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METHOD OF AND MEANS FOR WAVE RETARDATION

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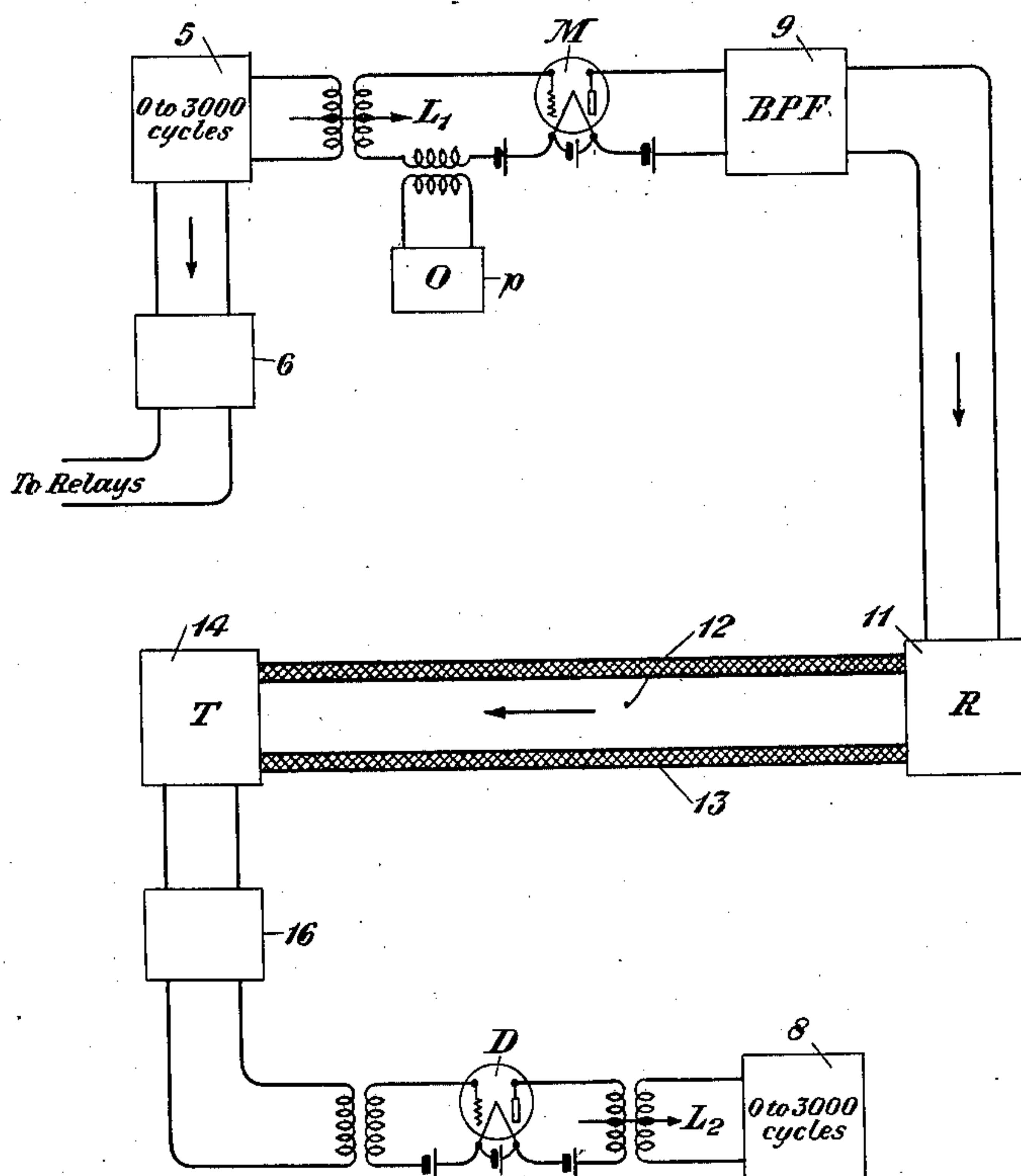


Fig. 1

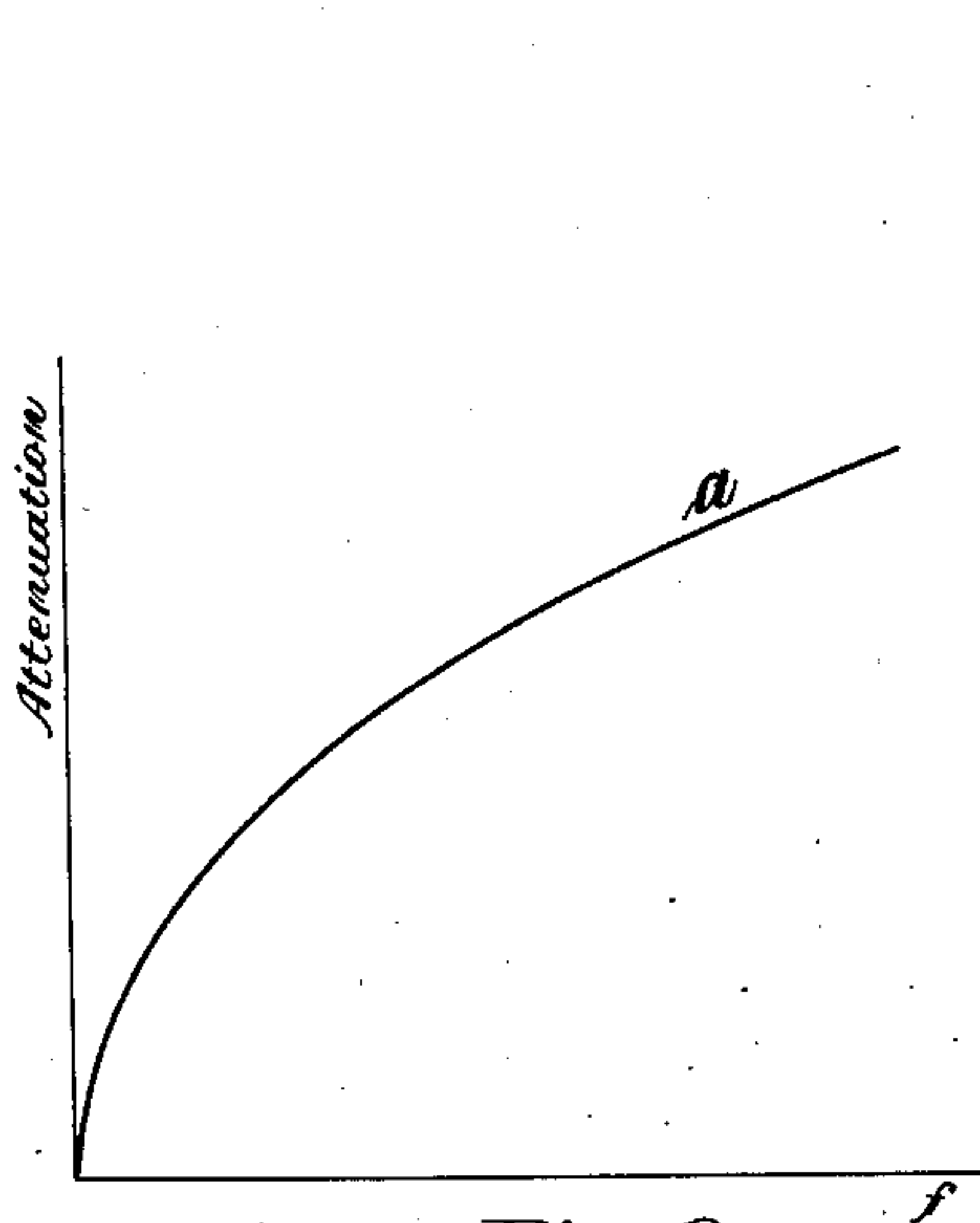


Fig. 2

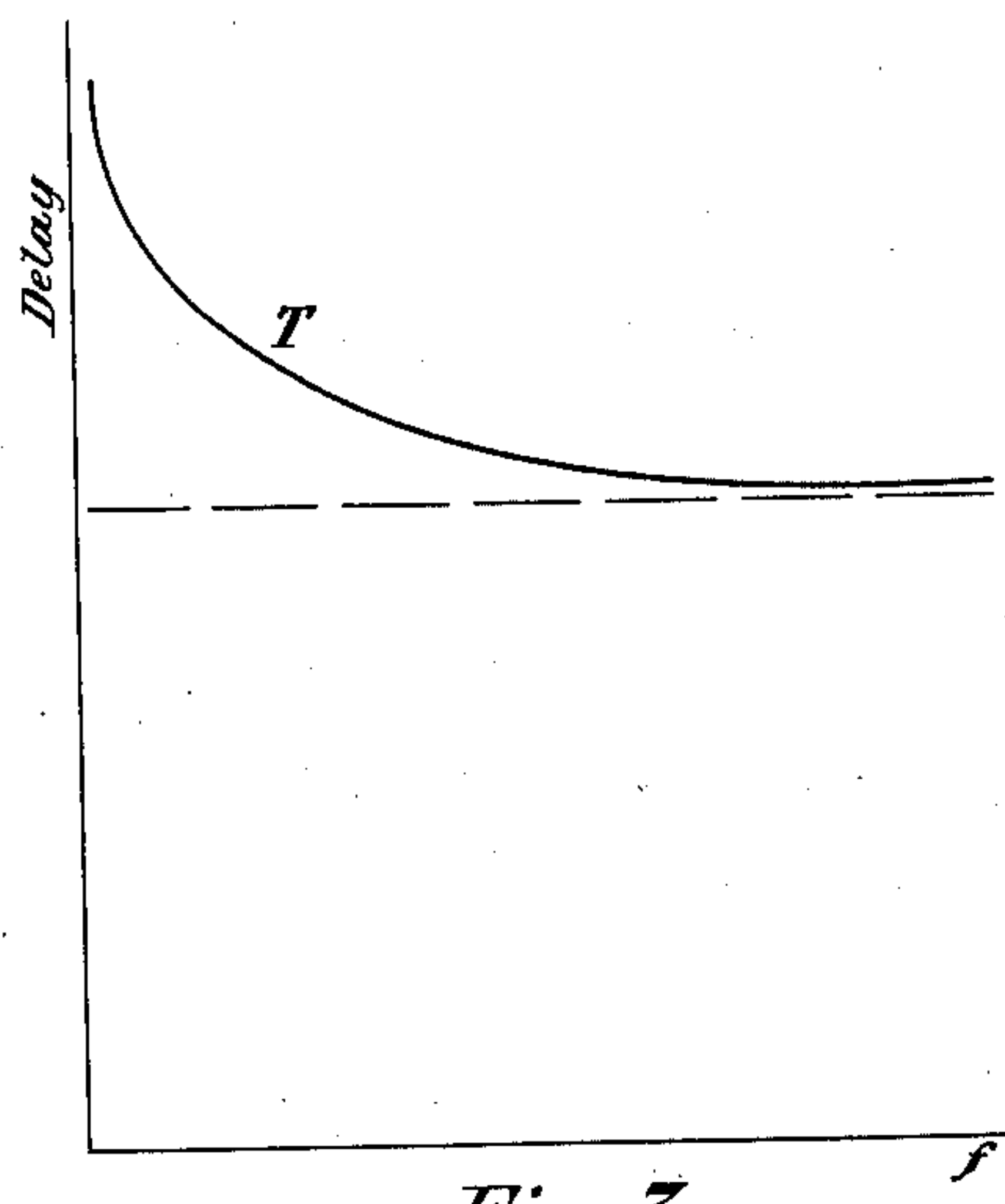


Fig. 3

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METHOD OF AND MEANS FOR WAVE RETARDATION

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This invention relates to a method of and means for wave retardation and more particularly the retardation in the time of arrival of an electric wave at a definite point in a circuit in order that certain desired operations, set in motion by the arrival of the wave at one point, shall have opportunity for execution before the arrival of the wave at the definite point in question.

In many cases of communication by waves it is desirable to obtain such a delay in the time of arrival of the wave at a certain point. This is particularly common in electrical transmission of speech, such as long distance telephone lines of trans-oceanic radio telephony, where speech is transmitted only in one direction at a time. For example, on a long distance telephone line on which there may be a plurality of repeaters, the so-called echo effects are frequently so serious as to make it advisable to employ echo suppressors working on the basis of permitting transmission in only one direction at a time as illustrated in patent to Mills, 1,434,790, November 7, 1922. Usually voice operated relays are used to change the direction of transmission, and in order to allow time for the relays to operate, the speech currents are delayed before being transmitted. While this delay is commonly introduced by more or less intensive electrical networks, it is the purpose of this invention to avoid the various difficulties inherent in such electrical networks, and I accomplish this by changing the electrical energy into sound wave energy and utilize for the delay the time required for transmission of the sound wave through a material medium such as a gas or a liquid, preferably in the form of a speaking tube.

Another purpose of the invention is to overcome the distortion introduced by most wave paths, electrical or mechanical, to waves whose component frequencies extend over so relatively wide a range as that for speech. This purpose I accomplish by shifting the band of frequencies to a higher frequency level, with the aid of a high frequency carrier wave, to a region where inequalities in transmission are found to be less.

Other purposes will appear in the follow-

ing description, taken with the accompanying drawing, in which Figure 1 illustrates a circuit arrangement associated with a tube containing a fluid, such as gas, and designed to carry out the purpose of the invention; Figs. 2 and 3 show certain characteristics of a tube containing gas as a medium for sound waves.

Referring more specifically to Fig. 1, there is shown at 5 a source of speech signals of the form used on telephone lines and which signals may be said to comprise all frequencies extending from 0 to 3,000 cycles. This speech signal is to be propagated from a line L_1 and L_2 to a receiving device 8, after which it may be used for any desired purpose. In the case in mind, however, it is understood that a delay in the time of transmission of the signal from 5 to 8 shall be introduced in order that certain elements, such as voice operated relays, may have sufficient time to operate. Such elements as the relays are indicated schematically at 6 as being associated with the source 5. Specifically this delay is obtained by the following steps: First, the speech signal is combined with locally generated oscillations of frequency p , from the oscillator O, in a modulator M of the thermionic discharge type. This modulation will yield a wave made up of the carrier p and two side bands given by $p+f$ and $p-f$ where f represents the variable speech frequency varying from say 0 to 3,000. If, for example, the carrier frequency p is taken as 100,000, there will appear in the output of the modulator the carrier itself and a side band extending from 97,000 to 100,000 and a side band extending from 100,000 to 103,000. It will be desirable to have this wave pass through a band pass filter 9 which will pass substantially nothing but the waves of the frequencies indicated. Second, this electric wave is now converted into a sound wave by any suitable converting device 11, such as a telephone receiver or a quartz crystal receiver operating by virtue of its piezo-electric properties. Third, the sound wave of this relatively high frequency is now propagated through a medium capable of transmitting sound waves. In this case I have shown a hollow tube 12 filled with some gas, such as air, and covered with suitable

sound-insulating material 13, such as felt. It will be appreciated that the velocity of propagation in this gaseous medium is much less than the velocity of propagation of the electric wave in this circuit, and that by suitable choice of length of the tube any desired delay may be introduced. Fourth, these mechanical waves are now converted back to electric waves by any suitable device, such as a microphone transmitter or a piezo-electric crystal 14, and are then impressed upon a demodulating device or detector D, which restores the signal to its original frequency range, following which it may continue for transmission over the line L₂.

A better understanding of the principles underlying this invention will be obtained by certain theoretical considerations, and as an example to further illustrate this we may assume the tube 12 to contain a fluid such as air at 0° centigrade. The sound waves then emitted from the receiver 11, at one end of the tube, will travel along the tube at about 1090 feet per second. The delay usually required in this kind of a circuit is of the order of .01 seconds, which can be obtained then by a tube 10.9 feet long. However, one objection to the transmission of sound waves of voice frequencies (0 to 3,000 cycles) over a speaking tube is that undesirable noises from other sources may become mixed up with the speech waves. Another objection is the distortion caused by reflections and resonance phenomena in the tube. At voice frequencies the attenuation is small, and reflections or echoes may be large enough to affect the quality at the receiving end of the tube. At certain frequencies the reflections combine in phase with the direct transmission, and hence the resultant wave sound at these frequencies may be more prominent than for adjacent frequencies, and the tube is said to resonate for these frequencies. The resonant frequencies in a tube closed at both ends are given by the expression $f = \frac{mV}{2S}$ where f equals resonant frequency, V equals velocity of sound waves, S equals length of tube, and m a positive integer equal to 1, 2, 3, 4, etc. Thus it will be seen that a tube having $\frac{V}{S} = 100$, corresponding to a delay of .01 seconds, is resonant at every 50 cycles.

The theory of the propagation of waves in various media is treated in numerous books, and reference may be made especially to Rayleigh's "Theory of Sound", Vol. 2, and Johnson's "Transmission Circuits for Telephonic Communication". In the propagation of a wave through a medium, a quantity which is characteristic of that medium is the propagation constant, which in the case of such a sound wave as here considered, may be defined as the natural logarithm of the ratio of the maximum velocity of the material par-

ticles taken at two points a unit distance apart. This constant is made up of a real part and an imaginary part, the real part being called the attenuation constant and the imaginary part being called the phase constant or wave length constant. From considerations and data contained in the references just noted it may be shown that the propagation constant in a cylindrical tube filled with air at 0° is given by

$$P = a + jb = \frac{k}{r} \sqrt{n} + j \left(\frac{n}{V} + \frac{k \sqrt{n}}{r} \right) \quad (1)$$

Where a = attenuation constant in nepers,
 b = phase shift in radians,
 $n = 2\pi \times$ frequency,
 r = radius of the tube,
 V = velocity of sound in free air. If the unit of length is feet, k takes on the value 12.24×10^{-6} .

It can be shown that the time required for the wave to travel a unit length of the tube is equal to the rate at which b changes with frequency, that is, expressed as a differential quantity,

$$t = \frac{db}{dn}$$

and the time of transmission along a tube of length S is

$$T = S \frac{db}{dn} = \frac{S}{V} + \frac{kS}{2r \sqrt{n}} \quad (2)$$

this being obtained by differentiating the last term in Equation (1). From Equations (1) and (2) it will be seen that both the attenuation constant a and the delay T will depend upon the frequency of the wave, and the manner in which they vary with frequency may be better seen from Figs. 2 and 3. In Fig. 2 the constant a is plotted as ordinates against frequency, and in Fig. 3 the delay T is plotted against frequency, the horizontal dotted line being the delay if a tube of very large diameter were used. It will be seen from these figures that the variations in delay and attenuation over a frequency band of given width are less at high frequencies than at low. Consequently more flat transmission of the sound wave will be obtained when the voice frequencies are transmitted by a carrier wave of high frequency, this being the equivalent of a shifting of the signal band.

The means for accomplishing this shifting of the signal band has already been described in connection with Fig. 1, but it will also be observed from Figs. 2 and 3 that the attenuation and the delay curves never become horizontal although their slope may be quite small, and a slight distortion will therefore be present. In order to reduce this latter, only one side band need be transmitted, such, for example, as that from 97,000 to 100,000, and in this case the device will be operated over a

frequency band of only one-half the width. Such small distortion as now remains may be further reduced or eliminated by electrical distortion correction networks, these networks being inserted at any appropriate point, as indicated at 16 of Fig. 1.

While this invention has been described in connection with air as the transmission medium, it is to be emphasized that any fluid medium may be used. Gases are especially advantageous because of the low velocity of sound and the corresponding reduction in the length of tube necessary to obtain the required delay. As a concrete illustration we may take a tube 10.9 feet long and with radius 1.04 inches, which will have a delay of approximately .01 seconds. For this tube

$$\frac{S}{r} = \frac{10.9 \times 12}{1.04} = 126.$$

At 100,000 cycles the attenuation is

$$a = \frac{kS}{r} \sqrt{n} = .00154 \sqrt{2\pi \times 100,000} =$$

1.22 napiers, which interpreted in terms of the units commonly used in the telephone art, is equal to 10.6 transmission units where 10 transmission units correspond to a ten-fold energy change. A reflection must travel twice the length of the tube before affecting the received sounds, and therefore would be 21.2 transmission units below the direct transmission. By reducing the radius of the tube this attenuation may be correspondingly increased, and thus with a suitable radius it is possible to reduce reflection and resonance phenomena to a negligible quantity.

It is apparent that numerous modifications or additions may be made to this invention without departing from the spirit thereof; for example, any desired form of sound-insulating material may be used on the tube. Also in order to eliminate the transmission of sound along the walls of the tube itself, it may be desirable to break the continuity of the tube walls by means of crevices and cracks or by making it of sound-insulating material.

What is claimed is:

1. In a mechanical path for transmission of sound waves, the method of eliminating frequency discrimination, which consists in shifting the frequency band to a high frequency and transmitting this band with its carrier over the said mechanical path.

2. In a mechanical path for transmission of sound waves, the method of eliminating frequency discrimination, which consists in shifting the frequency band to a portion of the frequency spectrum where its band width will be small compared to its average frequency and transmitting this band with its carrier over the same mechanical path.

3. In an electrical wave transmission sys-

tem the method of producing a delay, which consists in shifting the wave to a higher frequency level, converting the resulting wave into a corresponding sound wave, transmitting this wave over a mechanical medium, reconvertng it into an electric wave, and shifting the band to normal frequency level.

4. In an electric wave transmission system the method of producing a delay, which consists in modulating the message to a carrier frequency, converting the resultant wave into a sound wave, transmitting this wave over a mechanical medium, reconvertng the wave into an electric wave, and demodulating it to normal frequency.

5. In an electric wave transmission system, a delay-producing device comprising a tube filled with gas, a source of telephone current at one end, means for modulating said current to a high frequency carrier, means for eliminating one side band, means for converting the other side band into sound waves and impressing them on the said tube, and means at the other end for reconvertng the received sound wave into the original electric telephone current.

6. In a telephone transmission system, a transmission channel, a branch circuit therefrom containing a relay to be operated by voice currents, a delay device in the transmission channel to permit operation of the relay by the voice currents prior to their transmission, said delay device comprising means for shifting the voice frequency wave to a high frequency, a tube filled with a sound transmitting medium, means for converting the high frequency electric wave into a sound wave and impressing it on one end of the tube for transmission therethrough, means at the other end to receive and convert the sound wave into an electric wave, and a detector to shift the wave back to its original frequency, all as and for the purpose described.

7. In an electric wave transmission system, a delay producing device comprising a fluid path, a source of telephone current at one end, means for modulating said current to a high frequency carrier, means for eliminating one side-band, means for converting the other side band into sound waves and impressing them on the said fluid path, and means at the other end for reconvertng the received sound wave into the original electric telephone current.

In testimony whereof, I have signed my name to this specification this 5th day of August, 1926.

HARRY NYQUIST.