

[54] MULTIPLEX SYSTEM EMPLOYING
MULTIPLE QUADRATURE SUBCARRIERS
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[51] Int. Cl. H04h 5/00
[58] Field of Search..... 179/15 BT, 1 GQ; 325/36,
325/47, 50, 48, 138, 49, 60, 329

[56] References Cited

UNITED STATES PATENTS			
2,760,006	8/1956	Lieberman.....	179/15 BT
2,855,462	10/1958	Adams.....	179/15 BT
2,870,248	1/1959	Valeton	179/15 BT
2,904,628	9/1959	Haantjes	179/15 BT
2,912,492	11/1959	Haantjes	179/15 BT
2,960,573	11/1960	Hodgson.....	179/15 BT
3,046,329	7/1972	Reesor.....	179/15 BT
3,067,292	12/1962	Minter.....	179/15 BT
3,375,329	3/1968	Prouty.....	179/15 BT
3,679,832	7/1972	Halpern.....	179/15 BT
3,708,623	1/1973	Dorren.....	179/15 BT

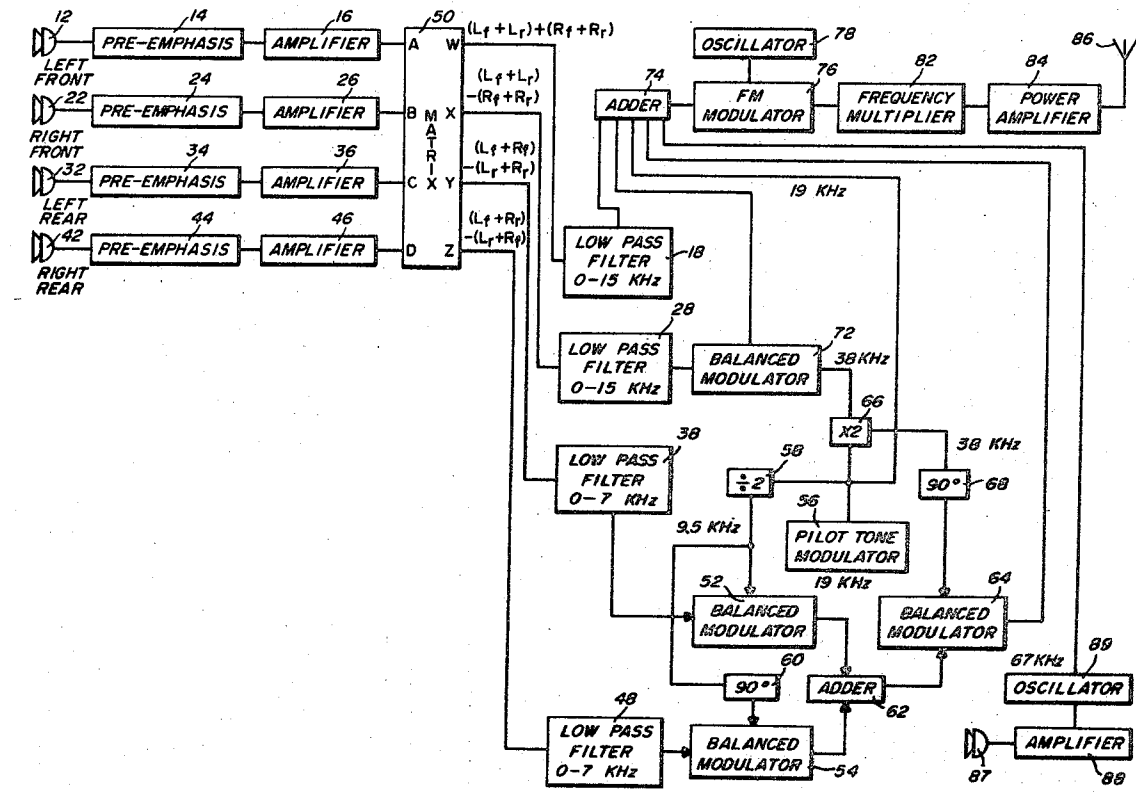
OTHER PUBLICATIONS
Quadrasonics on the Air Feldman Audio Magazine
Jan. 1970.
The Quart Broadcasting System Audio Magazine Sept.
1970.

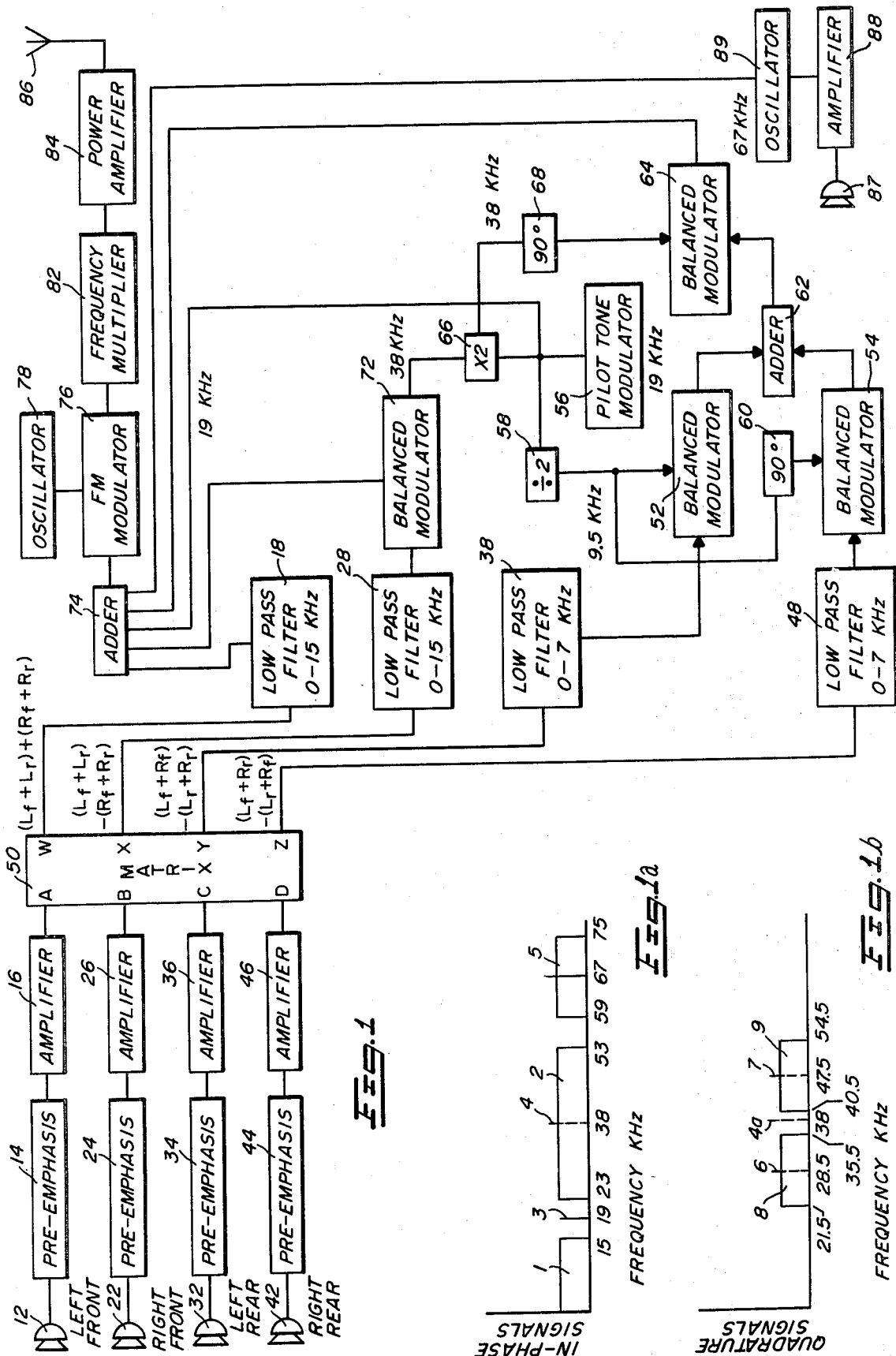
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[57] ABSTRACT

A system for broadcasting and receiving at least three stereophonically related audio components compatibly with present monophonic and stereophonic transmissions and receptions within the allotted bandwidth of present FM broadcast transmitters. Signals representative of the sum and difference of two stereophonically related audio components are broadcast in the audio band and on a 38 KHz suppressed subcarrier, respectively. A third signal, including a third component, is broadcast on a second 38 KHz suppressed subcarrier in quadrature with the first subcarrier. A fourth component may be transmitted on a third higher frequency suppressed carrier, or at reduced bandwidth about additional subcarriers generated about the second suppressed subcarrier. The components are distributed among signals so that monophonic reception may be achieved by receiving only the signals in the audio band and so that each additional signal received allows the recovery of an additional component.

6 Claims, 15 Drawing Figures





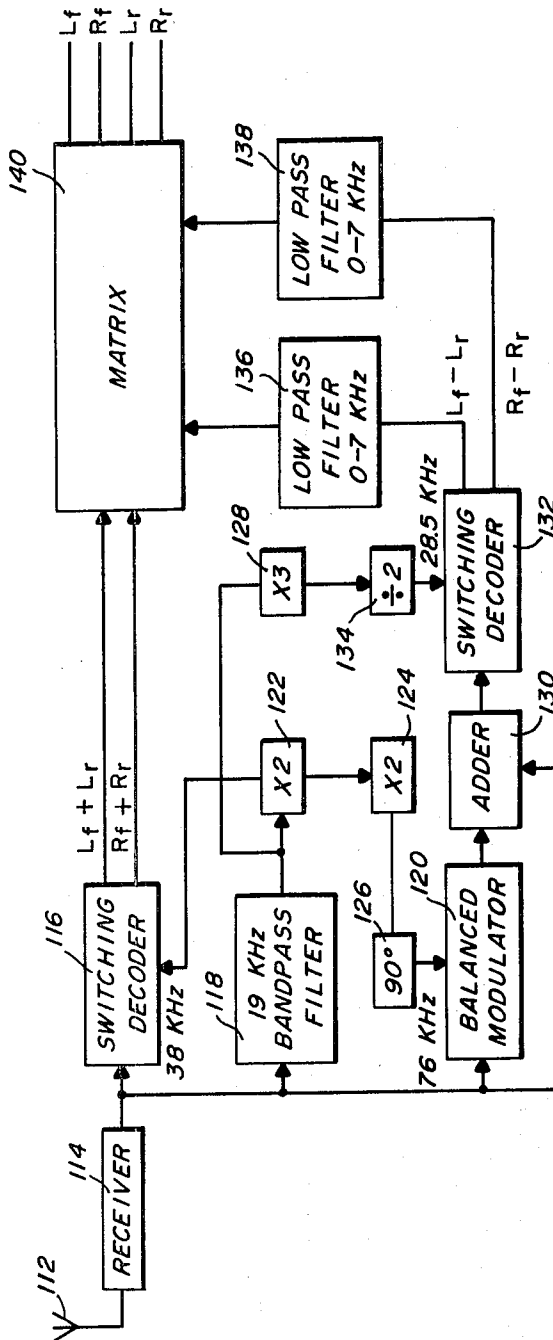


FIG. 2

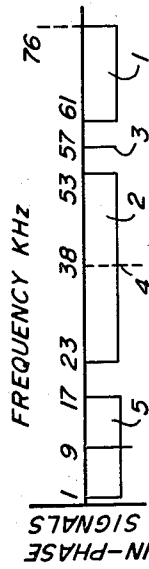


FIG. 2a

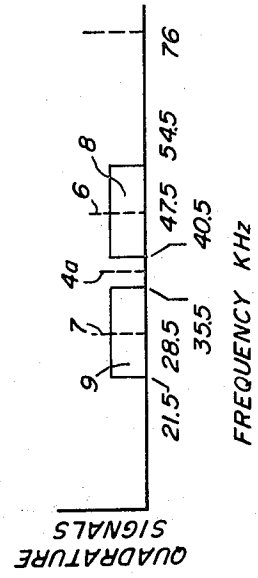


FIG. 2b

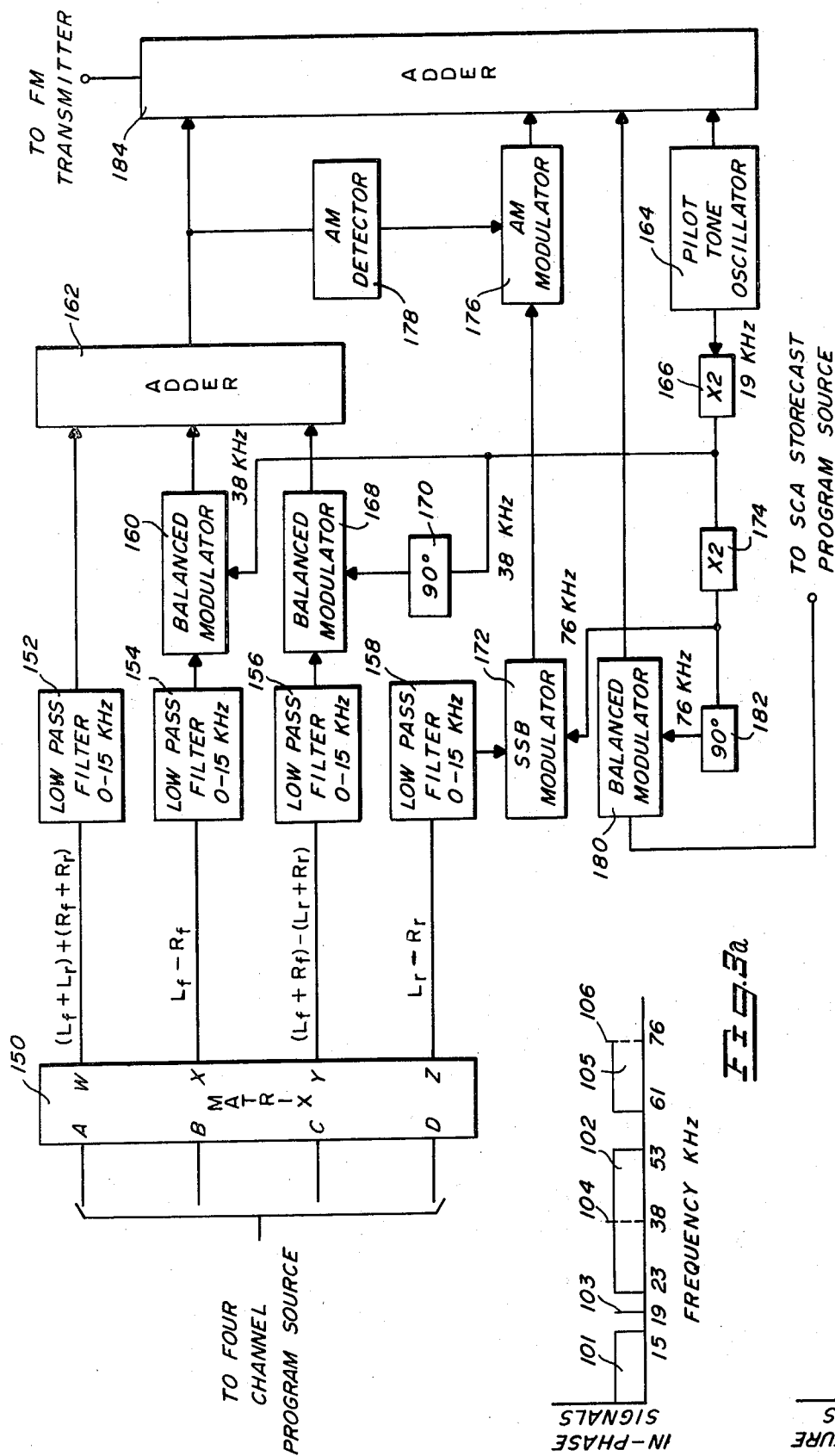


FIG. 3

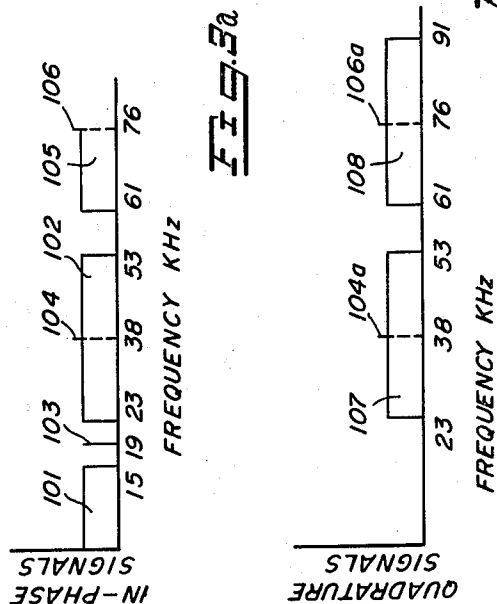


FIG. 3a

FIG. 3b

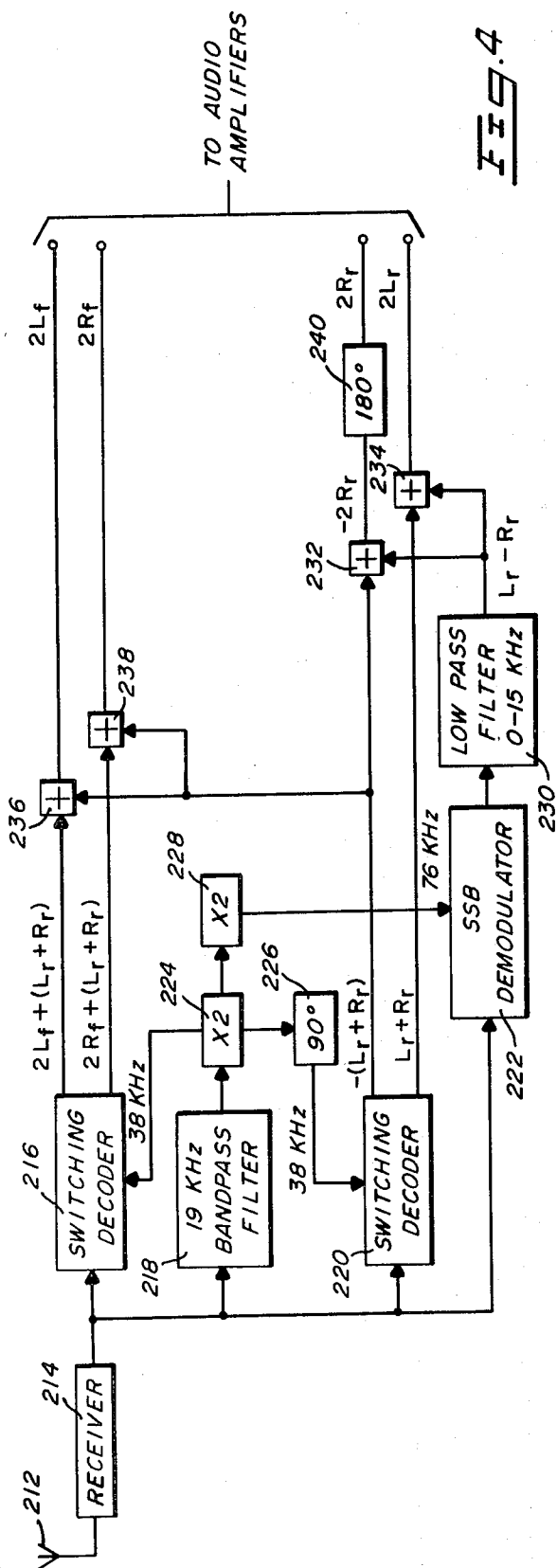


Fig. 4

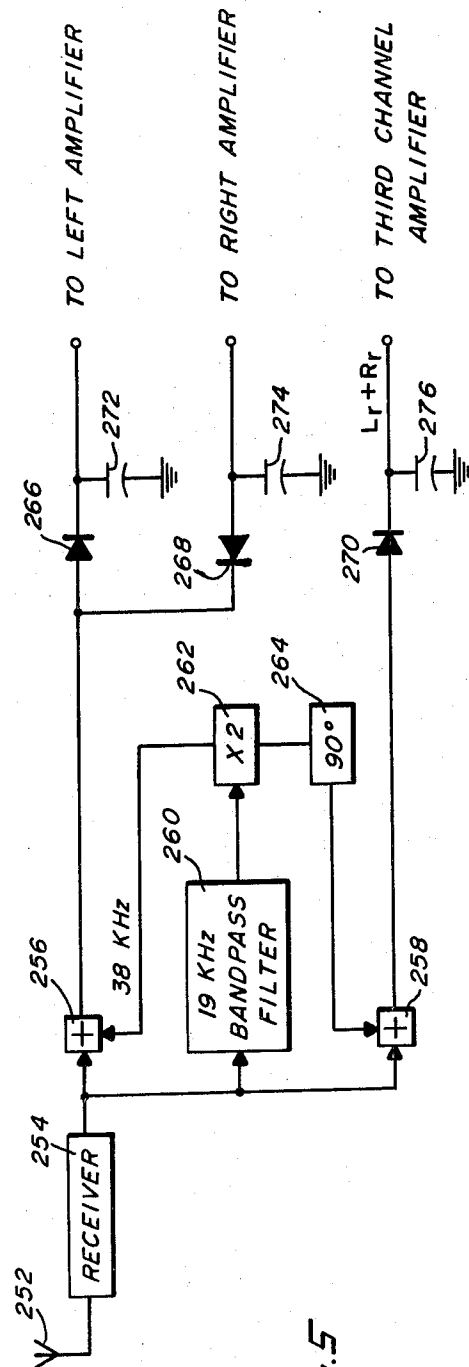


Fig. 5

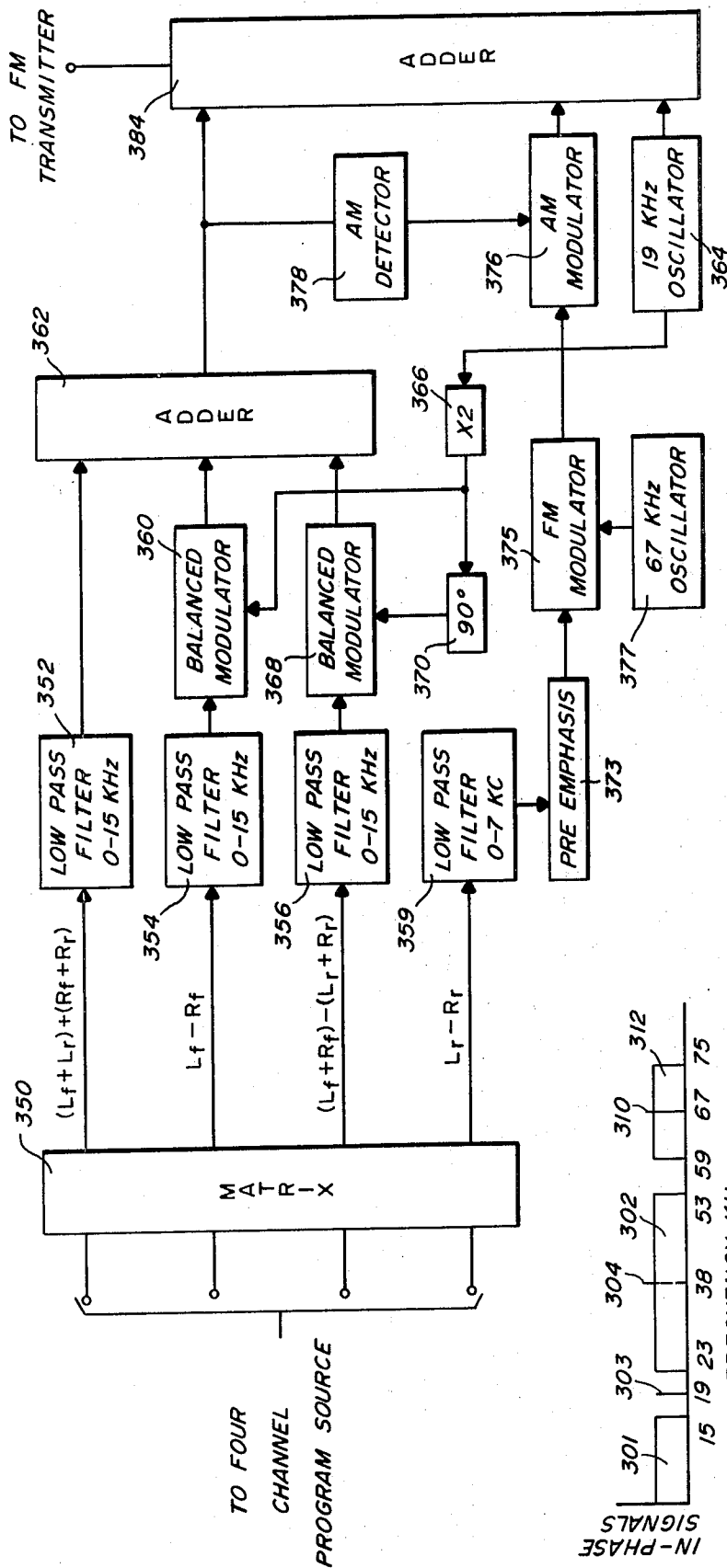
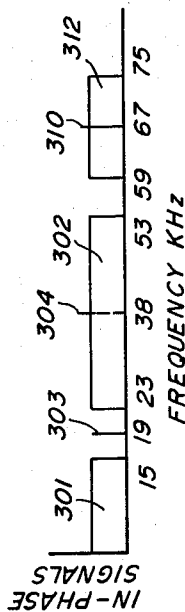
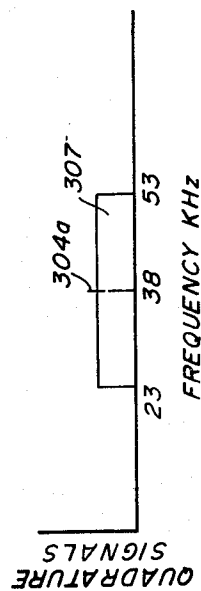


Fig. 6

Fig. 6a

Fig. 6b



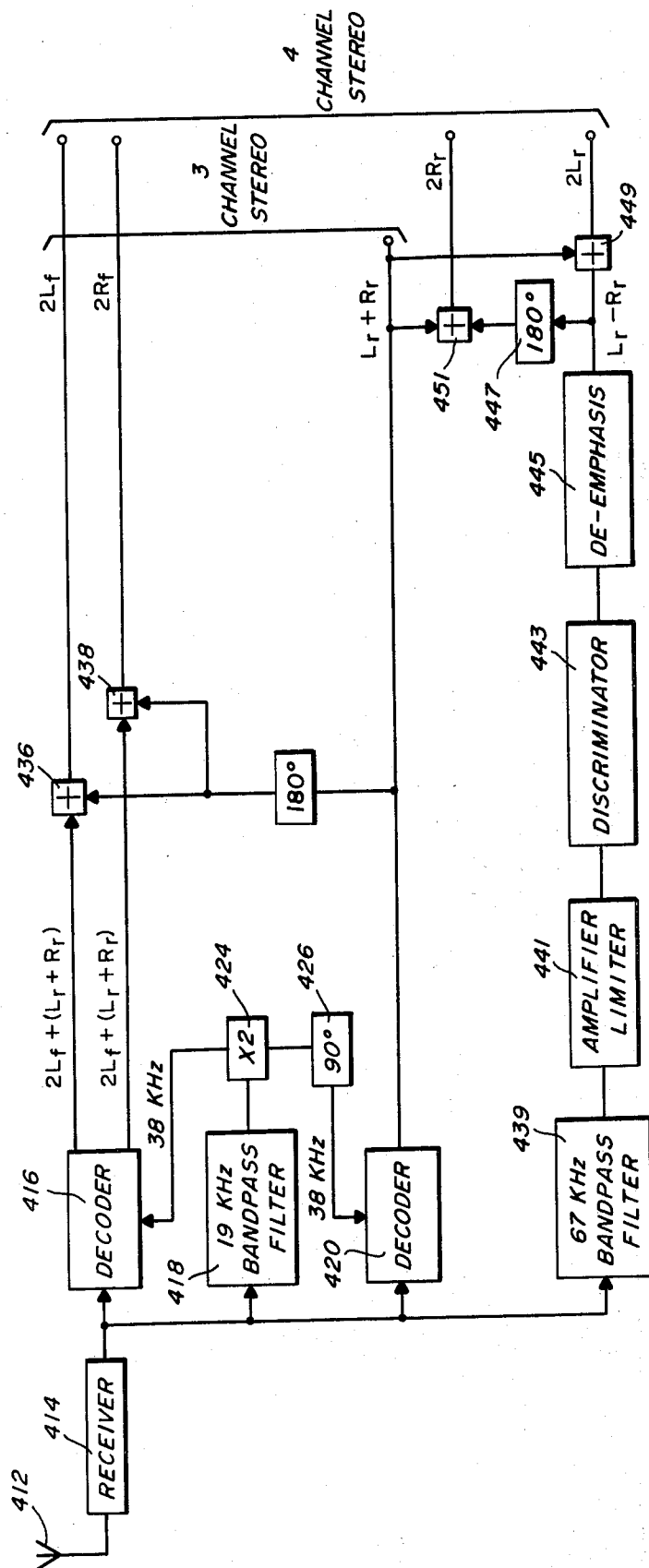


FIG. 7

MULTIPLEX SYSTEM EMPLOYING MULTIPLE QUADRATURE SUBCARRIERS

BACKGROUND

1. Field of Invention

This invention relates generally to multiplex systems, and more particularly to multiplex systems for broadcasting three and four channels of stereophonically related information within the FM broadcast band.

Stereophonic systems presently in commercial use utilize two separate spaced loudspeaker systems receiving independent stereophonically related audio signals to create an effect of spatial separation and motion about the listener. The two stereophonically related audio signals may be obtained from a variety of sources, including FM stereo multiplex transmissions. The spatial effect achieved by a two channel stereophonic system can be further enhanced by the placement of additional speakers receiving other stereophonically related audio signals around the listener. The additional audio signals required to operate the added loudspeakers can be relatively easily obtained from recorded sources, such as multi-track recordings, however, transmitting more than two audio signals on an FM broadcast compatibly with the requirements of present one and two channel receivers while providing satisfactory reception by new multi-channel receivers has been difficult to achieve.

2. Prior Art

Several techniques for broadcasting more than two stereophonically related signals on an FM transmission are known. In one such system, several stereophonically related audio signals (usually four) are mixed and transmitted as two channel information by a two channel stereo broadcast transmitter. The signal is then received by a two channel receiver, and the two received audio signals are selectively combined in various predetermined combinations to provide four audio signals for driving four loudspeaker systems. In another system, four stereophonically related audio signals comprising various combinations of four audio components are transmitted on separate subcarriers. The transmitted signals are received by a specially designed receiver which receives the four stereophonically related signals and separates them into the four audio components.

Whereas these techniques provide a way to broadcast more than two stereophonically related audio signals with an FM broadcast transmitter, the first technique does not provide a true four channel effect because directional information is lost in the combining process, and the second technique requires a greater bandwidth than the bandwidth required by a two channel stereophonic broadcast and does not allow for convenient three channel reception.

SUMMARY

It is an object of the present invention to provide a system for transmitting and receiving four stereophonically related audio signal components.

It is another object of this invention to provide a four channel stereophonic transmission and reception system that is fully compatible with present monophonic and two channel stereophonic equipment.

Yet another object of this invention is to provide a four channel FM multiplex system that operates within presently allocated frequency bands.

It is a further object of this invention to provide an FM multiplex system that is usable with a three channel stereophonic receiver to provide three stereophonically related audio signals.

It is yet another object of this invention to provide a four channel stereophonic FM multiplex system that allows the SCA storecast signal to be broadcast simultaneously with the four channel stereo signal without increasing the bandwidth allotment of the FM transmitter.

Still another object of this invention is to provide an FM multiplex system that can be readily operated as a monophonic, two channel, three channel or four channel system, depending on the type of receiver employed.

In accordance with a preferred embodiment of the invention, two audio components representative of left and right information are electrically added together and used to frequency modulate the transmitter carrier. A signal representative of the difference of the two aforesaid components is used to amplitude modulate a suppressed subcarrier having a frequency higher than twice the highest audio frequency to be transmitted. A pilot carrier, or pilot tone, having a frequency of one half that of the suppressed subcarrier is also transmitted. The aforementioned signals are similar to, and compatible with, the two channel pilot tone stereo multiplex systems currently in use. A third signal representative of a third stereophonically related component which may include, for example, left rear information, right rear information, a combination of left rear and right rear information, or simply rear information, is transmitted by amplitude modulating a second suppressed subcarrier that has the same frequency as the first suppressed subcarrier, but is orthogonal to, or in quadrature with, the first suppressed subcarrier. The components of the three signals thus transmitted are chosen to allow complete separation of the signals into three stereophonically related audio signals for reproduction by three loudspeaker systems.

A fourth signal including information to provide a fourth stereophonically related component may be transmitted upon a third suppressed subcarrier having a higher frequency than the second and third suppressed subcarriers, or at a reduced bandwidth about one of a set of subcarriers generated by amplitude modulating the third subcarrier by a predetermined frequency tone. The subcarriers thus generated are then suppressed carrier amplitude modulated by signals containing the third and fourth stereophonically related components to provide a four channel stereophonic system.

DESCRIPTION OF THE DRAWINGS

FIG. 1 shows, in block diagram form, apparatus for transmitting four stereophonically related signals by means of a composite signal;

FIG. 1a is a diagram of the frequency spectrum of the in-phase signals of the composite signal produced by the apparatus of FIG. 1;

FIG. 1b is a diagram of the frequency spectrum of the quadrature, or orthogonal, components of the composite signal produced by the apparatus of FIG. 1;

FIG. 2 is a block diagram of a receiving apparatus usable for receiving the composite signal transmitted by the apparatus of FIG. 1;

FIG. 2a is a spectral diagram of the in-phase components of the output signal from balanced modulator 120 of FIG. 1;

FIG. 2b is a spectral diagram of the quadrature component of the output signal from balanced modulator 120 of FIG. 2;

FIG. 3 shows, in block diagram form, a schematic diagram of apparatus for producing an alternate component signal usable for transmitting four stereophonically related signal components;

FIGS. 3a and 3b are spectral diagrams of the in-phase and quadrature components, respectively, of the composite signal produced by the apparatus of FIG. 3;

FIG. 4 shows, in block diagram form, receiving apparatus for receiving the composite signal produced by the apparatus of FIG. 3, and for deriving the four stereophonically related components from said composite signal;

FIG. 5 shows a partial block and schematic diagram of a simplified receiving apparatus for receiving the composite signal provided by the apparatus of FIG. 3, and for providing three output signals representative of three stereophonically related signal components;

FIG. 6 is a block diagram of apparatus for providing a third variation of the composite signal for transmitting four stereophonically related electrical signals;

FIGS. 6a and 6b show the frequency spectra of the in-phase and quadrature components, respectively, of the composite signal produced by the apparatus of FIG. 6; and

FIG. 7 is a block diagram of receiving apparatus suitable for receiving the composite signal produced by the apparatus of FIG. 6, and for providing three or four stereophonically related electrical signals to provide three or four channel stereophonic audio reproduction, as desired.

DETAILED DESCRIPTION

Referring to FIG. 1, there is shown in block diagram form, one embodiment of a transmission system for generating and transmitting a four channel stereophonic signal. A microphone 12, for receiving a stereophonically related component containing audio information associated with one of the channels, in this embodiment, the left front channel, is connected through a pre-emphasis network 14 to an amplifier 16. Similarly, microphones 22, 32 and 42, which receive components containing information associated with the other three channels, are coupled through pre-emphasis networks 24, 34 and 44 to amplifiers 26, 36 and 46, respectively. The outputs of amplifiers 16, 26, 36 and 46 are each coupled to a matrix 50 at input points A, B, C and D. Matrix 50 serves to selectively combine input signals from input points A, B, C and D to provide four combined signals at output points W, X, Y and Z. Output points W, X, Y and Z are connected to low pass filters 18, 28, and 38 and 48, respectively.

The outputs of low pass filters 38 and 48 are coupled to balanced modulators 52 and 54, respectively. A pilot carrier wave oscillator, in this embodiment, pilot tone oscillator 56, is connected through a divide by two frequency divider 58 to balanced modulator 52, and to balanced modulator 54 through divider 58 and a 90° phase shift network 60. Balanced modulators 52 and 54 are connected to an adder 62 which has an output coupled to a balanced modulator 64. Modulator 64 is fur-

ther coupled to the pilot tone oscillator 56 through a multiply by two frequency multiplier 66 and a second phase shifting network 68.

The output of low pass filter 28 is connected to a balanced modulator 72, which is also coupled to frequency multiplier 66. The outputs of low pass filter 18, balanced modulator 72 and balanced modulator 64 are each connected to an adder 74. The output of adder 74 is connected to an FM modulator 76, which is also connected to a radio frequency oscillator 78 and a frequency multiplier 82. Frequency multiplier 82 is connected to a power amplifier 84, which receives frequency multiplied signals from multiplier 82 and couples amplified signals to an antenna 86 for transmission. A fifth channel, usable for broadcasting SCA storecast signals, is obtained from microphone 87, which is connected to an FM oscillator 89 through an amplifier 88. FM oscillator 89 is connected to adder 74 and provides a frequency modulated SCA storecast subcarrier thereto for transmission by the system.

The information contained in the stereophonically related components provided by the microphones or other program source is determined by the physical arrangement of the loudspeakers with which the components will be reproduced. For example, when the well known "square" arrangement which locates two speakers in front of and two speakers behind the listener is employed, the four stereophonically related components include left front, right front, left rear and right rear information for driving the left front, right front, left rear and right rear speakers, respectively. When a "diamond" arrangement which has speakers located directly in front of, directly behind and to the left and right of the listener is employed, the stereophonically related components include front, rear, left and right information.

Three channel reproducing systems having, for example, speakers placed to the left, right and rear of the listener may be used in conjunction with transmission systems designed for use with either a "square" or "diamond" reproducing system. When the three channel reproducing system is employed with a "square" transmission system, the left speaker receives either the left front component or a sum of the left front and left rear components, the right speaker receives either the right front component of the sum of the right front plus right rear components, and the rear speaker receives the sum of the left rear plus right rear components. When the three channel reproducing system is employed with a "diamond" transmission system, the left, right and rear speakers receive the left, right and rear stereophonically related components, respectively.

In operation, four channels of stereophonically related program material are picked up by microphones 12, 22, 32 and 42. Although four microphones are shown, it should be noted that any four channel program source, including four track tape recordings and four channel records may be used. Signals from the four channels are each applied to a pre-emphasis network, according to standard FM practice, to improve the signal to noise ratio of the received signal. The four pre-emphasized signals are amplified by amplifiers 16, 26, 36 and 46 and applied to matrix 50. In this embodiment, matrix 50 has been chosen such that the output signal at point W is proportional to the sum of the input signals applied to points A through D, and hence, to the sum of the signals derived from the four channels, to

provide a signal suitable for monophonic reception. the output signal at point X is proportional to the difference of the left channel information and the right channel information, and is proportional, in this embodiment, to $(L_f + L_r) - (R_f + R_r)$, where L_f , L_r , R_f and R_r represent the left front, left rear, right front and right rear channels, respectively. It should be noted that since the output signals at points W and X correspond to sum and difference signals, respectively, of left related and right related information, these two signals may be subsequently decoded by a standard two channel stereo receiver to provide two channels of stereophonic sound.

The output signal at output point Y of matrix 50 is proportional to the difference between front related and rear related information and is equal to, in this embodiment, $(L_f + R_f) - (L_r + R_r)$. The signal appearing at point Y, when decoded along with the signals appearing at points W and X provides sufficient information to recover three channels of audio information, namely, left, right and rear information. The output signal at point Z of matrix 50 contains rear channel difference information, in this embodiment, $(L_f + R_f) - (L_r + R_r)$. The aforementioned signal allows the rear channel to be separated into a left rear and right rear channel if desired.

It should be noted that although particular sums and differences of the signals appearing at points A, B, C and D have been applied to output points W, X, Y and Z, any combinations that allows satisfactory monophonic reception when only one signal is received, compatible two channel stereophonic reception when two signals are received, three channel stereophonic reception when three signals are received and four channel reception when four channels are received, may be used.

The output signal from point W of matrix 50 is passed through a low pass filter 18 which removes all signal components having a frequency higher than 15 KHz. Similarly, the left minus right difference signal from point X is passed through filter 28, which also rejects signal components having frequencies higher than 15 KHz, to balanced modulator 72 to modulate a 38 KHz subcarrier obtained by doubling the frequency of the 19 KHz pilot tone from pilot tone oscillator 56. The output signals from filter 18 and balanced modulator 72 are applied to adder 74 along with a 19 KC tone from oscillator 56. The three aforementioned signals are combined in adder 74 to provide a composite signal having the spectrum indicated by spectral areas 1 and 2 and spectral line 3 of FIG. 1a, where spectral area 1 represents the sum signal, spectral areas 2 represents the left minus right difference signal and spectral line 3 represents the KHz pilot carrier or tone. Spectral line 4 (shown dotted) represents the 38 KHz subcarrier signal which was applied to balanced modulator 72 and suppressed during the modulation process. Note that the bandwidth of area 1 has been limited to 15 KHz by low pass filter 18, and the bandwidth of area 2 has been limited to 30 KHz (+15KHz) by low pass filter 28. Area 5 represents the storecast signal produced by frequency modulating FM oscillator 89 with a maximum deviation of 18 KHz in accordance with the audio signals applied to microphone 87.

The output signals from points Y and Z of matrix 50 are applied through low pass filters 38 and 48 to balanced modulators 52 and 54, respectively. Low pass

filters 38 and 48 have a 7 KHz bandwidth in this embodiment, but any bandwidth that sufficiently limits the spectrum to prevent overlap into area 1 or area 5 may be used. A 0.5 KHz reference wave obtained by dividing the pilot tone by two, is applied to each of the modulators 52 and 54, with the 9.5 KHz wave applied to modulator 54 being 90° out of phase, or in quadrature, with the 9.5 KHz wave applied to modulator 52. One of the 9.5 KHz subcarriers is modulated by the front minus rear difference signal from low pass filter 38, and the other 9.5 KHz subcarrier is modulated by the rear channel separation signal from low pass filter 48 to provide two quadrature, or orthogonal, signals about 9.5 KHz suppressed subcarriers. The two orthogonal signals thus generated are combined in adder 62 and applied to balanced modulator 64 to modulate a second 38 KHz subcarrier that is in quadrature with the 38 KHz subcarrier applied to balanced modulator 72. The output signal from balanced modulator 64 is in quadrature with the output signal from balanced modulator 72, and may, therefore, be combined with the other signals in adder 74 without interference. It should be noted that although 90° phase shifting networks have been employed to obtain quadrature signals, any method providing orthogonally related, and hence separable, signals may be used and still fall within the scope of the invention. The terms orthogonal and quadrature will sometimes be used interchangeably in this application, but it should be understood that the term quadrature refers to signals having the same frequency and a 90° phase shift therebetween, while orthogonal means that two signals within a band of frequencies are separable. Orthogonality may be achieved by a quadrature relationship or by other means.

A frequency spectrum of the output signal from balanced modulator 64 is shown in FIG. 1b. The signal includes a suppressed subcarrier 4a which is in quadrature with the suppressed subcarrier 4 of FIG. 1 to allow detection of any modulation on subcarrier 4a separately from any modulation on subcarrier 4. Subcarrier 4a is modulated by the signal from adder 62 which comprises a pair of quadrature related suppressed subcarriers which are modulated with audio information as previously described. The modulation of subcarrier 4a by the signal from adder 62 results in spectral areas 8 and 9 and their associated 9.5 KHz suppressed subcarriers 6 and 7. In this embodiment the subcarriers 6 and 7 and areas 8 and 9 were obtained by modulating subcarrier 4a, however, subcarriers 6 and 7 can also be derived from the pilot carrier 3 by frequency multiplication, and modulated by the appropriate audio signals without generating subcarriers 4a. Areas 8 and 9 each contain in-phase and quadrature components resulting from the modulation of the two quadrature related 9.5 KHz subcarriers. The in-phase and quadrature components may be separated to recover the modulating signal. Similarly, since subcarrier 4a is in quadrature with subcarrier 4, the sidebands about subcarrier 4a (areas 8 and 9) may be separately demodulated from the signals comprising area 2 of FIG. 1a.

Referring to FIG. 2, there is shown a block diagram of one embodiment of a receiving system for receiving signals of the type transmitted by the system of FIG. 1. A receiver 114 receives the transmitted signal from an antenna 112 and provides a recovered composite signal of the type shown in FIGS. 1a and 1b to a switching de-

coder 116. The composite signal from receiver 114 is also applied to a bandpass filter 118 and to a balanced modulator 120. The 19 KHz pilot carrier 3 from the composite signal is passed through the 19 KHz bandpass filter 118 to a times two frequency multiplier 112 and a times three frequency multiplier 128. The 38 KHz output from multiplier 122 is applied to switching decoder 116 and to another times two frequency multiplier 124 for multiplication and subsequent application to balanced modulator 120 through a 90° phase shift network 126. The output from balanced modulator 120 is applied together with the composite signal from receiver 114 to an adder 130 which combines the two aforementioned signals for application to a second switching decoder 132. The switching decoder 132 also receives a 28.5 KHz signal derived from a divide by two frequency divider 134 which is driven by the times three multiplier 128. Switching decoder 116 and switching decoder 132 each provide two audio frequency output signals. The signals from decoder 116 are applied directly to a matrix 140, and the output signals from decoder 132 are applied to the matrix 140 through a pair of low pass filters 136 and 138. Matrix 140 provides four audio output signals, each audio output signal being representative of one of the four signals applied to the transmission system of FIG. 1.

In operation, upon receipt of a signal from a suitable transmission source, receiver 114 provides a composite output signal similar to the in-phase and quadrature signals of FIGS. 1a and 1b. The signals contained in areas 1 and 2 of the composite signal are demodulated under the control of a 38 KHz subcarrier locally generated by multiplier 122 in response to the pilot tone 3 passing through the 19 KHz bandpass filter 118. Switching decoders of the type used in decoder 116 are well known in the art, and are currently used in two channel stereophonic receivers to provide left channel and right channel audio signals from a composite signal. In this embodiment, switching decoder 116 provides two signals, one being related to the sum of the left front and left rear signals, and the other being related to the sum of the right front plus right rear signals.

The quadrature signals of the composite signal may be demodulated in a variety of ways, and although representative means for demodulating the quadrature components are disclosed in this embodiment, it should be noted that other demodulation means may be used and still fall within the scope of the invention. In this embodiment, the composite signal is applied to the balanced modulator 120 to modulate a 76 KHz quadrature carrier. The 76 KHz carrier is obtained by frequency multiplying the 38 KHz subcarrier used to drive the switching decoder 116 by 2 and phase shifting the multiplied subcarrier by 90° through the phase shifting network 126. Modulating the 76 KHz subcarrier using a balanced modulator results in a spectrum of the composite signal being placed in a sideband relationship about a suppressed 76 KHz subcarrier. The lower sideband portion of the spectrum about the 76 KHz subcarrier is shown in FIGS. 2a and 2b. Referring to FIG. 2a, note that the lower sideband portion of the frequency spectrum of the in-phase component of the modulated signal is inverted in both phase and frequency with respect to the spectrum of FIG. 1a. Each of the spectral areas and subcarriers 1 through 5, has been phase-shifted 180° by the modulation process and is shown below the horizontal axis to indicate the phase shift.

The frequency inversion can be seen by the relative position of the area wherein area 5 is now the lowest frequency area and area 1, which was the lowest frequency area of FIG. 1a, is now adjacent to the 76 KHz suppressed subcarrier. Referring to FIG. 2b, note that the quadrature signals have been inverted in frequency, but not in phase. Hence, when the in-phase and quadrature components of the output of balanced modulator 120 are combined with the in-phase and quadrature signals from receiver 114 in adder 130, the quadrature components reinforce each other, while portions of the in-phase signals cancel. In particular, the in-phase components about the 38 KHz subcarrier 4 cancel, thereby allowing subsequent decoding of the quadrature components by switching decoder 132.

The output signal from adder 130, which includes the quadrature signals shown in FIG. 2b, is applied to switching decoder 132 for demodulation under the control of the 28.5 KHz signal from divider 134. When switching decoder 132 receives a 28.5 KHz locally generated carrier, the portion of the spectrum of FIG. 2 about the 28.5 KHz suppressed subcarrier is demodulated. Alternately, a 47.5 KHz locally generated carrier could be used to recover area 8 about the 47.5 KHz suppressed subcarrier 6. Switching decoder 132 is similar to switching decoder 116 and its operation is well known in the art. Switching decoder 132 provides two audio output signals in this embodiment, one output signal being related to the difference between the left front and left rear channel information, and the other output signal being related to the difference between the right front and right rear channel information. Both output signals are passed through low pass filters 136 and 138, which have a bandwidth of 7 KHz, to remove extraneous signals generated by switching decoder 132 and by the uncanceled sidebands of FIG. 2a. The signals from low pass filters 136 and 138 are then applied in combination with the output signals from switching decoder 116 to a matrix which selectively adds and subtracts portions of the four signals applied thereto to provide the left front, right front, left rear and right rear signal components on separate output leads for subsequent amplification and reproduction by the receiving system. In addition, the SCA storecast information broadcast in area 5 may be recovered by conventional storecast demodulation techniques and apparatus (not shown).

Referring to FIG. 3, there is shown a block diagram of apparatus according to the invention for providing an alternate form of the composite signal. Four stereophonically related audio signals are applied to a matrix 150, similar to matrix 50 of FIG. 1, at input points A, B, C and D. Matrix 50 provides output signals at output points W, X, Y and Z which are representative of sum and difference combinations of the signals applied to input points A through D. Although the output signals from matrix 150 may include the same sum and difference combinations of input signals as provided by matrix 50, different sum and difference signals will be used in this embodiment to illustrate the operation of systems using various matrix combinations. In this embodiment, the output signal from output point W is proportional to $(L_f + L_r) + (R_f + R_r)$, the output signal from output point X is proportional to $L_f - R_f$, the output from point Y is proportional to $(L_f + R_f) - (L_r + R_r)$ and the output signal from point Z is proportional

to $L_r - R_r$, where L_r , L_r , R_r and R_r represent the various left and right signals previously described.

The signals from output points W, X, Y and Z are applied to low pass filters 152, 154, 156 and 158, respectively. The output signal from the low pass filter 152 is applied to an adder 162, and the output signal from low pass filter 154 is applied to the adder 162 through a balanced modulator 160 which also receives a 38 KHz signal from a 19 KHz pilot tone oscillator 164 via a times two frequency multiplier 166. The output signal from low pass filter 156 is applied to adder 162 through another balanced modulator 168 which also receives 38 KHz quadrature signal from the times two multiplier 166 through a 90° phase shifting network 170.

The output signal from low pass filter 158 is applied to a single sideband modulator 172 to modulate a 76 KHz subcarrier obtained from a times two frequency multiplier 174. The output signal from the single sideband modulator 172 is applied to an AM modulator 176 which is controlled by an AM detector 178 which responds to the amplitude of the output signals from adder 162. The SCA storecast signal (if any) is applied to a balanced modulator 180 to modulate a second 76 KHz signal obtained from 90° phase shifting network 182. The output signals from adder 162, AM modulator 176, balanced modulator 180 and the pilot tone oscillator 164 are applied to a second adder 184 which provides a composite signal for subsequent transmission.

The signals from outputs W and X of matrix 150 are processed by low pass filters 152 and 154, balanced modulator 160 and adder 162 in a way similar to the way in which the signals from outputs W and X of matrix 50 are processed by the apparatus of FIG. 1. The output signal from output Y of matrix 150 is applied to balanced modulator 168 through the low pass filter 156 to modulate a 38 KHz subcarrier that is in quadrature with the 38 KHz subcarrier modulated by the audio signal applied to balanced modulator 160. The resultant spectra of the signals from the output of adder 162 are shown in FIGS. 3a and 3b. Referring to FIG. 3a, the signal from output point W results in a spectral area 101, and the signal from output point X results in a spectral area 102 about a suppressed 38 subcarrier 104. The signal from output point Y results in a spectral area 107 about a subcarrier 104a in FIG. 3b. Carriers 104 and 104a of FIGS. 3a and 3b, respectively, have the same frequency, but are in quadrature with each other to allow subsequent separation of the modulating signals.

The output of low pass filter 158 is applied to single sideband modulator 172 which provides the spectrum shown by area 105 adjacent to a 76 KHz suppressed subcarrier 106, as shown in FIG. 3a. The SCA storecast program signal is applied to balanced modulator 180 to provide a spectral area 108 about another 76 KHz suppressed subcarrier 106a in FIG. 3b. As in the case of the 38 KHz subcarriers, the 76 KHz subcarriers in FIGS. 3a and 3b are in quadrature with each other sideband stereo signal represented by area 105.

The output signals from adder 162, balanced modulator 180 and pilot tone oscillator 164, which provides pilot tone 103 in FIG. 3a, are applied to adder 184 for combination thereby to form a composite signal. The output signal from single sideband modulator 172 can also be applied to adder 184 to complete the composite signal shown in FIGS. 3a and 3b. However, it has been

found desirable to limit the amplitude of the single sideband signal 105 in accordance with the amplitude of the signals indicated by areas 101, 102 and 107 to limit the maximum deviation of the FM transmitter and to improve the signal to noise ratio of the received signal.

The degree to which the FM transmitter is modulated is dependent upon the amplitude of the output signal from adder 184. Since it is necessary to limit the deviation of an FM transmitter to prevent interference with other transmitters, the signal from adder 184 must be limited. This can be achieved by limiting the maximum amplitudes of the signals applied to the input of adder 184 to a level such that the sum of the input signals applied to adder 184 cannot exceed the level required for maximum deviation of the FM transmitter. This requirement limits the maximum allowable amplitudes of the output signals from adder 162 and single sideband modulator 172. Unfortunately, limiting the amplitudes of the aforementioned signals reduces the signal to noise ratio of the audio signals reproduced by receivers receiving the composite signal. The degradation can be minimized through the use of an AM modulator which regulates the amplitude of one of the input signals to adder 184.

In this embodiment, the AM detector 178 detects the amplitude of the signal from adder 162 and provides a control signal to AM modulator 176 to reduce the amplitude of the signal from modulator 172 passing through modulator 176 to adder 184 when the amplitude of the signal from adder 162 is large. Hence, when the amplitude of a signal from adder 162 is small, the signal applied to adder 184 from modulator 172 can be large to assure a good signal to noise ratio for the received signal without exceeding the maximum allowable deviation of the FM transmitter. Conversely, when the output from adder 162 increases, the output from modulator 176 is proportionately decreased to maintain the output from adder 184 below the predetermined level for achieving maximum allowable deviation.

Referring to FIG. 4 there is shown a block diagram of a receiving system for receiving and decoding a composite signal of the type generated by the system of FIG. 3. A receiver 214 receives radio frequency signals containing the composite signal from an antenna 212, and provides a signal similar to the composite signal shown in FIGS. 3a and 3b to a switching decoder 216, a 19 KHz bandpass filter 218, a second switching decoder 220 and a single sideband demodulator 222. The 19 KHz bandpass filter 218 provides a 19 KHz signal to a times two frequency multiplier 224, which in turn provides 38 KHz subcarriers to decoders 216 and 220, the signal to decoder 220 being applied through a 90° phase shift network 226. The output of the times two multiplier 224 is also coupled to a second times two frequency multiplier 228. A 76 KHz signal generated by multiplier 228 is applied to single sideband demodulator 222 to allow demodulation of the single sideband signal shown in area 105 of FIG. 3b. The output of the single sideband demodulator 222 is connected through a low pass filter 230 to summing circuits 232 and 234 which are also connected to the output of switching decoder 220. Similarly, switching decoders 220 and 216 are connected to summing circuits 236 and 238 to complete the matrixing process.

In operation, the two quadrature 38 KHz suppressed subcarriers are demodulated by switching decoders 216 and 220 in a manner similar to the operation of decoder 116 of FIG. 2. Due to the difference between matrix 50 of FIG. 1 and matrix 150 of FIG. 3, however, the output signals from switching decoders 216 and 220 will be different than the output signals from switching decoder 116 of FIG. 1. In the embodiment of FIG. 4, one of the output signals from switching decoder 216 will be equal to $2L_f + (L_r + R_r)$, and the other output will be $2R_r + (L_r + R_r)$. The numeral 2 in this discussion indicates relative amplitudes of the various signals only, and is not intended to define an absolute signal amplitude. Similarly, switching decoder 220, which demodulates the 38 KHz quadrature subcarrier, provides output signals of $L_r + R_r$ and $-(L_r + R_r)$. The single sideband demodulator 222 demodulates area 105 of FIG. 3a to provide an output signal having a $L_r - R_r$ in a band of frequencies lying in the range of 0 to 15 KHz. The low pass filter 230 passes only the $L_r - R_r$ signal to summing circuits 232 and 234, and rejects all other signals. The $-(L_r + R_r)$ and the $L_r + R_r$ signals from switching decoder 220 are combined with the $L_r - R_r$ from low pass filter 230 in summing circuits 232 and 234, respectively, to provide the rear information signals $2L_r$ and $2R_r$, the $2R_r$ signal being obtained by passing a $-2R_r$ signal from summing circuit 232 through a 180° phase inverting network 240. In a similar fashion, the signals for the front channels, $2L_f$ and $2R_f$, are obtained from summing circuits 236 and 238, which combine the various output signals from switching decoders 216 and 220.

It should be noted that due to proper selection of the matrixing function of matrix 150, the left front and right front signal components, and a component equal to the sum of the left rear and right rear components can be obtained without demodulating the 76 KHz subcarrier. This allows the design of a simplified receiver capable of receiving three channel stereo from the four channel stereophonic broadcast. FIG. 5 shows one embodiment of such a simplified receiving system.

Referring to FIG. 5, a receiver 254 receives a radio frequency signal containing the composite signal from an antenna 252 and provides a composite signal to summing circuit 256 and 258 and to a 19 KHz bandpass filter 260. The 19 KHz bandpass filter drives a times two frequency multiplier 262 to provide a 38 KHz signal to summing circuit 256 and to a 90° phase shifting network 264. The 90° phase shifting network 264 provides a second 38 KHz signal in quadrature with the 38 KHz signal from multiplier 262 for application to summing circuit 258. When the 38 KHz suppressed subcarriers are reinserted into the composite signal by summing circuits 256 and 258, the resultant signals can be demodulated by means of amplitude detectors. The amplitude detection function is provided by diodes 266, 268 and 270, and by capacitors 272, 274 and 276. The anode of diode 266 is connected to the output of summing circuit 256, and capacitor 272 is connected between the cathode of diode 266 and ground to form a positive peak detector for detecting the positive envelope of the signal from summing circuit 256. The cathode of diode 268 is connected to the output of summing circuit 256, and capacitor 274 is connected between the anode of diode 268 and ground to form a negative peak detector for detecting the negative envelope of the signal from summing circuit 256. In a simi-

lar fashion, diode 270 is connected to summing circuit 258 and capacitor 276 to form a positive peak detector for detecting the positive envelope of the output signal from summing circuit 258.

In this embodiment, the signal appearing across capacitor 272 will be proportional to $2L_f + (L_r + R_r)$, the signal appearing across capacitor 274 will be proportional to $2R_f + (L_r + R_r)$, while the signal across capacitor 276 will be proportional to the sum of the left rear and right rear signals. The signals appearing across capacitors 272 and 274 may be coupled directly to the left and right channel amplifiers, respectively. Although these signals contain rear channel components, a satisfactory stereophonic effect may nevertheless be achieved. In systems wherein it is desired to provide signals containing no rear channel information to the left and right signals, the signals may be matrixed as in the circuit of FIG. 4, or the encoding matrix 150 at the transmitter may be designed to eliminate the rear channel components from the left front and right front recovered signals.

Referring to FIG. 6, there is shown a block diagram of apparatus for producing another form of a four channel composite stereophonic signal. Four stereophonically related signals are applied to matrix 350 for selective combination and application to 15 KHz low pass filters 352, 354 and 356. The output from low pass filter 352 is applied directly to an adder 362, and the outputs from low pass filters 354 and 356 are applied to balanced modulators 360 and 368. Balanced modulators 360 and 368 also receive quadrature related 38 KHz signals from a 19 KHz oscillator 364 via a times two frequency multiplier 366 and a phase shift network 370. The quadrature related modulated output signals from balanced modulators 360 and 368 are combined with the signal from low pass filter 352 in the adder 362 to provide the portion of the composite signal denoted by spectral areas 301, 302, 304, 304a and 307 in FIGS. 6a and 6b.

The structure and operation of the above described portion of the system is similar to the structure and operation of the analogous portion of the system of FIG. 3 including matrix 150, filters 152, 154 and 156, balanced modulators 160 and 168, summing circuit 162, tone oscillator 164, multiplier 166 and phase shift network 170. As in the previous embodiments, the matrix 350 has been chosen such that the signals applied to filters 352, 354 and 356 contain sufficient information to allow recovery of three channel when only the above mentioned portion of the composite signal is detected.

The information required to recover the fourth stereophonically related channel is generated by the combination of a 7 KHz low pass filter 359, a pre-emphasis network 373, and FM modulator 375 and a 67 KHz oscillator 377. The fourth channel information is transmitted on a frequency modulated 67 KHz subcarrier in a band of frequencies presently used for the SCA store-cast signal. This signal is indicated by carrier 310 and spectral area 312 in FIG. 6a.

In operation, the fourth channel information signal is derived from matrix 350 and applied to the 7 KHz low pass filter 359. The signal is limited to 7 KHz to prevent the FM spectrum 312 from overlapping the difference signal spectrum 302. The output signal from low pass filter 359 is applied through the pre-emphasis network 373, which improves the signal to noise ratio of the sub-

sequently received signal, to the FM modulator 375. The FM modulator 375 serves to frequency modulate the 67 KHz output signal from oscillator 377 in accordance with the audio signal from pre-emphasis network 373. The deviation of the FM signal from FM modulator 375 is limited to a maximum deviation of 8 KHz about the 67 KHz subcarrier to prevent the FM spectrum 312 from overlapping the difference spectrum 302, and to maintain the total bandwidth of the spectrum produced by the FM transmitter within the allocated channel limits. The output of the FM modulator 375 is connected to an AM modulator 376, which is controlled by signals from an AM detector 378 in response to the amplitude of the signals from adder 362. AM modulator 376 serves to control the amplitude of the frequency modulated signal from modulator 375 in accordance with the amplitude of the signal from adder 362 to maintain the total signal magnitude applied to adder 384 below the level required to provide maximum allowable deviation of the FM transmitter. The operation of AM detector 378 and amplitude modulator 376 is similar to the operation of detector 178 and modulator 176, respectively, of FIG. 3.

FIG. 7 shows a block diagram of apparatus for receiving the transmitted composite signal from the apparatus of FIG. 6. The transmitted signal is received by an antenna 412 and coupled to a receiver 414 which provides a signal representative of the composite signal to decoders 416 and 420, and to a 19 KHz bandpass filter 418. The portions of the composite signal corresponding to areas 301, 302 and 307 of FIGS. 6a and 6b are decoded by decoders 416 and 412 under the control of 38 KHz signals obtained from the 19 KHz bandpass filter by means of a doubler 424 and a 90° phase shift network 426. The signals from decoders 416 and 420 are subsequently combined in summing circuits 436 and 438 to provide the left front and right front signals. Satisfactory three channel stereophonic operation may be achieved by utilizing the two signals from summing circuits 436 and 438 to provide left and right related information and the left rear plus right rear signal from decoder 420 to provide rear channel information. The operation of the aforementioned apparatus is similar to the operation of the analogous decoders and summing circuits of FIG. 4.

The information required to separate the $L_r + R_r$ signal from decoder 420 into individual L_r and R_r signals is demodulated by discriminator 443 and apparatus coupled thereto. The composite signal from receiver 414 is applied to a 67 KHz bandpass filter 439, which has a bandwidth sufficiently wide to pass the FM spectrum (indicated by area 312 of FIG. 6a) to amplifier limiter 441, but sufficiently narrow to reject other frequency components. The signal from the bandpass filter 439 is applied to an amplifier/limiter 441 which amplifies the aforementioned signal and removes the amplitude variations thereof. The amplified and limited signal from amplifier/limiter 441 is applied to the discriminator 443 which demodulates the 67 KHz frequency modulated subcarrier, and recovers the information thereon. The recovered audio signal from discriminator 443 is passed through a de-emphasis network 445, which is an inverse function of the pre-emphasis network 373 of FIG. 6 thereby restoring the flat audio response. The $L_r - R_r$ signal from de-emphasis network 445 is added to and subtracted

from the $L_r + R_r$ signal from decoder 420 by means of summing circuits 449 and 451, and by a 180° phase shifting network 447 to provide signals representative of the left rear and right rear stereophonically related channels, thereby providing a complete four channel reproduction system.

In summary, the techniques and apparatus of the instant invention provide a way to obtain true four channel stereophonic transmission and reception within the presently allotted FM channel allocations without having to eliminate the SCA storecast channel. The system is fully compatible with existing one and two channel receivers, and provides for three and four channel stereophonic reception when appropriate receivers are employed. Another advantage of the system of the instant invention over other systems is that the system of the present invention is the only system that allows three channel stereophonic reception without requiring decoding of more than three of the transmitted signal combinations.

In addition, it should be noted that although the system of the present invention has been explained in terms of mixing techniques for purposes of clarity, the system can also be constructed using well known sampling techniques and still fall within the scope of the invention.

I claim:

1. The method of transmitting four stereophonically related components by means of a single composite signal comprising the steps of:

generating a first signal representative of the sum of at least two of said stereophonically related components in a first frequency band;

generating a pilot carrier wave having a frequency higher than the highest frequency in said first frequency band;

generating a second signal representative of at least the difference of two stereophonically related components in a second frequency band about a first subcarrier wave higher than said pilot carrier wave;

generating a second subcarrier wave having the same frequency as said first subcarrier and in quadrature therewith;

modulating the second subcarrier wave by two quadrature related alternating current signals each having a frequency predeterminedly related to said pilot carrier wave, whereby the quadrature related sidebands resulting from the modulation of said second subcarrier by said alternating current signals form third and fourth subcarrier waves, said third and fourth subcarrier waves overlapping said second frequency band;

modulating said third subcarrier wave with a third signal representative of at least a third stereophonically related component to generate a third band of frequencies at least partially overlapping said second band and orthogonal thereto;

modulating said fourth subcarrier wave with a fourth signal representative of at least a fourth stereophonically related component to provide a fourth band of frequencies at least partially overlapping said second frequency band and orthogonal thereto; and

combining said first and second signals with said modulated third subcarrier wave, said modulated

15

fourth subcarrier wave, and said pilot carrier wave to provide said composite signal.

2. The method recited in claim 1 wherein the frequency of the reference wave is twice the frequency of the pilot carrier wave, and the frequency of each of the alternating current signals is one half the frequency of the pilot carrier wave, and wherein modulating the reference wave includes the steps of:

applying said reference wave and said alternating current signals to a balanced modulator wherein said reference wave is double sideband suppressed carrier amplitude modulated by said alternating current signals to provide said second and third subcarrier waves.

3. The method recited in claim 2 wherein the steps of modulating each of said subcarriers include the step of:

double sideband suppressed subcarrier amplitude modulating each of said subcarriers with the signal associated therewith.

4. Apparatus for transmitting three signals within a predetermined band of frequencies, including in combination:

means for generating a pilot carrier having a predetermined frequency;

means for generating a first subcarrier wave;

first modulating means connected to said first subcarrier generating means for modulating said first subcarrier wave with a first signal having a first predetermined bandwidth;

means for generating a second subcarrier wave having the same frequency as said first subcarrier wave and in quadrature therewith;

sideband generating means coupled to said second subcarrier generating means for generating a pair of equally spaced sidebands about said second subcarrier wave to thereby generate third and fourth subcarrier waves, said sideband generating means including means for modulating said second subcarrier wave by two quadrature related alternating current signals, each having a frequency predeterminedly related to said pilot carrier wave, whereby the quadrature related sidebands resulting from the modulation of said second subcarrier wave by said alternating current signals provide the third and fourth subcarrier waves;

second and third modulating means connected to said sideband generating means for modulating said third and fourth subcarriers with second and third signals, each of said second and third signals having a bandwidth narrower than said first predetermined bandwidth; and

means connected to said pilot carrier generating means, said first modulating means and said second and third modulating means for receiving and combining said pilot carrier and said first, third and fourth modulated subcarriers to provide a composite signal.

5. Apparatus as recited in claim 4 wherein said means for modulating said second subcarrier wave by two

16

quadrature related alternating current components includes a balanced modulator.

6. Apparatus for deriving three signals from a composite signal which has a first component having a predetermined bandwidth modulating a first suppressed subcarrier to thereby provide a first signal, a second signal having a second suppressed subcarrier having a frequency equal to the frequency of said first suppressed subcarrier and in quadrature therewith, said second suppressed subcarrier having a pair of equally spaced suppressed subcarriers thereabout providing third and fourth suppressed subcarriers, and second and third components modulating said third and fourth suppressed subcarriers, said second and third components each having a predetermined bandwidth less than one half the bandwidth of said first signal component, said composite signal including a pilot carrier wave, said apparatus including in combination:

means for receiving said composite signal;

reference carrier means coupled to said receiving means and responsive to said pilot carrier wave for generating a first fixed frequency reference wave having a frequency equal to the frequency of said first suppressed subcarrier and a second frequency reference wave having a frequency different than the frequency of said first fixed frequency reference wave, the frequency of said second fixed frequency reference wave being equal to a predetermined multiple of the frequency of one of said third and fourth suppressed subcarriers; and

demodulator means connected to said receiving means and said reference carrier means and responsive to said first and second signals and said first and second fixed frequency reference waves to provide three output signals representative of said first, second and third signal components in response to said composite signal, said demodulator means having first suppressed subcarrier demodulator means responsive to said first signal and said first fixed frequency reference wave for demodulating said first signal and providing a detected first signal component representative of the first signal component modulating said first suppressed subcarrier, said demodulator means further having second suppressed subcarrier demodulator means for demodulating said second signal and providing detected second and third signal components representative of the signal components modulating said third and fourth subcarrier waves, said second suppressed subcarrier demodulator means including 90° phase shifting means responsive to said first fixed frequency reference wave for providing a phase shifted reference wave, and means responsive to said phase shifted reference wave, said second fixed frequency reference wave and said second signal for demodulating said second signal under the control of said phase shifted reference wave and said second fixed frequency reference wave.

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