Feb. 4, 1941. E. W. KELLOGG 2,230,299

CONTROL CIRCUIT

Filed June 30, 1937

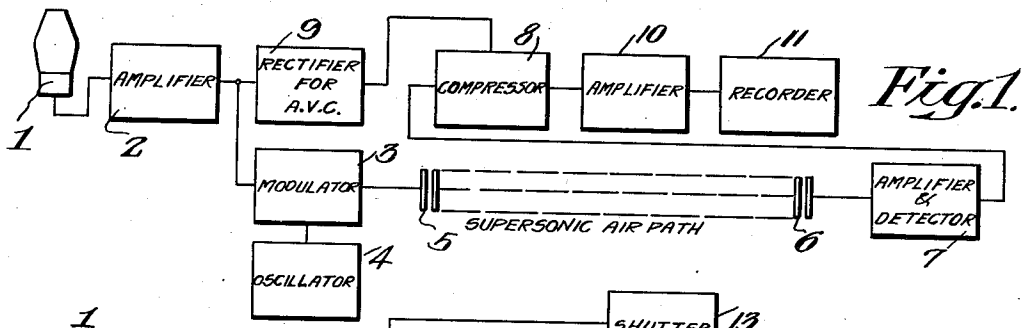


Fig. 1.

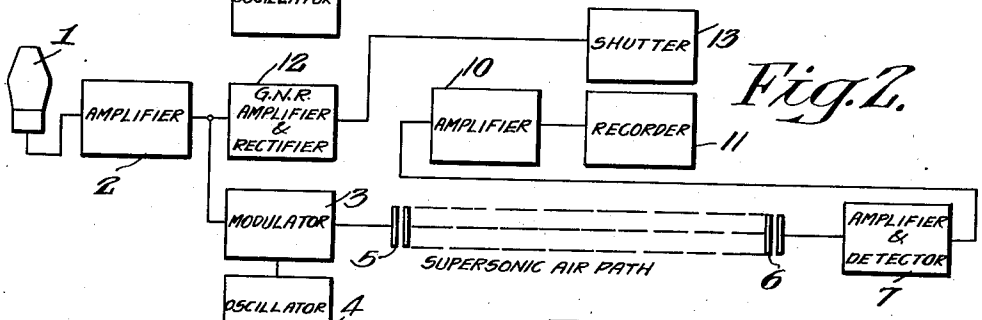


Fig. 2.

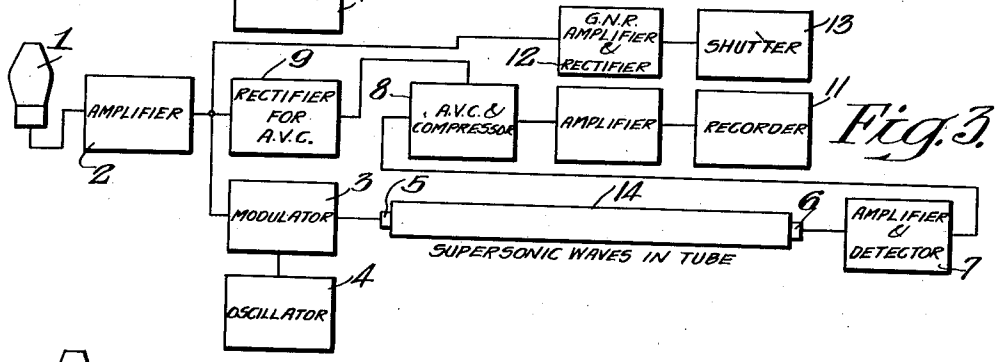


Fig. 3.

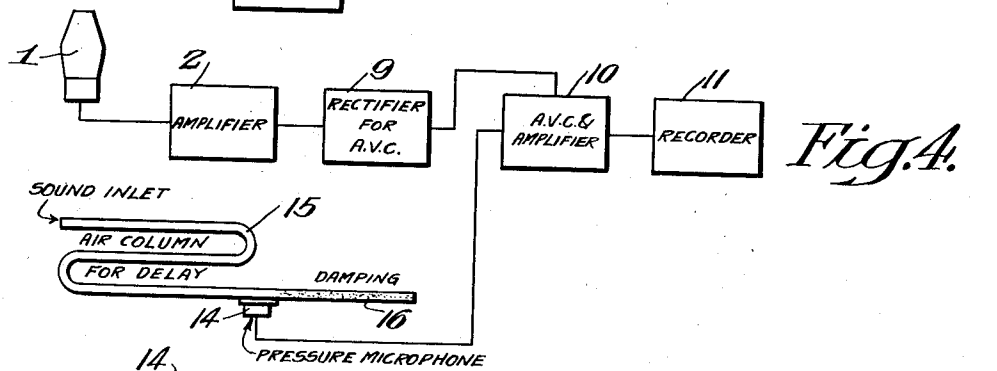


Fig. 4.

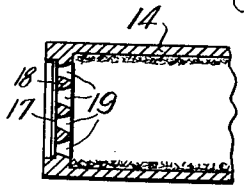


Fig. 5.

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CONTROL CIRCUIT

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5 Claims. (Cl. 179—100.1)

The present invention relates to control circuits, and more particularly to the type of control circuits used in sound recording, telephony, radio broadcasting and the like, wherein one component of a sound wave or a derivative thereof controls the sound wave, or a carrier wave, or some mechanism acting in coordination with the wave.

It has been proposed in the past to provide, for example, a current corresponding to the envelope of a sound wave or a current corresponding to the variations in amplitude of a carrier wave, or to some other characteristic of a wave or signal, either modulated or unmodulated, for controlling apparatus through which the wave passes. In connection with such devices, it is sometimes necessary to provide a delay circuit for transmitting the wave so that the control circuit can have the apparatus through which the wave is to pass properly conditioned for the wave on its arrival at the said apparatus.

The delay circuits used or proposed have been of many kinds including electrical, mechanical and acoustical. The procuring of the necessary delay by recording the sound and subsequently reproducing it from the record has also been proposed. It is evident that the production of such delay must be accomplished with little or no distortion, since the control is to be exercised on the delayed waves and unless the over-all result is better than that which is secured when such delay is omitted the purpose of the operation is defeated. The objection to recording the sound and subsequently reproducing it consists in the distortion which practically all devices for recording and reproducing sounds introduce.

The conversion of electrical waves into mechanical or acoustical waves, and the re-conversion into electrical waves also involves the use of translating devices such as loudspeakers and microphones which are not entirely free from distortion. For these reasons it would be desirable to keep the waves in the electrical form and secure the desired delay by transmitting them over an artificial electrical transmission line. The difficulty in employing this principal consists in the inherently high velocity of all electrical wave propagation, especially over types of transmission lines which are uniform. Thus any uniform line providing the required delay time become extremely bulky and expensive. If the electrical transmission line is constructed of series coils and shunt capacities, thus providing what is known as a "lumped" line, the line will act as a low-pass filter and eliminate all components having frequencies higher than a certain value. It is necessary that there be approximately three or more coils and condensers per wave length at the highest frequency which must be transmitted. If this highest frequency is taken as 10,000 cycles per second and it is desired to provide a delay of .05 second, for example, the line must carry $.05 \times 10{,}000$ equals 500 such waves at one time and in order that it may not cut off waves of this frequency, at least 1500 coils and 1500 condensers must be employed.

Since the waves must traverse this very large number of units, a very slight loss in each unit produces very serious over-all loss. Thus, if the loss is only slightly higher at high frequencies than at low frequencies, the over-all attenuation may be so much greater that it cannot be satisfactorily compensated in an amplifier.

A similar difficulty is encountered in efforts to transmit waves through mechanical media such as torsional or other waves in solid bars of various shapes. In general, such bars have rates of propagation which depend on the frequency, and the losses also vary with frequency making it very difficult to transmit the waves through a length of medium sufficient to produce the desired delay without serious distortion.

The most satisfactory results have been obtained with acoustic waves, or propagation through air, but even with this type of propagation, variations in attenuation with frequency become a serious factor, particularly in view of the fact that the highest audio frequencies which must be transmitted are of the order of 200 times the lowest required frequencies, for example, 10,000 and 50 cycles, respectively.

In accordance with my invention, I reduce the distortion which results from variations in the propagation characteristics of the medium, by employing waves in which the longest and shortest differ by only a relatively small percentage. If audio frequencies ranging up to 10,000 cycles per second are caused to modulate a wave of 100,000 cycles per second, the result is a band of frequencies ranging from 90,000 to 110,000 cycles; thus the shortest waves are only of about 20% higher frequency than the longest. Therefore, if the medium attenuates high frequency waves more than low frequency waves, total variation will not be so serious as would be the case if the shortest waves had a frequency 200 times that of the longest waves. Moreover, by employing modulated high frequency waves, the transmitting and receiving device can be made to cause comparatively slight distortion since they are not required to deliver a range of frequencies large compared with the average frequencies.

In the performance of my invention I provide an oscillator which generates electrical waves of constant frequency (for example, 100,000 cycles per second). The acoustical waves to be transmitted are caused to modulate the output of this oscillator. The resulting modulated high frequency electrical currents are applied to a high frequency device, which may be broadly tuned,

which radiates substantially plain waves of frequencies in the range of 90,000 to 110,000 cycles. At a suitable distance from the sound radiating device, an appropriately designed microphone is placed in which are generated voltages corresponding to the high frequency waves radiated, but delayed by the time required for the waves to travel from the radiating device to the microphone. The output of the microphone is amplified and demodulated and the result is a replica of the original audio frequency waves but with the desired delay.

It has been found that high frequency waves in air are sometimes attenuated so rapidly that it would not be practical to provide any considerable delay by this method. Small quantities of water vapor and carbon dioxide in the air result in very high attenuation. Attenuation is lowest of all if the high frequency sound waves are propagated in a monatomic gas such as argon. There is further advantage in employing a heavy gas, since this results in slower propagation and thus permits reducing the distance between radiator and the microphone. The heavy gas is also more effective in absorbing energy from the radiating device and imparting it in turn to the microphone. The advantage of better coupling between the radiating and receiving devices and the gas can be further improved by employing gas under pressure.

Since there are advantages in transmitting the waves through a medium other than air, I propose, in one form of my invention, to employ a closed tube between the radiator and the microphone, the tube being filled with the desired gas, which may be above atmospheric pressure. In order to avoid interference between the direct waves and those reflected from the walls of the tubes, I propose to line the tube with the absorbent material, the tube being made of sufficiently large diameter to accommodate this absorbent material in addition to providing a clear opening having a diameter of the order of ten or more wave lengths of the transmitted waves.

One object of my invention is to provide a novel sound recording apparatus.

Another object of my invention is to provide a novel type of delay circuit.

Another object of my invention is to provide a novel combination of a transmission line and a control circuit therefor.

Another object of my invention is to provide a novel type of volume compression or expansion apparatus.

Another object of my invention is to provide a novel type of ground noise reduction device for use in sound recording.

Other and incidental objects of my invention will be apparent to those skilled in the art from a reading of the following specification and an inspection of the accompanying drawing in which

Figure 1 shows schematically a form of my invention for volume compression in sound recording employing a delay circuit including a supersonic path in air,

Figure 2 shows a form of my invention as applied to ground noise reduction in sound recording, likewise using a supersonic air path,

Figure 3 shows a form of my invention applied to sound recording for the purpose of volume compression, and ground noise reduction, and using a supersonic wave path in a tube which may be filled with an appropriate gas,

Figure 4 shows a modified form of my invention using an acoustic air column for delay between the sound source and the pick-up microphone and a separate microphone for actuating the control circuit, and

Figure 5 is a longitudinal section of the input end of an acoustic transmission line.

Referring first to the form of the invention shown in Fig. 1. Sound is applied to the apparatus through an appropriate translating device 1 which is here represented as a ribbon microphone, although any other appropriate device for translating impulses into electrical energy may be used. Such devices include, for example, phonograph pickups, photoelectric pickups, etc. The output from this device is passed from the amplifier 2 where it is brought to a sufficiently high value and is then passed to the modulator 3. Supersonic waves of appropriate frequency are fed to the modulator 3 from the oscillator 4 and are modulated at 3 by the output from the amplifier 2 thereby producing modulated electrical waves of supersonic frequency. These waves are fed to an appropriate translating device 5 which is preferably a reproducer of the crystal or magnetostrictive type, although any other appropriate reproducer, such as an electromagnetic speaker or ribbon type speaker, capable of responding at the desired frequency may be used. The reproducer or radiator 5 should be capable not only of responding to the carrier frequency used, but should have a sufficiently wide range of response to transmit the side bands produced by modulation of the carrier. The output from the reproducer 5 is directed to the microphone 6 by any appropriate means. The air column between the elements 5 and 6 may be confined by a tube or other enclosure, or it may be defined by the beam from a reflector or acoustic lens placed adjacent the reproducer 5 and focused upon the microphone 6, or the radiator or reproducer 5 may be so constructed as to produce substantially plane waves, in which case other concentrating or directing means may be omitted. The microphone 6, like the reproducer 5, should be capable of responding to the carrier frequency and the entire range of side band frequencies. The output from the microphone 6 is fed to the amplifier and detector 7, where it is amplified to an appropriate value and then rectified to produce audio frequency waves corresponding to those impressed upon the translating device 1. The output from this detector 7 is fed to the compressor 8.

A portion of the output of the amplifier 2 is fed to the rectifier 9, where this output is rectified and applied as the control voltage to the compressor 8. In addition to rectifying devices proper, such, for example, as thermionic valves, the rectifier 9 contains a low pass filter to eliminate from the rectified currents such audio frequency components as may be present. Thus, the rectified and filtered output of element 9 will be a smoothly varying current, having a magnitude dependent on the amplitude of the audio frequency voltage applied to the input of element 9, but not having appreciable audio frequency fluctuations.

The low pass filter just mentioned produces a certain time lag. Thus, if there is a sudden increase in the amplitude of the audio frequency waves, the rectified and filtered current will change more or less gradually, finally reaching the value corresponding to the changed amplitude of the input waves. It is this delay in the fluctuation of the control current output of rectifier 9 that makes it important that the waves to

be controlled be likewise delayed by a corresponding time interval.

Since compressor circuits are well known in the art, it is not described in detail here, and the same applies to several other elementary circuits, such as the amplifier, modulator, oscillator, and detector.

In the compressor, the output from the rectifier 9 adjusts the control grid voltage to decrease the amplification on signals of large amplitude and to increase the amplification on signals of low amplitude, thereby compressing the volume range of the signals transmitted. Due to the delay in the filter circuit of the rectifier and due to the necessity for having the compressor prepared for the sound wave before the sound wave reaches it, it is necessary that the grid voltage on the compressor be altered before audio frequency impulses from the microphone 1 reach the compressor, and the delay in the supersonic air path is so chosen as to accomplish this result. The supersonic vibrations are propagated at substantially the same velocity as ordinary sound waves, and a comparatively short air path is therefore sufficient to delay the sound waves until the compressor circuit is properly conditioned to receive them. The period required for this delay is not less than the delay in the unit 9 which includes a rectifier and filter for smoothing out the sound waves.

After leaving the compressor 8, sound passes through the amplifier 10 to the recorder 11 which may be any appropriate type of sound recorder such as a photophonographic recorder or a wax recorder.

The arrangement shown in Fig. 2 differs from that shown in Fig. 1 only in that the control current is passed through the ground noise reduction amplifier and rectifier 12 and from there to the shutter 13, which serves to obscure the unused portion of a sound record in the recorder 11, as shown and described in McDowell Patent No. 1,855,197. The sound waves to be recorded pass through the modulator 3, the delay circuit 5, 6, the detector 7, and to the amplifier described above, as shown in Fig. 1.

In the form of the invention shown in Fig. 3, the features shown in Figs. 1 and 2 are combined. A portion of the output from the amplifier 2 passes to the modulator 3, through the supersonic delay circuit 5, 6, and the detector 7, to the compressor 8. Another portion passes through the automatic volume control rectifier 9 to the compressor 8, as described above in connection with Fig. 1. A third portion of the output from the amplifier 2 passes to the ground noise reduction amplifier and rectifier 12 and thence to the shutter 13, as described above in connection with Fig. 2. It will be apparent that in this arrangement the single delay circuit 5, 6 causes sufficient delay in the transmission of the sound waves to permit the functioning of both the compressor 8 and the shutter 13. In Fig. 3, the supersonic waves between the reproducer 5 and the microphone 6, instead of being in free air, are shown as confined within the tube 14 in order to increase the efficiency of the apparatus. This tube may be of any appropriate material and size, according to the time delay required.

Although it is permissible to employ a tube of sufficiently small diameter to avoid interference between the waves as propagated along the axis and as reflected from the walls, I prefer to use a large diameter tube such that waves are propagated substantially as if in free space, which means that the tube must have a diameter of a number of wave lengths, preferably of the order of ten or more wave lengths. In this manner, I avoid the attenuation which results from wall friction, which attenuation varies with frequency, and is of sufficient magnitude to cause difficulties.

In order to avoid reflections from the walls of the tube, which are quite serious in producing interference effects at supersonic frequencies, I prefer to line the walls of the tube with a sufficient layer of felt or other suitable material to prevent reflections of the sound waves within the tube. Likewise, in order to reduce attenuation, I prefer to use in the tube (instead of air) a gas of low viscosity, high molecular weight, and uniform composition, a monatomic gas being especially favorable. The avoidance of mixtures, and especially the employment of a monatomic gas, is insurance against certain excessive losses encountered with the use of air, especially when certain impurities are present, as described by V. O. Knudsen, in the Journal of the Acoustical Society of America, vol. VI, No. 4, April 1935, page 199. The use of a gas of low viscosity reduces attenuation, and high density or high molecular weight is of advantage in decreasing the length of the tube necessary, and thereby decreasing the absorption, since the velocity of sound propagation in a gas is inversely proportional to the square root of its molecular weight. The heavy gas has a further advantage in that it will absorb more energy from the sound radiating device 5 of Figs. 1, 2 and 3, and will better impart vibration to the microphone 6. A similar advantage is secured by using gas under pressure, and the increased pressure affords a further advantage in reducing attenuation, for the reason that pressure increases the density without increasing the viscosity.

The monatomic gas argon, which is readily available in quantity and has a density about 1.38 times that of air, is an especially favorable medium for the propagation of the supersonic waves.

In order further to improve the coupling between the gaseous propagation medium and the radiating and receiving devices 5 and 6, I may provide tapered tubes or horns or nested horns, in the manner already in use in loudspeakers for use at audio frequencies. The essential difference would be that the horns for the supersonic waves can be very short and can flare rapidly, and that only a very small cavity or space may be permitted between the diaphragm and the plate in which the expansion passages are bored. Fig. 5 shows such a construction. A diaphragm 17 is vibrated at supersonic frequency by means of a piezo-electric crystal, magnetostrictive element, or any other suitable known means. Close to the diaphragm 17 is a plate 18, in which a number of tapered holes 19 are bored, in honeycomb arrangement. The waves, after expansion in the horns or tapered holes 19, recombine into a single plane wave front which is propagated along the tube 14. A similar arrangement may be employed at the microphone 5.

The importance of thus increasing the coupling between the vibrating element and the propagation medium is not solely for the sake of increasing energy transfer, but also because most electroacoustic devices for operation at supersonic frequencies are mechanically tuned, and the improved acoustic loading obtained by the horn arrangement, as well as that obtained by use of

a heavy gas, tends to broaden the tuning, and thereby reduce distortion.

If the design of the radiating device is such that it tends to radiate waves which are not plane, as, for example, if the diaphragm is not large in comparison with the wave length, some acoustic expedient may be employed to secure plane waves where the waves start their propagation through the tube. One such device is a parabolic reflector. Another consists in a large number of passages, the lengths or contours of which are designed to bring their several wave fronts into phase where they combine into a single plane wave.

In the form of the invention shown in Fig. 4, the microphone 1 and amplifier 2 are used only to provide input for the rectifier 9 which controls the amplification in amplifier 10, in order to automatically regulate the volume. It will be apparent, of course, that this unit 9 may be connected to a volume compressor, to an expander, to a ground noise reduction device, or to any device for which it is desirable that the control be capable of anticipating a change in level of the sound waves. In this form of the invention, in order to secure a time delay, I provide a pipe 15 through which the sounds to be recorded are transmitted. In this case, supersonic waves are not employed. The microphone 14, which is here shown as a pressure microphone, is located at an appropriate place along the pipe and connected thereto so that the waves will reach the microphone 14 after a predetermined time delay. The portion of the pipe 15 beyond the microphone 14 is filled with loosely packed tufts of felt or equivalent material, to provide acoustic damping and prevent the reflection of sound waves.

In the form of the invention shown in Fig. 4, in which the delay is obtained by providing an acoustic path for waves of audio frequency, rather than of supersonic frequency, the same advantages are secured by employment of heavy gases, or of gases under pressure, as are obtained in the transmission of waves of supersonic frequency. The employment of a heavy gas reduces the necessary transmission distance, thereby reducing the size of the apparatus, and reducing the attenuation of the waves. In reducing the total attenuation, the difference in attenuation of short waves as compared with long waves is also reduced, and distortion is thereby reduced. Attenuation is also reduced by employment of a gas under pressure, whether this attenuation is the result of losses within the gas itself or of friction against the sides of the tube.

One of the reasons why it is difficult to construct radiating devices and sound pick-up devices or microphones free from distortion is that the vibrating elements are necessarily heavy compared with air, and it is difficult to avoid resonances in the mechanical structures. Increased coupling between the diaphragm and the propagation medium, obtained by employment of a denser medium, tends to damp the oscillations of the radiating and receiving devices, and make it possible to secure more uniform response and freedom from distortion.

In Fig. 4, a heavier gas might be employed within the pipe 15 by providing a very light diaphragm across the open end. In order to employ a propagation medium in the delay pipe at other than atmospheric pressure, it would be necessary to close the end in such a manner as to resist the pressure difference. The most satisfactory method of employing a gas at high pressure is to provide an electro-acoustic device for producing the sound in the tube, and to extend the pressure chamber so as to completely enclose both the radiator and the microphone. The sound radiator is, in this arrangement, supplied with electrical power from a microphone and amplifier. The system then becomes substantially equivalent to Fig. 3, except for the employment of acoustic frequency radiators and microphones rather than instruments designed for supersonic frequencies, and the omission of the oscillator 4, the modulator 3, and the detector 7.

Having now described my invention, I claim:

1. Means for translating sound waves into electrical currents, means for rectifying said electrical currents, a second means for translating said sound waves into electrical currents, the second translation occurring subsequently to said first translation, and means for controlling said second translated currents with said rectified currents.

2. A sound recording system comprising means for translating sound waves into electrical currents, additional means for translating said sound waves into electrical currents, means for delaying the second translation of said sound waves before translation thereof, and means for combining said currents into a common circuit for recording a sound record thereof.

3. A sound recording system comprising means for translating sound waves to be recorded into electrical currents, means for dividing said currents into three portions, means for modulating a carrier frequency with one of said portions, means for individually rectifying each of said other portions, a supersonic delay circuit for said modulated portion, a detector for said supersonic waves, means for combining said detected supersonic waves with one portion of said rectified currents, and means for subsequently combining said last-mentioned combination currents with the other portion of said rectified currents.

4. A sound recording system comprising a source of sound waves, means for translating said sound waves into electrical currents, a second means for translating said sound waves into electrical currents, means interposed between said source of sound waves and said second translating means for delaying the second translation of said sound waves, and means for combining the currents of both of said translation means into a common circuit.

5. A sound recording system comprising means for translating sound waves to be recorded into electrical currents, means for dividing said currents into three portions, means for modulating a carrier frequency with one of said portions, means for individually rectifying each of said other portions, a supersonic delay circuit for said modulated portion, a detector for said supersonic waves, means for controlling said detected supersonic waves by one portion of said rectified currents, and means for simultaneously recording said last-mentioned controlled detected supersonic waves with the other portion of said rectified currents.

EDWARD W. KELLOGG.