March 28, 1967 W. R. LEWIS ETAL 3,311,833

METHOD AND APPARATUS FOR INCREASING THE READABILITY OF AMPLITUDE MODULATED WAVES

Filed April 11, 1963

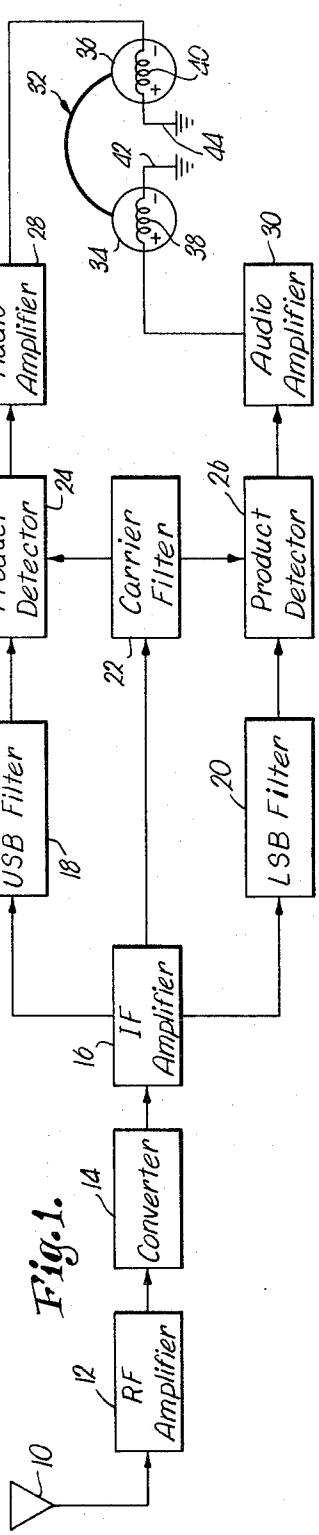


Fig. 1.

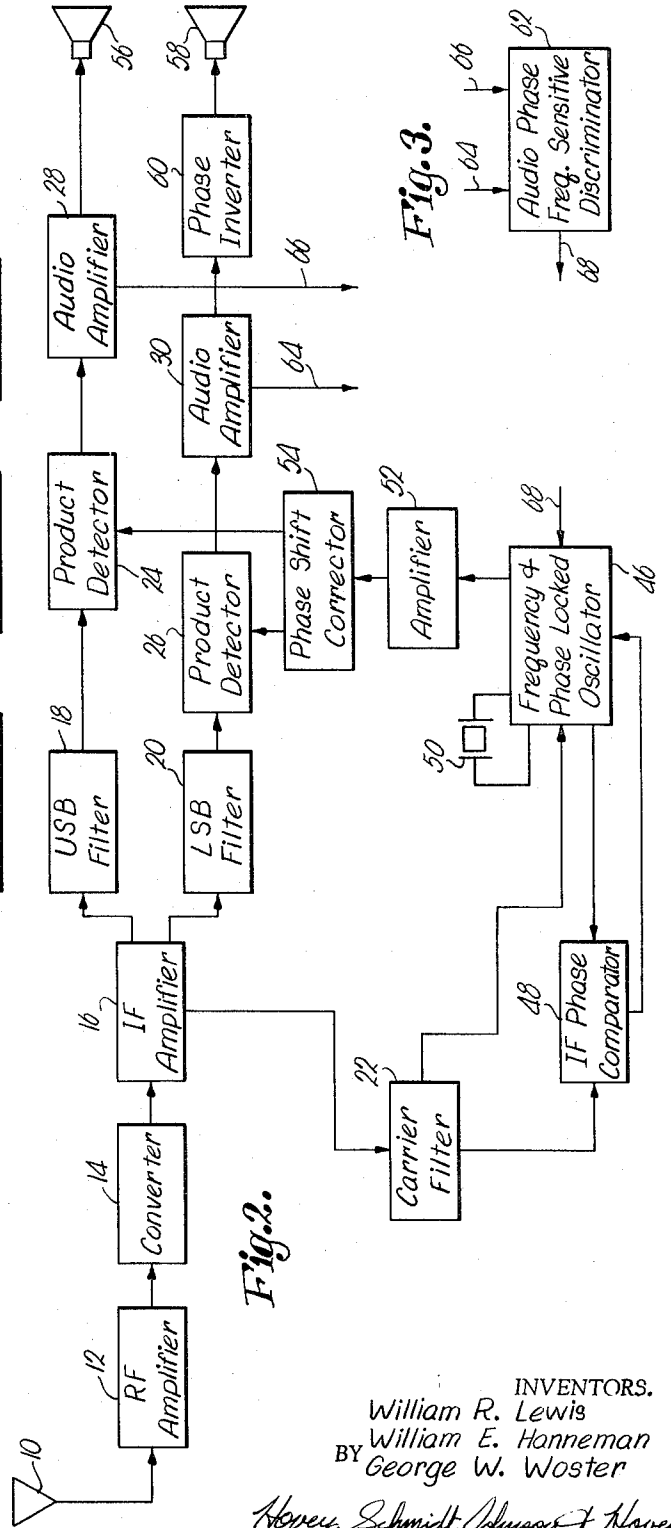


Fig. 2.

Fig. 3.

INVENTORS.
William R. Lewis
William E. Honneman
George W. Woster

BY Hovey, Schmidt, Johnson & Hovey.
ATTORNEYS.

United States Patent Office

3,311,833

Patented Mar. 28, 1967

3,311,833

METHOD AND APPARATUS FOR INCREASING THE READABILITY OF AMPLITUDE MODULATED WAVES

William R. Lewis, Kansas City, and William E. Hanneman, Independence, Mo., and George W. Woster, Mission, Kans., assignors to Wilcox Electric Company, Inc., Kansas City, Mo., a corporation of Kansas

Filed Apr. 11, 1963, Ser. No. 272,487
4 Claims. (Cl. 325—474)

This invention relates to a method and apparatus for increasing the readability of amplitude modulated, double side band signals.

It has been noted heretofore that the human ear is capable of distinguishing certain sounds or intelligence from background noise or undesired intelligence due to the differences in the phase relationships between the wanted and the unwanted sounds. For example, conversation emanating from a speaker directly in front of the listener reaches each ear of the listener at the same instant. Therefore, the sounds received by the listener are in phase with one another. Conversely, the sounds emitted by a speaker positioned to one side of the listener will not reach ear of the listener at the same time; hence, the sounds will reach the listener's ears out-of-phase.

The human mind apparently tends to fix its attention on sounds having a certain phase difference independent of the frequency thereof. Thus, the mind is able to focus its attention on a particular sound source due to the fixed phase difference between the sound waves reaching the ears from that particular source. Furthermore, the mind appears to place the source of a sound best when the amplitudes at the ears are equivalent, or nearly so.

The above effect is, of course, helpful to one when it is desired to place the source of a sound. The human ears might, therefore, be visualized as a binaural or dual channel sound-receiving system which is capable of placing the source of a sound due to the phase difference existing between the two channels.

Although the effects discussed above are useful in determining the source of an external sound, another effect heretofore noted also enhances the mind's ability to focus on a given sound. It has been found that when one sound wave is directed to one ear and another sound wave, carrying the same intelligence as the first wave, is directed to the other ear 180 degrees out-of-phase with the first wave, the source of the sound then appears to be located within the head of the listener. Therefore, other sounds not 180 degrees out-of-phase will appear to be located externally of the listener and thus, attention may readily be focused on the intelligence received by the ears 180 degrees out-of-phase.

Various schemes have been proposed for utilizing this effect. One such scheme is that of increasing the amount of useful information that can be transmitted on a given number of channels by sending each message on a pair of channels. In this manner, several messages may be placed on each channel, but the listener will be able to pick out the desired message by reversing the phase of the appropriate channel with respect to a second appropriate channel. Additionally, it has been proposed that intelligence could be transmitted on two separate radio frequencies along with random conversations or noise. Such random conversations or noise, however, would

contain no like counterpart on the other channel, i.e., only the desired intelligence would be transmitted on both channels. Therefore, it is evident that the desired intelligence may be extracted by the listener by the phase reversal technique.

Unlike the prior means of utilizing this effect, the present invention is directed to a system for enhancing the reception of amplitude modulated, double side band signals produced by conventional means and transmitted to the listener. Generally, such signals during transmission to the listener will take the form of radio waves, but the concepts of this invention are equally applicable to wire transmission systems. The invention may be utilized to increase the readability of normal amplitude modulated signals having an unsuppressed carrier and an upper and a lower side band, double side band partially suppressed carrier signals, or double side band fully suppressed carrier signals.

The means provided by this invention for extracting the intelligence from amplitude modulated signals utilizes the listener's ability to focus attention upon the apparent origin of the desired intelligence when that intelligence seems to originate from a source which appears to be positioned differently than the apparent source of the undesired interference. The desired intelligence in the side bands constitutes the majority of the audio components which retains one specific phase relationship. Undesired side bands (whose carriers are removed by a few cycles or more), heterodyning carriers, random noise, intentional jamming, etc, either occur only in one of the reception channels of the invention or where they appear in both channels, have random frequency and phase relationships and, therefore, seem to originate from a random spherical source about the listener. These unwanted signals give the sensation to the listener of moving; unwanted signals rotate around the head of the listener in a manner characteristic of the particular changing phase difference.

In brief, this is achieved in the instant invention by detecting each side band separately and then feeding each of the detected signals to different ears of the listener, the phase of one signal being reversed with respect to the other signal. By this scheme it is possible to read intelligence which otherwise would be completely masked by interference and unreadable when received by an amplitude modulated receiver of equivalent band width employing conventional techniques. Furthermore, it is noteworthy that some enhancement of the intelligence is achieved without reversing the phase of one of the detected side band signals, but by merely directing the intelligence in one side band to one ear of the listener while the intelligence in the other side band is directed to the other ear of the listener.

It is, therefore, the primary object of this invention to provide a method and apparatus for increasing the readability of amplitude modulated, double side band signals by detecting each side band separately to thereby obtain a pair of intelligence signals and then reversing the phase of one of said intelligence signals.

It is another object of this invention to provide a method and apparatus for increasing the readability of amplitude modulated, double side band signals by detecting each side band separately and directing each of the two channels of intelligence so obtained to different ears of the listener.

It is another object of this invention to provide a method and apparatus for increasing the readability of amplitude modulated, double side band signals by detecting each side band separately to obtain a pair of intelligence signals, reversing the phase of one of said intelligence signals, and then directing the phase-reversed intelligence signal to one ear of the listener while the other intelligence signal is directed to the other ear of the listener.

It is another object of this invention to provide apparatus for separating the components of an amplitude modulated, double side band signal to permit separate detection of the side bands and subsequent phase reversal of the intelligence obtained from one of the side bands.

It is another object of this invention to provide apparatus for separating the side band signal components from an amplitude modulated, double side band signal and for providing a de-modulating electrical signal phase locked with the carrier signal component of the AM signal to permit separate detection of the side bands.

It is still another object of this invention to provide apparatus for generating a de-modulating carrier signal for use in the detection of amplitude modulated, double side band, fully suppressed carrier signals wherein said de-modulating carrier is of a frequency and phase such that the detected side bands will be in phase, and for converting the detected side bands into a pair of sound waves 180 degrees out-of-phase with one another.

It is yet another object of this invention to provide a scheme for detecting amplitude modulated signals having a carrier signal component and a pair of side band components wherein the components are each separated from the parent signal by filter means, the carrier component being injected into the feedback circuit of a crystal oscillator for phase locking said oscillator with the carrier component, the side band components being fed to individual mixers or product detectors along with the output signal from said oscillator to thereby effect detection of each side band separately and permit subsequent phase inversion of the intelligence obtained from one of the side bands.

Other objects will become apparent as the detailed description proceeds.

In the drawing:

FIGURE 1 is a block diagram showing the basic system concept of the present invention applicable to amplitude modulated, double side band signals having either an unsuppressed or a partially suppressed carrier;

FIG. 2 is a block diagram showing an improved detection scheme for utilization with amplitude modulated, double side band signals having a carrier signal component; and

FIG. 3 is a block diagram showing a modification of FIG. 2 for use with amplitude modulated, double side band, fully suppressed carrier signals.

Referring to FIG. 1, it may be seen that the antenna **10**, radio frequency amplifier **12**, converter **14** and intermediate frequency amplifier **16** comprise apparatus found in conventional superheterodyne receiver systems. At the output of the IF amplifier **16**, the carrier signal component of the incoming radio wave will be at the intermediate frequency regardless of the actual frequency of the wave as it is transmitted. This, of course, is in accordance with well known principles of superheterodyne receivers.

An upper side band filter **18**, a lower side band filter **20**, and a carrier filter **22** are each coupled with the output of IF amplifier **16**. The upper and lower side band filters may comprise band-pass filters of conventional design, the width of the pass band being determined by the selectivity characteristics desired for the particular receiver. For an intermediate frequency of 455 kc., a suitable pass band width would be from 2 to 3 kc.

The carrier filter **22** may also be a band-pass filter.

The width of the pass band, however, should be quite narrow and may be on the order of 2 or 3 c.p.s. or less. Therefore, it may be appreciated that the output from carrier filter **22** will contain only the carrier component of the incoming radio wave which it is desired to receive unless, of course, interfering carriers of nearly the same frequency are present.

The outputs from upper side band filter **18** and carrier filter **22** are coupled with a product detector **24**. The output from carrier filter **22** is also coupled with a product detector **26** along with the output from the lower side band filter **20**. Any of a variety of product detectors or mixers commonly employed in superheterodyne receivers are suitable for product detectors **24** and **26**. These detectors **24** and **26** employ the heterodyne principle to beat one input thereto against the other input to produce output signals having frequencies comprising various combinations of the input signals.

Referring to product detector **24**, one output signal therefrom will be of a frequency equal to the frequency of the upper side band signal less the frequency of the carrier signal. Detection of the intelligence in the upper side band thus occurs. Generally speaking, this difference signal will be of audio frequency. Similarly, product detector **26** produces a signal of a frequency equal to the frequency of the carrier signal less the frequency of the lower side band signal and, therefore, detection of the lower side band intelligence occurs.

The intelligence signals appearing at the outputs of product detectors **24** and **26** are fed, respectively, to audio amplifiers **28** and **30** wherein such signals are boosted to a suitable amplitude level for transmittal to a transducer in the form of a headset **32**. Headset **32** contains a pair of earpieces **34** and **36** of conventional design. Within earpieces **34** and **36** are coils **38** and **40**, respectively, polarized as shown in the drawing. Those skilled in the art will appreciate that coils **38** and **40** in conventional type headsets form a part of an electromagnet which actuates a diaphragm in accordance with the amplitude and polarity of the electrical signal appearing in the coil. It should be noted that coils **38** and **40** are grounded respectively at **42** and **44** and that the negative side of coil **38** is connected to ground **42**, while the positive side of coil **40** is connected to ground **44**.

From the foregoing it may be seen that the sound waves emanating from earpieces **34** and **36** will be 180 degrees out-of-phase due to coils **38** and **40** being oppositely polarized. It should be understood that the respective signals reach the earpieces in phase but that inversion of one with respect to the other occurs when such signals are converted into sound.

When the listener places headset **32** in position with the earpieces covering the ears, it is evident that the intelligence from the upper side band will be impressed exclusively upon one ear, while the intelligence from the lower side band will pass only into the other ear. Therefore, the wanted intelligence will appear to be emanating from the center of the listener's head in accordance with the effect previously described. Other, unwanted signals will appear to be coming from a source outside of the listener's head and, in the case of an interfering amplitude modulated signal of nearly the same frequency as the wanted signal, the interference will actually seem to be moving. The moving phenomenon is caused by the fact that the de-modulating carrier emanating from carrier filter **22** and utilized by the product detectors to demodulate the respective side bands is of the proper phase for only those desired side bands. Therefore, interfering side band signals within the pass bands of the filters **18** and **20** will not be provided with a proper carrier and thus will be out-of-phase with another and also of slightly different frequencies. Hence, the phase difference between the interfering side band signals will be constantly changing, and it is believed that this explains the moving effect noted by the listener.

The apparatus shown in FIG. 1, though effective, can be improved by supplementing the carrier filter **22** with additional de-modulating carrier re-insertion means. It is inherent in the apparatus as shown in FIG. 1 that any interfering carrier signal within the pass band of carrier filter **22** will necessarily be transmitted on to the product detectors and thus provide a proper de-modulating carrier for the side band components of the undesired signal.

An improvement on the FIG. 1 scheme is shown in FIG. 2 wherein apparatuses common to both figures carry like reference numerals. The upper and lower side bands of the incoming radio wave are separated therefrom in the manner as described for the system shown in FIG. 1 and fed to the corresponding product detectors. When a carrier is transmitted with the other components of the radio wave the carrier filter **22** in FIG. 2 separates the carrier therefrom in like manner as for FIG. 1. The output of the carrier filter is fed to an oscillator stage **46** which generates an output signal that is frequency and phase locked with the carrier signal from carrier filter **22**. The carrier signal is also conducted from the output of carrier filter **22** to an intermediate frequency phase comparator **48**. Comparator **48** is coupled with oscillator stage **46** and functions in a manner to be hereinafter described. Crystal control of oscillator stage **46** is illustrated by the connection of a piezoelectric crystal **50** to stage **46** and will be discussed fully hereinafter.

The function of the oscillator stage **46** is to generate an electrical signal for utilization by product detectors **24** and **26** as a de-modulating carrier. Such de-modulating carrier must be frequency and phase locked with the transmitted carrier signal or detection of the side band intelligence will not occur. Minor variations in the phase relationship between the output of oscillator **46** and the transmitted carrier will effect a degree of detection, but any substantial phase diffference will result in severe distortion of the intelligence appearing at the outputs of the product detectors.

A simple and reliable means of achieving the requisite phase lock is through the use of the crystal **50** to control the oscillator. The crystal is ground to resonate at the intermediate frequency of the receiver which, of course, corresponds to the frequency of the carrier after conversion thereof in converter **14**. The output from carrier filter **22** is injected into the feedback circuit of the oscillator stage and serves to trigger the oscillation of the stage and maintain such oscillation in phase with the carrier signal.

Furthermore, the piezoelectric crystal **50** has an inherent attribute in that the crystal is not readily susceptible to intentional jamming by a frequency modulated signal. If the oscillator stage **46** were not crystal-controlled, other suitable means would usually have to be employed to eliminate the tendency of the oscillator stage to follow the modulations of the frequency modulated jamming signal. The tendency to follow or momentarily shift frequency would, of course, produce distortion at the outputs of the product detectors.

The intermediate frequency phase comparator **48** serves as a check on the phase of the signal locally generated by oscillator stage **46**. Comparator **48** receives the oscillator signal and the carrier signal and delivers an error signal to the oscillator stage if the two signals are not in phase with one another. (The subject of oscillator phase control by an error signal derived from a comparison of the phases of a pair of electrical signals is dealt with in references cited later in this specification pertaining primarily to the embodiment of FIG. 3.) This again is a desirable feature if the oscillator stage were not crystal controlled. However, when a crystal-controlled oscillator is utilized, the piezoelectric crystal inherently performs the phase comparing function of comparator **48** and thus renders such additional control circuitry unnecessary.

An amplifier **52**, having its input coupled with the output of oscillator stage **46**, may be employed to boost the amplitude of the oscillator signal to a level sufficient for utilization by the product detectors. A phase shift corrector **54** is interposed between the output of amplifier **52** and the product detectors to correct any phase errors induced in the signal by the circuitry of oscillator stage **46** or amplifier **52**. There is frequently a tendency for a phase shift to occur in these two stages. Therefore, the phase shift corrector **54** is adjustable to allow the receiver to be aligned to compensate for this shift. Corrector **54** may be any of a variety of conventional phase shift networks.

The output from corrector **54** is fed to each of the product detectors **24** and **26** and employed as a de-modulating carrier in the same manner as for the system shown in FIG. 1. Following amplification by audio amplifiers **28** and **30**, the intelligence signals are conducted, respectively, to speakers **56** and **58**. Alternatively, a headset such as illustrated and described for FIG. 1 may be employed instead of speakers **56** and **58**. It should be understood that flow lines **64** and **66** from audio amplifiers **30** and **28**, respectively, and line **68** to oscillator **46** are not a part of the FIG. 2 embodiment.

Phase inversion of one of the intelligence signals may be accomplished by polarizing the voice coil of one of the speakers oppositely to that of the other speaker or, alternatively, a phase inversion stage **60** may be interposed as shown between the output of audio amplifier **30** and the input of speaker **58**. Phase inverter **60** may be any of a variety of conventional phase inversion networks. It is evident that the phase inverter may be interposed between audio amplifier **28** and speaker **56** with equal effectiveness.

If speakers **56** and **58** are employed to convert the audio frequency outputs of the audio amplifiers into sound waves, optimum enhancement of AM reception is achieved when the listener is positioned between the two speakers and equidistant therefrom. Equidistance, of course, assumes that the output levels from the two speakers are equal in intensity.

At this juncture it should be understood that exact phase inversion of one of the intelligence signals is not absolutely necessary for the invention to be operable. Optimum performance is achieved when the two signals are 180 degrees out-of-phase with one another, but a variation of plus or minus 5 to 15 degrees yields acceptable performance. Furthermore, some enhancement is achieved with no phase inversion by merely directing one sound wave to one ear of the listener and the other sound wave to the listener's other ear. Without phase inversion, of course, the increase in readability is considerably less than achieved with the phase inversion technique since the sound phenomenon discussed earlier in this specification is not present.

In the reception of amplitude modulated, double side band signals wherein the carrier is not transmitted with the signal but fully suppressed, the carrier filter **22** is useless in phase locking the oscillator output with the carrier signal and may be omitted from the circuitry along with comparator **48** and crystal **50**, if desired. Instead, referring to FIG. 3, an audio phase and frequency sensitive discriminator **62** is employed in cooperation with oscillator stage **46** to provide a de-modulating carrier signal.

Flow lines **64** and **66** couple the inputs of discriminator **62** with the respective outputs of audio amplifiers **30** and **28**. Discriminator **62** compares the two intelligence signals from amplifiers **28** and **30** in frequency and in phase. The discriminator employs means whereby an error voltage is developed if the two intelligence signals are not in phase. This error voltage is fed from the discriminator output to the oscillator stage **46** along line **68** to control the phase of the oscillator output. This provides a signal from the oscillator that is of proper

phase to be utilized by the product detectors in extracting the intelligence from the side bands. Thus, detection is achieved even though the carrier is not transmitted with the side bands.

It may be appreciated that the above detection scheme, referred to in the art as "synchronous detection," operates on the principle that like intelligence in the two side bands of an amplitude modulated signal will be in phase when the side bands are separately detected only if the carrier signal component of the AM signal is employed in such detection. Therefore, when the carrier is not transmitted with the side bands, a carrier may be locally generated for de-modulation purposes by comparing the phase of the separately detected side bands. When the detected side bands are in phase, it is evident that a demodulating carrier of proper phase is being employed. For further information on the synchronous detection technique and the manner in which the phase of the local oscillator is controlled, see, for example, "Synchronous Communications," John P. Costas, Proceedings of the I.R.E., Dec. 1956, and "A Synchronous Detection Adaptor For Communications Receivers," John K. Webb CQ, June, 1957.

In the light of the foregoing description of apparatus suitable for practicing the invention, the method aspect of the invention may now be readily understood. The method of increasing the readability of an amplitude modulated signal having a pair of side bands comprises the following steps:

First, each of the side bands is separated from the amplitude modulated signal.

Secondly, each of the separated side bands is detected to obtain a pair of intelligence signals. This step is executed by providing an electrical signal of the same frequency and phase as the carrier signal for the side bands and combining one of the side bands with said electrical signal to obtain a first intelligence signal of a frequency equal to the difference of the frequencies of the one side band and said electrical signal. In like manner, the other side band is combined with said electrical signal to obtain a second intelligence signal.

Thirdly, the first intelligence signal is converted into a first sound wave.

Fourthly, the second intelligence signal is converted into a second sound wave substantially 180 degrees out-of-phase with the first sound wave.

Fifthly, the first sound wave is directed to one ear of the listener.

Sixthly, the second sound wave is directed to the other ear of the listener.

Conservative estimates of the results obtained by this method during actual tests are as follows. With random atmospherics interfering with the wanted signal the enhancement of the wanted signal was at least 2 to 4 decibels over conventional amplitude modulation reception techniques where both receivers had equivalent band widths. With heavy heterodyning, side band interference, and jamming, the apparent enhancement was at least 10 to 15 decibels. It is apparent, therefore, that many signals will be rendered readable over interference which would otherwise be impossible to copy.

The method of the present invention can also be applied to data ICW and tone RTTY which is transmitted by normal AM or double side band suppressed carrier. In these cases the upper side band and the inverted lower side band (or vice versa) are compared and only that signal which exactly cancels the other signal is passed on to the subsequent data converter.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. Apparatus for increasing the readability of an amplitude modulated signal having at least a pair of side band signals as components thereof, said apparatus comprising:

first filter means responsive to said amplitude modulated signal and adapted to have the same applied thereto for attenuating the components of said amplitude modulated signal except one of said side band signals;

second filter means responsive to said amplitude modulated signal and adapted to have the same applied thereto for attenuating the components of said amplitude modulated signal except the other side band signal;

means for providing a carrier signal for said side band signals;

first electrical means coupled with said first filter means and said carrier providing means for subtracting the frequency of the lower of said one side band and carrier signals from the frequency of the higher thereof to produce a first intelligence signal;

second electrical means coupled with said second filter means and said carrier providing means for subtracting the frequency of the lower of said other side band and carrier signals from the frequency of the higher thereof to produce a second intelligence signal,

said carrier providing means comprising an oscillator stage for locally generating said carrier signal and discriminator means coupled with said stage and responsive to said first and second intelligence signals for controlling the phase of said generated carrier signal to maintain said first intelligence signal in phase with said second intelligence signal;

transducer means coupled with said first electrical means and responsive to said first intelligence signal for converting the latter into a first sound wave; and

phase reversal means coupled with said second electrical means and responsive to said second intelligence signal for converting the latter into a second sound wave substantially 180 degrees out-of-phase with said first sound wave.

2. Apparatus for increasing the readability of an amplitude modulated signal having a carrier signal and a pair of side band signals as components thereof, said apparatus comprising:

first filter means responsive to said amplitude modulated signal and adapted to have the same applied thereto for attenuating the components of said amplitude modulated signal except one of said side band signals;

second filter means responsive to said amplitude modulated signal and adapted to have the same applied thereto for attenuating the components of said amplitude modulated signal except the other side band signal;

carrier reinsertion means including third filter means responsive to said amplitude modulated signal and adapted to have the same applied thereto for attenuating the components of said amplitude modulated signal except said carrier signal, an oscillator stage, and means operably coupling said stage with said third filter means for phase locking the oscillation of the stage with said carrier signal;

first electrical means coupled with said first filter means and the output of said stage for subtracting the frequency of the lower of said one side band and carrier signals from the frequency of the higher thereof to produce a first intelligence signal;

second electrical means coupled with said second filter means and the output of said stage for subtracting the frequency of the lower of said other side band and carrier signals from the frequency of the higher thereof to produce a second intelligence signal;

transducer means coupled with said first electrical means and responsive to said first intelligence signal for converting the latter intot a first sound wave; and

phase reversal means coupled with said second electrical means and responsive to said second intelligence signal for converting the latter into a second sound wave substantially 180 degrees out-of-phase with said first sound wave.

3. The invention of claim 2, said oscillator stage including means for maintaining the oscillation frequency of the stage equal to the frequency of said carrier signal.

4. The invention of claim 2, said stage comprising a crystal controlled oscillator stage having a frequency of oscillation equal to the frequency of said carrier signal.

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KATHLEEN H. CLAFFY, *Primary Examiner.*

R. LINN, *Assistant Examiner.*