the interval T_1 current i_{11} flows through relay NR_1^1 as shown in the oscillograms, and consequently relay NR_1 is also operated due to closure of contact by tongue d_1 of relay NR_1^1 and a connection **75** indicated in Figs. 6 and 9.

Shortly after the interval T_1, relay SR_{31} operates to ground its lower tongue momentarily whereuon current i_{22} flows from source E_{11} over tongue e_3 of relay NR_3^1 through the winding of relay NR_2^1, tongue b_2, tongue c_1, tongue of relay SR_{31} and to ground. Accordingly relay NR_2^1 operates and remains operated after release of SR_{31} because of current i_{22} now flowing over tongue a_2 to ground. During operation of relay NR_2^1, tongue a_2 makes contact before tongue b_2 breaks contact. The make before break feature can be obtained by suitable mechanical design. Operation of NR_2^1 opens the contact of tongue e_2 so that relay NR_1^1 releases and i_{11} falls to zero as shown in the oscillograms of Fig. 7.

At about the same time as relay NR_1^1 releases, relay NR_1 releases as relays NR_1, NR_2, and NR_3 are all made fast release relays. However they are made slightly slow to operate so that closure of contact does not occur until after the previously operated relay in this group has released. Slow operation may be attained when necessary by inserting a separate inductance (not shown) in series with the winding of each relay to be slowed.

Operation of relay NR_2^1 permits current to flow over relay NR_2 to ground by way of tongue d_2, and a connection **76** shown in Figs. 6 and 9 and shortly thereafter relay NR_2 operates. The timing is such that it operates after NR_1 has released and before the start of time interval T_2.

Shortly after time interval T_2 another brief closure of the lower contact on relay SR_{31} occurs. This time current i_{33} flows from source E_{11} over tongue e_1, winding of NR_3^1, tongue b_3, tongue c_2, to lower tongue of relay SR_{31}, and thence to ground.

Immediately relay NR_3^1 operates and continues to remain operated due to current i_{33} flowing over tongue a_3 after release of SR_{31}. (Tongue a_3 makes contact just before tongue b_3 opens contact.)

Operation of relay NR_3^1 stops current i_{22} due to opening of the contact of tongue e_3. Due to operation of tongue d_3 and current through a connection **77** the operation of relay NR_3 takes place shortly after NR_2 releases caused by opening of contact by tongue d_2.

The next closure of relay SR_{31} permits the rise of i_{11} again by way of tongue e_2, winding of NR_1^1, tongue b_1, tongue c_3, and lower contact of SR_{31}. After SR_{31} releases, i_{11} continues by way of tongue a_1 and i_{33} is stopped by opening of contact e_1. (Tongue a_1 makes contact just before tongue b_1 breaks contact.) This concludes one complete cycle of events in the noise indicator auxiliary relays, and again places condenser C_1 in condition for charging just as soon as relays NR_1 operate due to closure of tongue d_1.

Spark killers K_1, K_2, K_3 . . . K_{11} are shown to reduce relay contact erosion. Condensers and resistances should be adequate to quench the sparks but should not slow down the current decay too much.

Alternative gating systems for sending terminal

An electric counting circuit shown in Fig. 11 and comprising a plurality of vacuum tubes and varistors may be used in place of the gas tubes and relays of Fig. 3 to reduce weight and cost of maintaining relay contacts. The oscillograms in Fig. 4 apply to Fig. 11 as regards currents shown in the latter, except for the insertion of a one-way device **78** so that only the negative pulses of current I_5 are received by the gate control device of Fig. 11.

An N-digit counter **79** of any suitable known kind may be used. The operation of the counter is such that during the first period of .04 second corresponding to a desired rectangular spurt of fixed high frequency f_a in the current I_6, the potential on output lead **81** of the counter **79** is positive with respect to that on lead C. This causes gate **8** to open because direct current passes over its varistors in the forward direction. At other times the potential of lead **81** is less than that of lead C and gate **8** is closed. During the third period of .04 second corresponding to a desired rectangular spurt of variable high frequency f_b, gate **9** is similarly operated, but at other times it is closed. Gate **8** may contain a plurality of varistors **86** and a resistor R_{83} and gate **9** may contain a plurality of varistors **87** and a resistor R_{81} as shown.

Values for resistors R_{81} and R_{83} are to be chosen by trial to obtain a high ratio between amplitude of gate output when open as compared to the closed condition, 35 decibels or more usually being satisfactory. When necessary to obtain a higher ratio, a multiplicity of such gates may be used in tandem, controlled by the same gate control output leads.

Switches may be provided by means of which one can open leads **81** and **83** and insert positive direct potential upon either gate for the purpose of obtaining a continuous current of either frequency f_a or f_b. This is useful when adjusting the sending levels.

Some care will have to be used in order not to render the counting mechanism inoperative due to the gate varistors having too low an impedance in the forward direction. If trouble is experienced in this respect one may use a pentagrid gate so that the control lead goes to a high impedance grid, as shown in Fig. 12.

Fig. 12 shows the alternative form of gate using a pentagrid tube **88**. Lead **81** or **83**, as the case may be, from the counter **79** is connected to grid **103** of tube **88** and lead C is connected to grid **105**. The input from either source **40** or oscillator **11** is connected through a transformer to the grid **101** and the output is taken from the anode. Grids **102** and **104** are connected together and function as screens between grids **101** and **103**, and **103** and **105**, respectively. An 18-volt biasing battery **200** shown in series with lead C keeps the gate closed during times when lead **81** or **83** has no positive potential. This biasing battery could also be in series with lead **81** or **83** instead of lead C, or could be partly in each lead so long as it is poled to make grid **103** more negative than grid **105**.

Alternative receiving arrangement

Fig. 13 shows a portion of a receiver similar to the arrangement of Fig. 6 except that all relays but those in the reset device are eliminated. The latter relays could also be eliminated if one would put their contact leads instead on a multiple contact switch including contacts of S_{11}. From the line to the differentiators the system is the same as that of Fig. 6. Also, the megacycle counter **23** and indicator and the auxiliary binary counter **24** are respectively the same in Figs. 6 and 13. The impulse generators **14** and **19** are the same in both figures except that in Fig. 13 negative pulses instead of positive pulses appear at their outputs, due to a reversal in the leads at their inputs, since negative pulses are required for operation of certain known types of binary counter. Counters **24**, **89** and **115** are shown as of such type, while counter **23** is shown as operatable on positive pulses, or when I_{14} consists of negative current as in Fig. 8, counter **23** operates on negative pulses.

The desired negative voltage pulses E_{51} and E_{52} have shapes similar to the current pulses I_{51} and I_{52} shown in oscillograms in Fig. 7 except for the change in sign.

Vacuum tubes **114** and **151** shown do not have continuous plate supply sources but are operable momentarily by negative pulses of suitable strength as in E51 or E52, under the further control of their respective grids, so that either tube is disabled when its grid is sufficiently negative with respect to its cathode.

When the power is first turned on, gas tube G. T. **111** will not be firing, but it fires when a sufficient number of pulses of E_{52} have acted on the auxiliary counter to produce a stop pulse at its output which acts on the grid of G. T. **111** through the associated input transformer. Counters **23** and **115** stop when G. T. **111** fires as explained below.

Before a delay measurement is made, one must press key S_{11} to operate the reset device which places all counters in the zero condition in the manner hereinabove described. It is necessary that all counters shall be reset to the zero condition before pulses of E_{51} or E_{52} are allowed to reach them. Therefore, key S_{11} is designed to make contact to the fast acting reset relays before plate current of tube G. T. **111** is cut off by the key, in order that all counters shall reach the zero condition before the plate current is cut off, which has the effect of removing negative grid bias from vacuum tube **114** and opening this vacuum tube gate to permit the next negative pulse of E_{51} to act on counter **115**.

In case a pulse of E_{52} occurs ahead of said pulse in E_{51} and after opening of vacuum tube gate **114**, that pulse of E_{52} can have no effect on B. C. **115** because with B. C. **115** on zero the potential of its output lead 1 is less than that of its output lead 0 which biases the grid of vacuum tube **151** negatively by about 22.5 volts and prevents plate current from flowing therein due to the pulses of E_{52}. Thus, it is evident that no pulse of E_{52} is received by any counter until the first pulse of E_{51} has acted on B. C. **115** to operate this counter to the 1 condition so that lead 1 at its output is about 22.5 volts more positive than lead 0 which opens the gate consisting of V. T. **151**. Resistors R_{86} and R_{87} may be provided if necessary to limit current flowing from leads 0 and 1 so that changes in potential on these leads shall not affect the performance of counter **115** through feedback action.

Gate **21** may be of either of the types shown in Figs. 11 and 12, and opens promptly when G. C. **115** is in the 1 condition, to permit megacycle current I_{13} to flow into the wave shaper **65** when the first pulse of E_{51} occurs after operation of the start button S_{11}.

The next pulse of E_{52} may pass through the anode-cathode circuit of V. T. **151** because the negative grid bias has been removed.

As soon as the negative pulse E_{52} reaches counter **115**, the counter operates to close gate **21** and terminates the duration of the spurt of megacycle current. Succeeding pulses of E_{51} and E_{52} also respectively start and stop the megacycle current I_{13} in the same manner. The result is the same as in Fig. 6 in that the starting and stopping of the megacycle current occur respectively as the impulses in E_{51} and E_{52} build up.

The purpose of varsitor V_{85} is to prevent pulses of E_{51} from operating the auxiliary counter **24** or the ternary counter **115** described below in connection with the noise indicator. Varistor V_{86} is provided to cut off the output impedance of impulse generator No. 1 during a pulse of E_{52} so that the full effect of the pulse acts on the counters.

In order to insure uniform action, the wave fronts of E_{51} and E_{52} should be steep and the counter **115** should be made fast acting the same as the first stage of the megacycle counter **23** hereinabove described.

When the desired number of repetitions of the megacycle spurt has been obtained, the auxiliary counter has received a corresponding number of pulses of E_{52} and its last stage then sends out a pulse which fires gas tube G. T. **111** as in the case of Fig. 6. In Fig. 13 the firing of G. T. **111** causes a voltage drop across resistor R_{85} which biases negatively the grid of vacuum tube **114** and prevents further operation of counters **115** and **23** inclusive due to succeeding pulses until after the operator has again pressed key S_{11}.

Whenever a pulse of E_{52} passes through vacuum tube **151** to operate binary counter **115** from the 1 to the 0 condition, the same pulse operates the auxiliary counter **24** with a signal similar to I_{15} of Fig. 7 except that it occurs at the end of the time intervals T_1, T_2, et cetera. Also, the same pulse operates a second auxiliary counter shown in Fig. 13 as ternary counter **89** for use in controlling gates **91**, **92** and **93** of the noise indicator. These gates replace relays respectively designated as NR_1, NR_2, and NR_3 in Fig. 9.

The gates **91**, **92** and **93** are opened one at a time in the order mentioned for the duration of .04N second after the respective pulse of E_{52}. N has the same meaning as in the previous description.

When gate **91** has opened, the megacycle current flowing through gate **21** after the next pulse of E_{51}, can also flow over gate **91**, amplifier A_4 and diode rectifier **94** to charge mica condenser C_{94} through a high resistance R_{94} so that the final charge on C_{94} when gate **91** closes on the next pulse of E_{52}, is proportional to the duration of the megacycle spurt, for example, T_1, in Fig. 7.

As soon as the ternary counter **89** closes gate **91**, it opens gate **92**, and during the next spurt of megacycle current, mica condenser C_{95} is charged in a similar manner to C_{94}, until its final charge is proportional to T_2.

As soon as gate **92** has closed, the ternary counter opens gate **93** so that both condensers C_{94} and C_{95} discharge simultaneously over one-way valves **96** and **97**, respectively, and over resistors R_{96}, R_{97}, R_{98} and the alternating current meter **98**. As described hereinabove the discharge circuit is balanced so that there is no meter indication when times T_1 and T_2 are equal. Since this noise indicator circuit will vary somewhat from time to time due to temperature changes in the condensers and resistances, et cetera, it should occasionally be readjusted for balance. Since it is not always possible to obtain a perfectly quiet line for use between the sender and receiver when making such adjustment, an inexpensive low frequency local oscillator should be provided in the receiver to provide signals with no fluctuation noise.

The plate supply for gas tube **111** as well as its grid bias battery (if used), are non-grounded in order not to interfere with the operation of the counters, all of which operate on a separate single plate supply which is assumed to have its negative terminal grounded.

As in the case of the meter **73** in Fig. 9, the meter **98** may be calibrated preferably in terms of the exponent n which determines the number of samples which should be counted to reduce to a desired degree the probable error of the measured delay time. It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

While in the sample-counting stages and in the preliminary standard wave cycle stages, binary counters are shown and are desirable in order that the number of samples may be readily variable in powers of two, it is nevertheless feasible to use ternary counters or counters based upon other numbers. Also, wherever decimal counters are shown, counters using systems of numeration with other bases may be used instead. Where the number of events to be counted is fixed, as in the noise measuring circuit of Fig. 13, there may be but one advantageous choice of the base of the system of numeration, for which reason the use of the ternary counter **89** may be preferred for controlling the three essential steps in the noise measuring operation.

What is claimed is:

1. A system for measuring relative delay of wave envelopes in transmission at different frequencies over a given path, comprising means for sending pulses of two frequencies to be compared alternately over the given path with a known interval between the starting time of successive pulses, means at the far end of said path for determining the instants of arrival of the successive pulses, and means to measure the elapsed time between the said instants of arrival.

2. A system for measuring relative delay of wave envelopes in transmission at different frequencies over a given line, comprising a source of waves of standard frequency, means for sending pulses of two test frequencies to be compared alternately over the given line with a known interval between the starting time of successive pulses, means at the receiving end of the line for determining a distinctive portion of each pulse to represent the instant of arrival of the respective pulse, and means to count cycles of waves of standard frequency as a measure of the elapsed time between the instants of arrival of successive pulses.

3. A system for measuring relative delay of wave envelopes in transmission at different frequencies over a given line, comprising a source of modulating potentials of substantially sinusoidal wave shape, means controlled by said modulating potentials for sending alternately over the given line pulses of two test frequencies to be compared with a known interval between the starting times of successive pulses, differentiating means at the far end of said line for determining a distinctive portion of each received pulse to represent the instant of arrival of the respective pulse, a source of waves of standard frequency, and means to count the number of cycles of waves of standard frequency occurring during the time interval between the instants of arrival of successive pulses.

4. Measuring apparatus comprising means for producing reference frequency pulses, means for producing comparison frequency pulses, control means controlled to a desired degree of accuracy for determining the time interval between successive pulses, means for alternately applying to a device to be tested pulses of reference frequency and pulses of comparison frequency following

each other at accurately determined time intervals, and means at the output of the device to be tested to measure the time interval between the arrival time at the said output of a pair of pulses comprising a pulse of reference frequency and a pulse of comparison frequency, whereby the relative envelope delay time for transmission through said device to be tested is determined for the reference and comparison frequencies.

5. Measuring apparatus comprising a source of carrier waves, a frequency stabilized low frequency source of modulating potentials, a first modulator controlled jointly by said carrier source and by said modulating potentials to produce accurately spaced carrier pulses, a reference frequency source, a comparison frequency source, a second modulator, gating means controlled by said low frequency modulating potentials for impressing alternately upon said second modulator waves of said reference frequency and of said comparison frequency whereby reference pulses and comparison pulses accurately spaced are impressed alternately upon the input of a device to be tested, and means at the output of the device to be tested for measuring the time interval between the arrival at the said output of a pair of pulses comprising a reference pulse and a comparison pulse, whereby the relative pulse delay time through the device to be tested is determined for the reference and comparison frequencies.

6. Measuring apparatus comprising a source of reference frequency waves, a source of comparison frequency waves, a source of pulse forming potentials of a repetition frequency relatively low with respect to said reference and comparison waves and controlled as to frequency to a desired degree of accuracy, means controlled by said source of pulse forming potentials to produce pulses of reference frequency and of comparison frequency respectively occurring alternately at accurately spaced time intervals, means to send said pulses over a line to be tested, and means to measure the time interval between the arrival time of a pair of pulses comprising a pulse of reference frequency and a pulse of comparison frequency, whereby the relative envelope delay time of the line for said pulses is determined for the reference and comparison frequencies.

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