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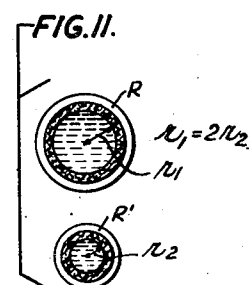
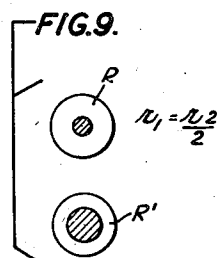
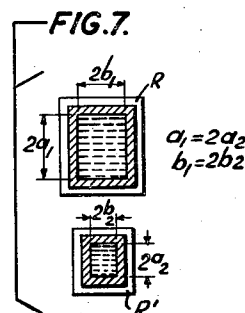
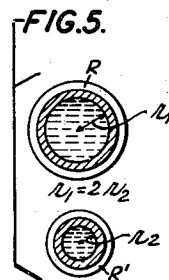
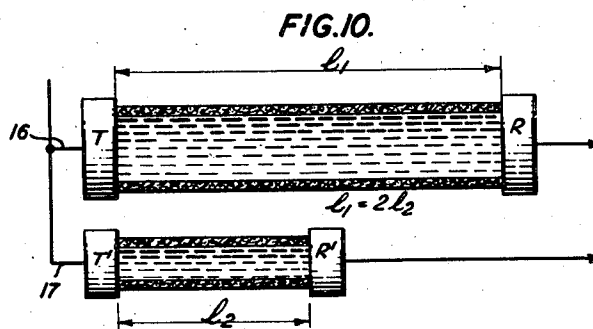
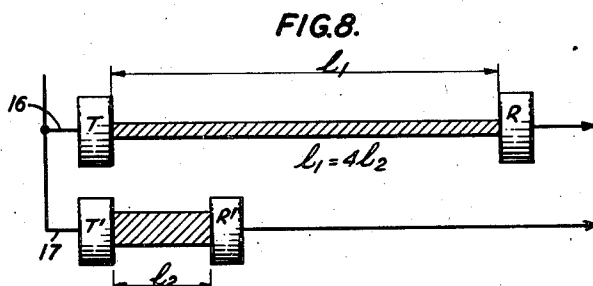
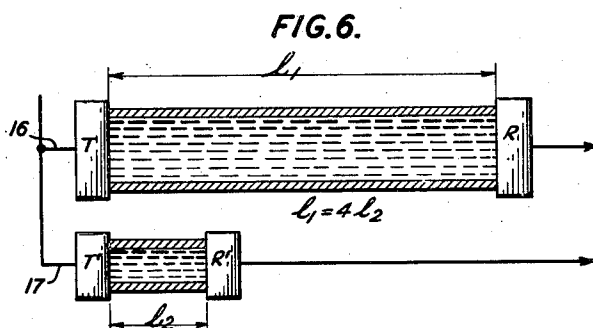
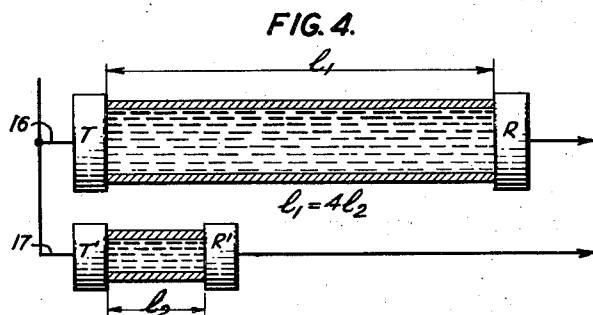
W. P. MASON

2,480,038

COMPENSATION OF DISTORTION IN GUIDED WAVES

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2 Sheets-Sheet 2



INVENTOR
W. P. MASON
BY
Harry C. Hart
ATTORNEY

UNITED STATES PATENT OFFICE

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COMPENSATION OF DISTORTION IN
GUIDED WAVESWarren P. Mason, West Orange, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

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This invention relates to signal delay devices and particularly to the transmission of signals through or over a wave guide delay line.

A general object of the invention is to compensate or correct for the modification of wave shape or distortion which accompanies the transmission of signals in many signal delay devices. A related object is to provide an improved balance between a signal which has been delayed by propagation over a wave guide delay line and a signal of later origin which has not been so propagated. Another related object is to provide an improved balance between a signal which has been modified in form by propagation over a wave guide of substantial length and another signal which has not been so propagated.

Delay devices, and especially wave guide delay lines, are characterized, in general, by attenuation and phase shift. The attenuation can usually be compensated by an amplifier which provides a gain equal to the transmission loss or attenuation of the line. The phase shift is more difficult to compensate, and in some applications a comparatively small amount of phase distortion may seriously affect the performance of the apparatus. For example, systems have been proposed in which a sequence of energy pulses are transmitted over two parallel paths one of which contains a delay line, the output signals from the two paths being balanced against each other in a suitable indicating device to give a null signal as long as all pulses of the sequence are alike, and a difference signal when they differ. However, as a result of phase distortion in the delay line, the delayed pulses always differ from the undelayed pulses so that an undesired difference signal appears, even when the original pulses of the sequence are identical, and masks the difference signal. It is a specific object of the invention to reduce this masking effect.

One type of phase distortion for which this invention provides compensation arises from the fact that each pure sinusoidal component of a guided wave of a particular type is propagated with a phase velocity which depends on its frequency, being, in general, greater than the phase velocity in the unconfined medium, approaching this value as the frequency increases without limit, but departing therefrom to an ever greater extent as the cut-off frequency of the guide is approached. Components having lower phase velocities are delayed more than are components having higher phase velocities. There is thus a relative phase delay between components, and phase distortion results. (The cut-off frequency

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of a wave guide is the frequency below which the guide will not support a wave of the type in question over any substantial distance, serving rather to attenuate rapidly any oscillatory energy delivered to its proximate end.)

At frequencies in the useful range of the guide, that is to say at frequencies which are not too close to the cut-off frequency, it turns out that the phase distortion for each particular type of guide is related in a specific manner to the length and the transverse dimensions of the guide. For example, in the case of a non-absorptive supersonic compression wave guide of length l and of circular cross-section radius r , the "relative phase delay" distortion coefficient for any particular angular frequency ω is given by

$$D_r = k_1 \frac{l}{r^2}$$

whereas the signal delay is of course proportional to the length l and independent of the radius r . This relation is developed below.

For a guide of rectangular cross-section, the corresponding expressions are two, namely:

$$D_r = k_2 \frac{l}{a^2}, \quad D_r' = k_2' \frac{l}{b^2}$$

where $2a$ is the length of the longer side of the section, and $2b$ is the length of its shorter side. Similar relations hold for electromagnetic waves in dielectric guides of rectangular or circular cross-section. In the case of an absorptive acoustic or supersonic guide, the corresponding relation is

$$D_r = k_e \frac{l}{r}$$

In the case of a compression wave in an elastic solid rod or wire the corresponding expression is

$$D_r = k_3 l r^2$$

For a torsional wave in a solid rod or wire the expression is similar, namely

$$D_r = k_4 l r^2$$

In these expressions k_1 , k_2 , k_3 , k_4 , etc. are constants depending only on the characteristics of the wave-supporting medium and on the frequency. They are independent of the dimensions of the guide.

The feature which is common to these expressions and which characterizes wave guides of the types above referred to as well as others is that the relative phase delay is a definite assignable function, for each particular type of guide, of its length and transverse dimensions. In ac-

cordance with the invention in its wave guide aspect, therefore, two wave guide delay lines of a particular type are provided, instead of one as in the past, and their dimensions are so adjusted that the relative delay function is the same for both, while their signal delays are different. Energy is fed to a matching circuit by two parallel paths, the longer delay line being connected in one path and the shorter line in the other. Thus the waves which reach the matching circuit by the two different paths, though delayed by unequal amounts, will have been distorted by equal amounts, so that for equal input signals, a substantial balance may be had in the matching circuit.

The invention in its wave guide aspects, therefore, is of use wherever it is required to balance or compensate for the distortion which results from propagation of a wave along a guide while still retaining the useful effects of the propagation. In its delay device aspects it is of use wherever a delay device of any type is employed for the sake of its useful delay and it is desired to compensate for the inherent phase distortion of the delay device. Among other applications it finds use in a moving target indicator (MTI) system, in which embodiment it will be described in the ensuing detailed description and illustrated in the accompanying drawings, in which:

Fig. 1 is a functional schematic diagram of a moving target indicator system modified to include the distortion compensator of the invention;

Fig. 2 is a diagram illustrating the relations between delayed and undelayed pulses for a fixed object;

Fig. 3 is a diagram illustrating the relations between delayed and undelayed pulses for a moving object;

Fig. 4 shows a longitudinal section and Fig. 5 a cross-section of both members of a matched pair of circular cross-section hollow wave guide delay lines dimensioned in accordance with the invention;

Fig. 6 shows a longitudinal section and Fig. 7 a cross-section of both members of a matched pair of rectangular cross-section hollow wave guide delay lines dimensioned in accordance with the invention;

Fig. 8 shows a longitudinal section and Fig. 9 a cross-section of both members of a matched pair of circular cross-section elastic solid rod or wire wave guide delay lines dimensioned in accordance with the invention; and

Fig. 10 shows a longitudinal section and Fig. 11 a cross-section of both members of a pair of absorptive-walled acoustic wave guide delay lines dimensioned in accordance with the invention.

Referring now to the figures, Fig. 1 is a functional schematic diagram of a circuit arrangement adapted to provide an indication of the movement of any object or target 1 which may be within the radiation field of an antenna 2 and to be non-responsive to the presence of fixed or momentarily stationary objects or targets within the field. Such systems may take various forms and may differ in major or in minor particulars. In the simple system shown, a multivibrator 3 or other source supplies a periodic sequence of short, sharp pulses 4 spaced apart by a time interval Δt_1 . The repetition rate may be of the order of 1000 pulses per second, in which case $\Delta t_1 = 0.001$ second. These pulses modulate the amplitude of a carrier wave, derived from an oscillator 5, any suitable modulating device 6 being provided for the purpose. After suitable amplification as by

an amplifier 7, the resulting pulse modulated carrier is radiated by the antenna 2 as short, sharp spurts of radio frequency energy spaced apart at intervals Δt_1 , the system being quiescent between. The carrier frequency is preferably very high, for example, 200 megacycles per second so that, by the use of a suitable antenna, high directivity of radiation may be obtained. The radiation may be directed toward any desired object by any desired means.

The pulse-modulated radio frequency energy travels outward from the antenna 2 in the desired direction, is reflected by any objects 1 that may be in its path, and returns to be picked up by a receiving antenna 11. After suitable amplification, as by an amplifier 12, the radio frequency may be beaten down as by an oscillator 13 and modulator 14 to a suitable intermediate frequency, for example, 5 megacycles per second. This process does not alter the wave shape of the envelope, which is schematically indicated at 15, and consists of short, sharp spurts of energy of the intermediate frequency, for example 5 megacycles per second, spaced apart by intervals Δt_1 .

This pulse-modulated intermediate frequency wave is next passed through two parallel paths, 16, 17, one of which 16 contains a guided wave delay device 18, adjusted to give a propagation delay Δt_2 between input terminals and output terminals. In prior systems the line propagation delay Δt_2 is equal to the pulse period Δt_1 , though in the present system Δt_2 exceeds Δt_1 , as will appear hereinafter. The delay line 18 may comprise a tube, pipe or trough of appropriate length containing a wave-supporting medium such as a liquid 19. The characteristics of mercury are such that it is well suited for the purpose. The pipe, tube, or trough may be straight or folded as preferred. If a high impedance liquid such as mercury is employed, the interior surfaces 20 of the tube walls and of any internal reflectors are preferably etched or ground. Energy may be applied to the near end by a transmitter T and abstracted from the distant end by way of a receiver R. The transmitter T and the receiver R may each comprise an electro-mechanical transducer such as a piezoelectric crystal element. To prevent or reduce transmission of guided wave energy in undesired modes, the external electrode of either or both crystals may be domed. A mercury delay line wave guide including these features is described and claimed in H. J. McSkimin application Serial No. 653,255, filed March 9, 1946. Features of corresponding function for dielectric wave guides are described and shown in United States Patent 2,147,717 to S. A. Schelkunoff.

The pulse-modulated intermediate frequency waves 15 which are propagated over the delay line 18 and delayed thereby by a time interval Δt_2 are then amplified, as necessary, as by an adjustable gain amplifier 21. The intermediate frequency is removed by a detector 22 and the resulting pulses are supplied by way of a transformer 23 to an indicating device, for example to the vertical deflection plates 24 of a cathode-ray oscilloscope 25 which may be of conventional construction.

In known systems to which the present invention has not been applied, the pulse-modulated intermediate frequency energy also travels over a by-path 17 which does not include any delay device, through a variable gain amplifier 27, a detector 28 which removes the intermediate fre-

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quency, and to the same vertical deflection plates 24, in inverted phase.

When the object 1 is fixed and stationary, the spurts 15 of pulse-modulated intermediate frequency energy entering the delay line 18 and the by-path 17 from the demodulator 14 are all alike, recurring at intervals Δt_1 . If it were not for distortion in the delay line 18 the $(n+1)$ th pulse arriving at the vertical deflection plates by way of the by-path would be exactly cancelled by the preceding n th pulse arriving by way of the delay line, so that no indication would appear on the screen of the cathode-ray oscilloscope 25. This situation is illustrated in Fig. 2. But with a moving object 1, this cancellation does not take place. Because the later delayed pulse and the earlier undelayed one do not reach the vertical deflection plates 24 at the same instant, but at instants which differ by an amount proportional to the speed of movement of the object 1, a signal is applied to the vertical deflection plates which is the difference between the signal propagated over the delay line 18 and the by-path signal. Furthermore any noticeable movement of the object 1 such as a change in its orientation without noticeable translation produces the same result by effecting a difference between the magnitude of the earlier, delayed (n th) pulse and that of the later undelayed ($n+1$)th pulse. Thus the system gives an indication of the presence of moving objects. This indication may easily include a measure of the object distance by various known expedients. For example, the cathode-ray oscilloscope beam may be swept horizontally at constant speed as by a saw-tooth wave voltage applied to the horizontal deflection plates 30, which saw-tooth wave voltage may be derived from a saw-tooth wave oscillator 31 synchronized with the multivibrator 3. With such an arrangement the indication due to the difference, either in magnitude or in time of occurrence, between the delayed pulse and the undelayed pulse, which is illustrated in Fig. 3, appears on the cathode-ray oscilloscope screen as a pip whose location along a horizontal axis is proportional to the object distance. Various known refinements and modifications of the "ranging" feature may be employed as desired.

However, certain phase distortion is characteristic of all guided wave delay lines. As a result, the pulse shape at the far end of the line 18 is not the same as that of the pulse applied to the near end, so that, even with a fixed object 1 there results incomplete cancellation between the later delayed pulse and the earlier undelayed one. The resulting difference signal from a large fixed object may be sufficient to mask the desired signal from a smaller and more important moving object.

In accordance with the invention the later undelayed pulse is distorted to the same extent and in the same manner as the earlier delayed one, by passing the later pulse in the by-path 17 through an auxiliary guided wave delay line 35 having the same relative phase delay distortion coefficient as the primary delay line, but a different time delay Δt_3 . For example, with liquid compression wave delay lines the auxiliary delay line 35 in the by-path 17 may be provided with a transmitter T' and a receiver R' like those of the primary line 18 and may be of identical construction with the primary delay line 18 but having one-quarter the length and one-half the diameter of the latter. If these ratios are selected then the dimensions should be such that the delay due to the primary line is $\Delta t_2 = \frac{1}{4}\Delta t_1$ and the delay due to the auxiliary line is $\Delta t_3 = \frac{1}{4}\Delta t_1$, so that the dif-

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ference between these delays is equal to the multivibrator pulse period, i. e., $\Delta t_2 - \Delta t_3 = \Delta t_1$. These relations are shown in Figs. 4a to 4d, inclusive. Or, the auxiliary line length may be $\frac{1}{2}$ the primary delay line length and its diameter $\frac{1}{2}$ that of the primary line, in which case $\Delta t_2 = \frac{1}{2}\Delta t_1$ and $\Delta t_3 = \frac{1}{2}\Delta t_1$. Any ratios will serve which satisfy the relations

$$f(l, r) = k_1 \frac{l}{r^2} = k_1 \frac{l_1}{r_1^2} = k_1 \frac{l_2}{r_2^2}$$

$$l_1 - l_2 = v \Delta t_1$$

where l_1, r_1 are the length and radius of the primary line, l_2, r_2 are the length and radius of the auxiliary line, and v is the propagation velocity of the waves in an unconfined medium.

The origin and significance of these relations will be evident from an analysis of the behavior of a compression wave guide comprising a tube of circular cross-section and of non-absorptive, low-impedance walls, containing, for example, a high impedance liquid such as mercury.

The wave equation which describes this situation is

$$\frac{\partial^2 \varphi}{\partial r^2} + \frac{1}{r} \frac{\partial \varphi}{\partial r} + \frac{1}{r^2} \frac{\partial^2 \varphi}{\partial \theta^2} + \frac{\partial^2 \varphi}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 \varphi}{\partial t^2}$$

where

φ = velocity potential of a disturbance to be propagated

r = radial distance from tube axis

θ = angular distance about tube axis

x = distance along tube axis (direction of principal propagation)

t = time, and

v = propagation velocity in the unconfined medium.

On the assumption that each component part of any disturbance may be treated as periodic with an angular frequency $\omega = 2\pi f$, then

$$\varphi = \varphi(r, \theta, x) e^{i\omega t} \quad (2)$$

Substitution in (1) gives

$$\frac{\partial^2 \varphi}{\partial r^2} + \frac{1}{r} \frac{\partial \varphi}{\partial r} + \frac{1}{r^2} \frac{\partial^2 \varphi}{\partial \theta^2} + \frac{\partial^2 \varphi}{\partial x^2} - \frac{\omega^2}{v^2} \varphi = 0 \quad (3)$$

The standard method of solution is to assume

$$\varphi = R(r) \Theta(\theta) X(x) \quad (4)$$

substitute in (3) and divide by (4). This gives

$$\frac{d^2 \Theta}{d\theta^2} + n^2 \Theta = 0$$

$$\frac{d^2 R}{dr^2} + \frac{1}{r} \frac{dR}{dr} + \left(\frac{a^2}{r_0^2} - \frac{n^2}{r^2} \right) R = 0 \quad (5)$$

$$\frac{d^2 X}{dx^2} + \left(\frac{\omega^2}{v^2} - \frac{a^2}{r_0^2} \right) X = 0$$

where r_0 is the radius of the delay line tube, and a is discussed below. These three equations have the solutions

$$\Theta = A \cos m\theta + B \sin n\theta \quad (6a)$$

where $n=0, 1, 2, 3$, etc.

$$R = C J_n \left(\frac{ar}{r_0} \right) + D K_n \left(\frac{ar}{r_0} \right) \quad (6b)$$

$$X = E \cos \sqrt{\frac{\omega^2}{v^2} - \frac{a^2}{r_0^2}} x + F \sin \sqrt{\frac{\omega^2}{v^2} - \frac{a^2}{r_0^2}} x \quad (6c)$$

where A, B, C, D, E, and F are constants.

In the first equation n must be an integer because the value of Θ must repeat itself each time θ increases by 2π radians. If $n=0$ the velocity po-

tential is independent of θ ; i. e., the behavior has axial symmetry. In the second equation

$$J_n\left(\frac{ar}{r_0}\right)$$

is the Bessel's function of the first kind of order n and

$$K_n\left(\frac{ar}{r_0}\right)$$

is the Bessel's function of the second kind and of order n . Since the latter is infinite when $r=0$, D can be set equal to zero for a cylindrical guide.

As explained in H. J. McSkim in application Serial No. 653,255, filed March 9, 1946, the impedance of the etched or ground interior surfaces of a metal tube, which support a film of gas, is substantially less than that of a heavy liquid such as mercury. To a good approximation it may be taken as zero. Then the boundary condition at the low impedance tube walls is that the pressure, and hence the velocity potential, shall be zero at the tube wall. This gives, from Equation 6b

$$J_n(a)=0 \quad (7)$$

The various roots, a_1, a_2, a_m , etc. of the Bessel functions of the various orders, J_0, J_1, J_2 , etc. are reproduced in the following table. Because they distinguish the various modes in which energy may be propagated through the guide, they are known as modular constants.

Order n	Mode m			
	1	2	3	4
0.....	2.40	5.52	8.65	11.79
1.....	3.83	7.02	10.17	13.32
2.....	5.14	8.42	11.62	14.80
3.....	6.38	9.76	13.02	16.22

in which n indicates the order of the Bessel function and m the degree of the root, or "mode" of the oscillation.

For the usual case in which the delay line is driven by an axially vibrating crystal only the zero order vibration will be generated in which case the modular constants are given by the first line of the table above.

Similarly, for a low impedance medium such as a gas, confined in a tube having high impedance walls, the appropriate boundary condition is that the radial velocity, given by the negative radial derivative of the velocity potential, is zero at the walls. That is,

$$\left(\frac{\partial \varphi}{\partial r}\right)_{r_0}=0 \quad (8)$$

which gives, by differentiation of (6b),

$$J'_n(a)=0 \quad (9)$$

The roots of various degrees (m) of this equation, for various orders n of the Bessel's function, are reproduced in the following table.

Order n	Mode m			
	1	2	3	4
0.....	0	3.83	7.02	10.17
1.....	1.84	5.33	8.54	-----
2.....	3.05	6.70	9.96	-----
3.....	4.20	8.01	11.34	-----

In either case the complete solution of (3) is

$$\varphi = \sum_{m=0}^{\infty} \sum_{n=1}^{\infty} [A_n \cos n\theta + B_n \sin n\theta] J_n\left(\frac{a_m r}{r_0}\right) e^{i\omega t}$$

$$\left[E_m \cos \sqrt{\frac{\omega^2}{v^2} - \frac{a_m^2}{r_0^2}} x + F_m \sin \sqrt{\frac{\omega^2}{v^2} - \frac{a_m^2}{r_0^2}} x \right] \quad (10)$$

This expression represents a wave of frequency

$$f = \frac{\omega}{2\pi}$$

propagated in the x direction, the propagation constant being

$$\gamma = \alpha + i\beta = \sqrt{\frac{a_m^2}{r_0^2} - \frac{\omega^2}{v^2}} \quad (11)$$

where α is the attenuation constant and β is the phase constant of the guide; i. e., the phase shift per unit length.

The "cut-off frequency" of the guide is the frequency at which the propagation constant is zero. From (11) it is evidently

$$f_c = \frac{\omega_c}{2\pi} = \frac{a_m v}{2\pi r_0} \quad (12)$$

Below this frequency the wave will be attenuated. At frequencies above the cut-off it will be propagated without attenuation. When unattenuated propagation takes place, the phase velocity is given by

$$v_p = \frac{\omega}{\gamma} = \frac{v}{\sqrt{1 - \frac{a_m^2 v^2}{\omega^2 r_0^2}}} = \frac{v}{\sqrt{1 - \frac{f_c^2}{f^2}}} \quad (13)$$

From (11) at frequencies in the range of unattenuated propagation and not too close to the cut-off frequency, the total phase shift from end to end of the guide is given by

$$\beta l = \frac{\omega l}{v} = l \sqrt{\frac{\omega^2}{v^2} - \frac{a_m^2}{r_0^2}} = \frac{\omega l}{v} \left(1 - \frac{1}{2} \frac{a_m^2 v^2}{r_0^2 \omega^2} \right) \\ = \frac{\omega l}{v} - \frac{1}{2} \left(\frac{a_m^2 v}{\omega} \right) \cdot \frac{l}{r_0^2} \quad (14)$$

This expression is seen to contain two terms. The first is directly proportional to frequency, which is desirable for undistorted transmission. The second is inversely proportional to frequency and therefore represents the relative delay of one component frequency as compared with another which gives rise to phase distortion.

However, it will also be observed that for each component frequency

$$f = \frac{\omega}{2\pi}$$

and for each root a_m , where m is the modular constant, that the distortion will be alike in two guides which are characterized by the same value of l/r_0^2 . In accordance with the invention use is made of this relation by providing an auxiliary wave guide delay line which has the same value of l/r_0^2 as does the principal delay line, but, of course, a different length and therefore a different delay, and balancing the output of one against that of the other.

The manner in which this balancing or cancellation comes about may be formulated mathematically as follows. Referring to Equations 10, 11 and 14, the signal strength at the output of the primary delay line is proportional to the velocity potential due to a pulse which entered

the line at time t . It may be written in complex form as

$$\varphi_1 = \sum_{n=0}^{\infty} \sum_{m=1}^{\infty} K_{1n, m} e^{i(\omega t - \beta_1 l_1)} \quad (15)$$

where K_{nm} is an amplitude factor which includes the effects of all the factors of (10) other than those included in the above exponential factor l_1 is the length of the primary line 18 and β_1 is its phase constant, given by (14). Similarly for the auxiliary delay line 35, the output signal strength due to a pulse originating later by the interval Δt_1 is

$$\varphi_2 = \sum_{n=0}^{\infty} \sum_{m=1}^{\infty} K_{2n, m} e^{i(\omega t - \omega \Delta t_1 - \beta_2 l_2)} \quad (16)$$

Adjustment of the relative gains of the amplifiers makes the magnitudes of these two series alike, term for term, in which case

$$K_{1n, m} = K_{2n, m} = K$$

Then each term of (15) may be balanced against the corresponding term of (16), giving, for the difference, a series of terms each of which is of the form

$$\varphi_1 - \varphi_2 = K e^{i\omega t} [\epsilon^{-i(\omega \Delta t_1 + \beta_2 l_2)} - \epsilon^{-i\beta_1 l_1}] \quad (17)$$

From (14), series expansion of the bracketed term in (17) gives terms containing successive powers of the quantity

$$\omega \Delta t_1 - \beta_1 l_1 + \beta_2 l_2 = \omega \Delta t_1 - \frac{\omega}{v} (l_1 - l_2) + \frac{1}{2} \frac{a_m^2 v}{\omega} \left(\frac{l_1}{r_1^2} - \frac{l_2}{r_2^2} \right) \quad (18)$$

When the dimensional relations of the invention are met,

$$\frac{l_1}{r_1^2} = \frac{l_2}{r_2^2}, \quad l_1 - l_2 = v \Delta t_1$$

so that each of these terms vanishes individually. Therefore the whole expression (17) for the difference signal is equal to zero.

The principles of the invention are applicable to wave guide delay lines of many types other than those analyzed in detail above. In each case the relative phase delay is found to be some assignable function of the length and transverse dimensions, and it is only necessary, in order to practice the invention in its wave guide aspect, to provide an auxiliary guide in which this function is the same as it is for the principal guide but which has a different length and therefore a different signal delay, to apply the same signals to both, and to balance their outputs. The same principles may be applied to delay devices other than wave guides.

For the mathematical formulation of the behavior of wave guides of configurations and types other than the one analyzed herein, which are diagrammatically illustrated in Figs. 6 to 11, inclusive and from which may be derived the expressions given above for the relative phase delay coefficients of rectangular guides, dielectric guides, absorptive compressional guides and solid elastic guides, compressional or torsional, reference is made to "Electromechanical Transducers and Wave Filters," by W. P. Mason (Van Nostrand 1942); to United States Patent 2,147,717 to S. A. Schelkunoff; to United States Patent 1,775,775 to Harry Nyquist; and to "Theory of Sound" by Lord Rayleigh, vol. I, page 252.

What is claimed is:

1. In a pulse-reflection, object-detecting-and-ranging system, a source of a sequence of pulse

signals recurring at equal time intervals, means for radiating said pulsed signals in a desired direction, means for receiving only echo pulsed signals reflected from objects lying in the path of said radiated signals, a relatively long delay unit, a relatively short delay unit, the difference in the delay of said units being equal to the pulse recurrence interval, the phase distortion coefficient of the short delay unit being substantially identical with the phase distortion coefficient of the long delay unit, means for launching said received echo pulse signals simultaneously into the proximate ends of both of said units, means associated with the distant end of each of said delay units for picking up signals propagated lengthwise of said delay unit, means for deriving a signal related to the difference between the signal picked up from said longer unit and signal picked up from said shorter unit, whereby said received echo signals reflected from stationary objects lying in the path of said radiated signals will be precisely balanced out and measurable difference signals will be obtained only from reflecting objects which are in motion, and means for indicating said difference signals along a timed sweep whereby the range of reflecting objects in motion only is indicated.

2. In a pulse-reflection, object-detecting-and-ranging system the combination with a source of pulsed signals recurring at equal time intervals and means for radiating said pulsed signals in a desired direction, of a signal receiver responsive only to reflections of said pulsed signals reflected from objects lying in the path of said radiated signals, a plurality of parallel transmission paths intermediate said source and said receiver, a primary delay unit having longitudinal and transverse dimensions in one of said paths, adapted to introduce a preassigned time delay into signals in said path and introducing undesired distortion in proportion to a specified function of said longitudinal and transverse dimensions, an auxiliary delay unit in another of said paths, having a delay differing from that of said primary unit by precisely the time interval between said recurring pulses and different longitudinal and transverse dimensions which impart to said auxiliary delay unit the same distortion function as said primary delay unit, and means for balancing signals traveling by one of said paths against signals traveling by the other of said paths to produce a difference signal only when said time of recurrence of said signals is changing whereby pulses reflected from objects in motion only will produce a measurable difference signal.

3. In combination with a signal source and a signal receiver, a plurality of parallel transmission paths connecting said source to said receiver, a primary liquid delay unit in one of said paths, adapted to introduce a preassigned time delay into signals propagated through said unit in proportion to its length and introducing undesired distortion in proportion to its length and in inverse proportion to the square of its transverse dimensions, an auxiliary liquid delay unit in another of said paths, having a different length to the square of transverse dimensions, and different dimensions and the same ratio of length and means for balancing signals traveling by one of said paths against signals traveling by the other of said paths to produce a difference signal.

4. In combination with a signal source and a signal receiver, a plurality of parallel transmis-

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sion paths connecting said source to said receiver, a primary elastic solid delay unit in one of said paths, adapted to introduce a preassigned time delay into signals propagated along said unit in proportion to its length and introducing undesired distortion in proportion to the product of its length and the square of its transverse dimensions, an auxiliary elastic solid delay unit in another of said paths, having a different length and different transverse dimensions and the same product of length and transverse dimensions, and means for balancing signals traveling by one of said paths against signals traveling by the other of said paths to produce a difference signal.

5. In combination with a source of a recurring sequence of signal pulses and a pulse signal receiver, a plurality of parallel transmission paths connecting said source to said receiver, a primary delay unit having longitudinal and transverse dimensions in one of said paths, adapted to introduce a preassigned time delay exceeding the interval between successive signal pulses into pulse signals propagated therethrough and introducing undesired phase distortion into

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said signals in proportion to a specified function of said longitudinal and transverse dimensions, an auxiliary delay unit in another of said paths, having a time delay equal to the difference between the time delay of said primary delay unit and the time interval between successive signal pulses, and having different longitudinal and transverse dimensions and the same phase distortion function of longitudinal and transverse dimensions as said primary delay unit, and means for balancing each pulse as propagated through said primary unit against a later pulse propagated through said auxiliary unit to produce a difference signal.

WARREN P. MASON.

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