Jan. 13, 1931. J. W. HORTON 1,788,522

SIGNALING SYSTEM

Filed Aug. 6, 1924

Fig. 1

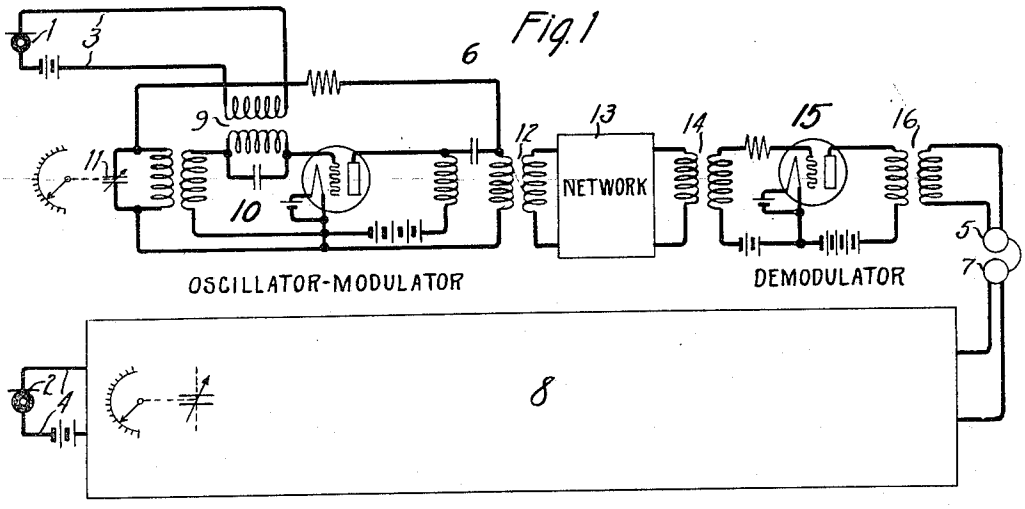


Fig. 2

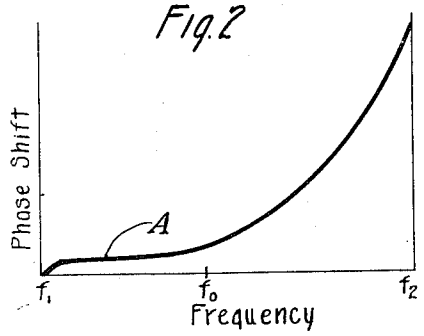


Fig. 3

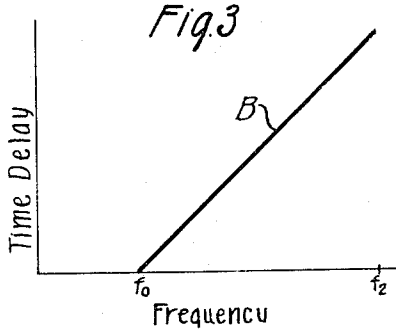


Fig. 4

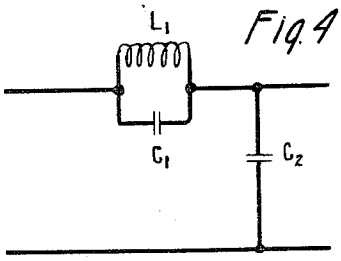
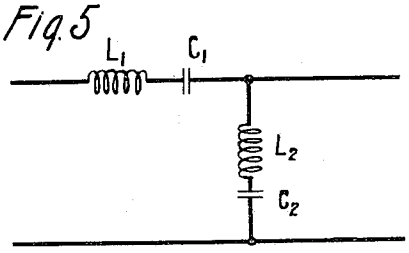


Fig. 5



Inventor:
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by E. W. Adams Atty.

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UNITED STATES PATENT OFFICE

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SIGNALING SYSTEM

Application filed August 6, 1924. Serial No. 730,334.

This invention relates to indicating systems, and particularly to such systems employed in determining the direction of propagation of wave energy.

An object of the invention is to facilitate the location of a source of sound.

A related object of the invention is to provide a new and improved system for controlling the binaural observation of sound effects.

It has been proposed, in determining the direction of propagation of sound waves from a source of sound, to utilize a pair of sound receivers, either electrically or acoustically connected to the opposite ears of an observer, making use of the so-called binaural sense of the observer to fix the direction of the source of sound.

This has been accomplished by adjusting the effective lengths of the transmission paths associated with the receivers until the observer senses the sound to be directly in front of him, which sensation occurs when the sound effects reach the ears of the observer substantially in phase.

Various mechanical and electrical means may be employed for adjusting the relative lengths of the transmission paths associated with the receivers so that the sound effects may reach the ears of the observer in phase. Knowing the amount of adjustment or phase shift required to produce the sensation of binaural balance, it is possible to determine the direction of the source of sound from the observing point.

The relative lengths of the transmission paths may be adjusted electrically, for example, by taking advantage of the well-known characteristics of certain electrical filters or networks which have the quality of retarding or imposing a phase shift upon electrical waves transmitted thereover. This has been accomplished by employing in the transmission paths, variable networks which may be adjusted until the sound effects finally reach the observer's ears simultaneously, at which time a condition of binaural balance is said to exist.

The variable networks employed in systems of the above type are often very complicated and necessarily of large dimensions. Furthermore, such variable networks require more time to adjust than is warranted in systems of this type in which the location of the source of sound must be determined without substantial delay.

According to a feature of the invention, the vibratory effects which it is desired to detect are converted by means of translating devices such as microphones, into corresponding variations in electrical currents, which variations are retranslated at the ears of the observer into sound effects by means of telephone receivers. Two translating devices are used, each of which is connected by an independent path with the receivers at the observing station. Fixed retardation networks are included in each of the paths, and means are provided for varying the frequency level at which the electrical variations are impressed upon these networks whereby the amount of retardation of the electrical vibrations set up in the electrical paths may be controlled.

In order to employ a retardation network of fixed constants, the received current variations that are impressed upon the receivers are caused to modulate waves of higher frequencies, the modulated waves being passed through the retardation networks and then demodulated. It has been found that the amount of delay introduced in the transmission is a function of the frequency of the modulated wave. Thus, various times of delay may be had by merely changing the frequency level at which the received sound waves are transmitted through the compensating networks, and compensation can therefore be accomplished without varying the adjustment of the networks.

Other features and advantages of the invention will appear from a consideration of the following description taken in connection with the accompanying drawing, in which,

Fig. 1 is a diagrammatic illustration of a system embodying the invention.

Figs. 2 and 3 show curves illustrating the characteristics of the retardation networks employed in the system of Fig. 1.

Figs. 4 and 5 illustrate two different types

of networks which may be employed in the system of Fig. 1.

As shown in Fig. 1, a pair of microphone detectors 1 and 2, which may be mounted in a fixed position either in air or water are connected to low frequency lines 3 and 4, respectively. Microphones 1 and 2 may be of the type commonly used in telephone transmitters.

The low frequency line 3 is connected to a telephone receiver 5 by an electrical path or transmission line which is indicated as a whole by the reference character 6, and the low frequency line 4 is connected to a receiver 7 by a similar electrical path or transmission line 8. The transmission lines 6 and 8 are identical, and accordingly only the elements of the transmission line 6 have been shown in detail.

The output of the low frequency circuit 3 is coupled by means of a transformer 9 to the input of an oscillator-modulator 10 which may be of any well known construction. The carrier wave generated by the oscillator-modulator 10 is modulated by the current variations set up in the low frequency line 3 by the detector 1. The frequency of the carrier 1 may be varied by means of the variable condenser 11 in the usual manner.

The output of the oscillator-modulator 10 is coupled by means of a transformer 12 to a retardation network 13 adapted to impose a phase shift upon electrical waves transmitted therethrough. Since it is desirable to suppress the unmodulated current variations of the signal frequency from transmission through the network 13, the output circuit of the oscillator-modulator 10 may be tuned to transmit only currents of frequencies in the neighborhood of the carrier frequency. The characteristics of the network 13 may also be such as to suppress the unmodulated signal waves from transmission, or, if desired, a separate high pass filter may be inserted in the input of the network 13 for the purpose of suppressing such unmodulated waves. The output of the network 13 is coupled by means of a transformer 14 to detector or demodulator 15, which may be of the well known three-element electron discharge type. The detector 15 is connected to the receiver 5 through the transformer 16.

The network 13 is of the general type disclosed in the United States patent to Campbell, No. 1,227,113, issued May 22, 1917, and is designed in accordance with well known laws to have a considerable range of variation of time delay with respect to the frequency over the operating range of the network. Fig. 2 shows a curve representing the characteristics of a network suitable for this purpose, in which the phase shift is plotted against frequency.

The curve A of Fig. 2 represents the phase shifts imposed upon the wave transmitted through the network 13 at any given frequency within the operating range of the network. It will be observed that the phase shift increases other than linearly with the frequency of the transmitted wave, there being no phase shift at the frequency f_1 and a maximum phase shift at the maximum cut-off frequency f_2. The portion of the curve from f_0 to f_2 is assumed to be parabolic, and the network may be designed to have this shaped phase-frequency characteristic, although, as pointed out below, this is not essential.

Network 13, if designed to have a parabolic phase shift characteristic, will have a linear relation between the frequency and the time delay over any desired operating range, for example, over the range of frequencies from f_0 to f_2. It may be assumed, for example, that f_0 represents a frequency of 10,000 cycles per second, while f_2 represents a frequency of 50,000 cycles per second. The transmission characteristics of the network for frequencies below the frequency f_0 and for frequencies higher than the frequency f_2 are, of course, of no importance.

The derivative of the phase shift with respect to frequency of the curve A for the range from 10,000 cycles per second to 50,000 cycles per second is illustrated in Fig. 3, in which the derivative, which is also a measure of the time delay, is plotted against frequency. For example, the time delay imposed by the network 13 upon any frequency from f_0 to f_2 may be read from the line B of Fig. 3. In other words, the rate of change of slope of the curve A of Fig 2 with frequency has a linear relation, so that as the frequency transmitted through the network 13 increases, the retardation or the time delay imposed upon the wave likewise increases. Hence, by taking readings from the variable condenser 11, which is adjusted to vary the frequency of the carrier wave, the time delay or the phase shift imposed upon the wave transmitted through the network 13 which is necessary to produce the sensation of binaural balance may be readily observed. The direction of the source of sound from the observing point may then be determined from the phase shift or time delay.

It is not essential that the network 13 have a linear relation between the frequency and time delay over the complete operating range of the network, as various different types of networks may be employed having a characteristic that is equally satisfactory, though not linear. For example, it is possible to calibrate such a network, plot its characteristic, and utilize this information to determine the phase shift imposed upon a wave transmitted through such network at any given frequency

In general, any low pass filter or band pass filter has a phase constant throughout at

least a portion of the transmission band such that the time delay increases with increasing frequency, so that there is a variety of types of network which may be used for the retardation network 13 in practicing the invention. However, it is found that a network of either the type shown in Fig. 4 or that in Fig. 5, possesses a characteristic such that the phase constant has a substantially parabolic variation with frequency within a portion at least of the transmission band width of the filter. In building up a network, several sections of the type illustrated in either Fig. 4 or Fig. 5 would, of course, be employed and, in general, the greater the number of sections employed, the greater is the phase shift of the network.

Design formulæ for retardation networks of the type shown in Fig. 4 or Fig. 5 are to be found in an article entitled "Theory and design of uniform and composite electric wave filters", by Otto J. Zobel, published in the Bell System Technical Journal for January, 1923, pages 1 to 46. The type of filter indicated in Fig. 4 is shown on page 39 of the Zobel article and the type indicated in Fig. 5 is shown on page 42 of the Zobel article, Type VIII. As will be seen from the Zobel article, the former is a low pass filter and the latter a band pass filter. The designs as to the frequency characteristics of these filters accompany the showings of the filter types in the Zobel article, and from these formulæ the values of the impedances used to make up the filter may be determined to suit any particular band width of transmission or any cut-off frequency. The design to secure the desired phase shift may be obtained from pages 4, 37 and 38 of the Zobel article, where, in particular, the equation

$$\cos B = 1 + \frac{1}{2}\frac{Z_1}{Z_2}$$

is given, showing the relation between the phase angle and the series and shunt impedances. This formulæ is to be used in conjunction with the frequency design formulæ and the ratio of the series to the shunt impedances is to be chosen such as to give the desired value of phase constant. While those skilled in filter design will prefer to calculate beforehand from the particular formulæ such as given in the Zobel article, the particular values which the complete network is to have in order to provide the desired phase characteristic, it should be pointed out that to persons of less experience in filter design it may be preferable to use the design formulæ merely as rough guides and to perfect the design of the network by trial.

The operation of the system is as follows: When it is desired to explore the area within the range of the vibration detectors 1 and 2, carrier currents of the same frequency, say 10,000 cycles per second, are supplied to the transmission lines 6 and 8 by the oscillators associated therewith. If now, a sound producing body, such as a submarine, enters the area under observation at a point equidistant from the detectors 1 and 2, the vibrations set up by the detectors will cause varying currents to flow through the low frequency lines 3 and 4 to the input of the oscillator-modulators associated with the two transmission lines. In the transmission line 6, for example, the varying currents in the low frequency line 3 are caused to modulate the carrier wave in the oscillator-modulator 10, and the components of modulation are transmitted through the transformer 12 to the input of the retardation network 13, the unmodulated low frequency currents being suppressed from transmission as pointed out above, and thence through the transformer 14 to the detector or demodulator 15. The signaling component detected in the demodulator 15 is impressed upon the receiver 5 through the transformer 16. The vibrations of the sound detector 2 are transmitted to the receiver 7 in a similar manner. Since the sound-producing body is at an equal distance from detectors 1 and 2, the varying currents set up in the low frequency lines 3 and 4 have the same phase, and since they are caused to modulate carrier waves of the same frequency in the transmission lines 6 and 8, the phase shift imposed upon the waves transmitted over the two transmission lines by the retardation networks therein are equal. In this case, therefore, the effective lengths of the transmission lines 6 and 8 are equal, and since the sound effects reach the receivers 5 and 7 in phase, the observer will sense the sound to be directly in front of him and the angular relation of the source of sound to a base line joining the detectors 1 and 2 may readily be determined.

When the observer hears a characteristic sound of interest which appears to come from some other direction than straight ahead, he changes the frequency of the carrier current supplied to one of the transmission lines 6 or 8 to adjust the effective length of one transmission line until the sound effects finally reach the observer's ears simultaneously, that is, until the source of sound appears to have moved around to the straight ahead position. The angular relation of the source of sound to a base line joining the detectors 1 and 2 may readily be calculated from the amount of phase shift imposed upon the waves transmitted over the transmission line, which was necessary to produce a condition of binaural balance, as determined from the condenser readings showing the required change in frequency level, in conjunction with the calibration curves.

The invention set forth herein is, of course, susceptible of various modifications and

adaptations and accordingly the invention is not to be considered as limited in any way except as defined by the scope of the appended claims.

What is claimed is:

1. In the art of determining the direction of propagation of sound vibrations involving intercepting the sound vibrations at a plurality of separate points, and converting such vibrations into corresponding waves in electrical circuits, the method comprising combining said waves with carrier waves of higher frequency, and passing the combined waves through an element having a phase shift that varies with the frequency to shift the phase of said combined waves in accordance with the frequency of said carrier waves, and varying the frequency of the carrier waves to bring said combined waves into a definite phase relation at a common observing point.

2. In the art of determining the direction of propagation of sound vibrations involving intercepting the sound vibrations at a plurality of separate points, and converting such vibrations into corresponding waves in electrical circuits, the method comprising combining said waves with waves of carrier frequency, passing the combined waves through an element having a phase shift that varies with frequency to shift the phase of said combined waves in accordance with the frequency of said carrier waves, varying the frequency of the carrier waves to bring said combined waves into a definite phase relation, detecting said combined waves, and translating the detected waves into observable effects.

3. The combination, with a plurality of sound responsive current varying devices, a plurality of sound translating devices, and transmission circuits connecting the current varying devices to the sound translating devices, of means in said circuits for varying the frequency level of waves transmitted thereover, and means for shifting the phase of such waves in accordance with the frequency level.

4. The combination, with a plurality of sound responsive current varying devices, a plurality of sound translating devices, and transmission circuits connecting the current varying devices to the sound translating devices, of a modulator circuit including a source of sustained waves of variable frequency in each of said circuits, and means for introducing a controllable degree of time delay in the waves transmitted over each of said circuits comprising a network for shifting the phase of waves transmitted over said circuits in accordance with the frequency of said source.

5. The combination, with a plurality of sound responsive current varying devices, a plurality of sound translating devices, and transmission circuits connecting the current varying devices to the sound translating devices of a modulator circuit comprising a source of sustained waves of variable frequency in each of said circuits, and means for introducing a controllable degree of time delay in the waves transmitted over each of said circuits and comprising retardation networks included in said circuits for shifting the phase of waves transmitted therethrough in accordance with the frequency of said source.

6. The combination, with a plurality of sound responsive current varying devices, a plurality of sound translating devices, and transmission circuits connecting the current varying devices to the sound translating devices, of a modulator circuit comprising a source of sustained waves of variable frequency in each of said circuits, and means for introducing a controllable degree of time delay in the waves transmitted over each of said circuits and comprising retardation networks having a substantially linear relation between the frequency and phase shift included in said circuits.

7. The combination, with a plurality of sound responsive current varying devices, a plurality of sound-controlling devices, and transmission circuits connecting the current varying devices to the sound-controlling devices of sources of carrier waves associated with said transmission circuit, means for varying the frequency of said carrier waves, means for modulating the carrier waves in accordance with the current variation set up by said current-varying devices, retardation networks in said circuits for shifting the phase of the waves produced by modulation, in accordance with the frequency of such waves, said sound-controlling devices converting the waves transmitted through said networks into observable effects.

8. In a binaural system including a receiver and a sound translating device, means to delay transmission of waves from said device to the receiver to effect binaural compensation comprising a phase-shifting network having a regularly varying retardation characteristic with frequency, and means for changing the frequency level of said waves to predetermined values and to impress the waves of changed frequency upon said network for transmission to said receiver.

9. In combination, a source of electrical variations, an indicator, means to impress said variations on said indicator including means for introducing predetermined retardations into the variations impressed on the indicator comprising a network interposed in the transmission path between said source and said indicator, having a regularly varying retardation characteristic with frequency, and means to shift the frequency level at which said variations are transmitted through said network.

10. The method of delaying by predetermined amounts the arrival of electrical variations at a receiver from a given point of origin comprising producing phase lags in the transmitted variations depending on the frequency in such a way that the first derivative of the phase lag with frequency has a predetermined rate of increase with increasing frequency, and shifting the frequency level of said variations before such phase lag is introduced, to control the amount of delay.

11. The method of effecting delay in transmission of given waves comprising modulating a carrier wave with said given waves, passing the modulated waves through a phase changing medium, varying the frequency of the carrier wave to determine the degree of time lag introduced into the transmitted waves, and detecting the waves after transmission through said medium to restore the given waves.

12. In a transmission system for transmitting waves with required time delay, means to shift the waves upward in frequency, a network having the property of introducing a time delay in waves transmitted through it dependent upon the frequency level of the waves, means to pass the waves of shifted frequency through said network at a frequency level to give the required time delay, and means to thereafter reduce the waves in frequency to the desired level.

In witness whereof, I hereunto subscribe my name this 4th day of August, A. D. 1924.

JOSEPH W. HORTON.