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ELIMINATION OF FREQUENCY SHIFT IN SUPPRESSED CARRIER SYSTEMS

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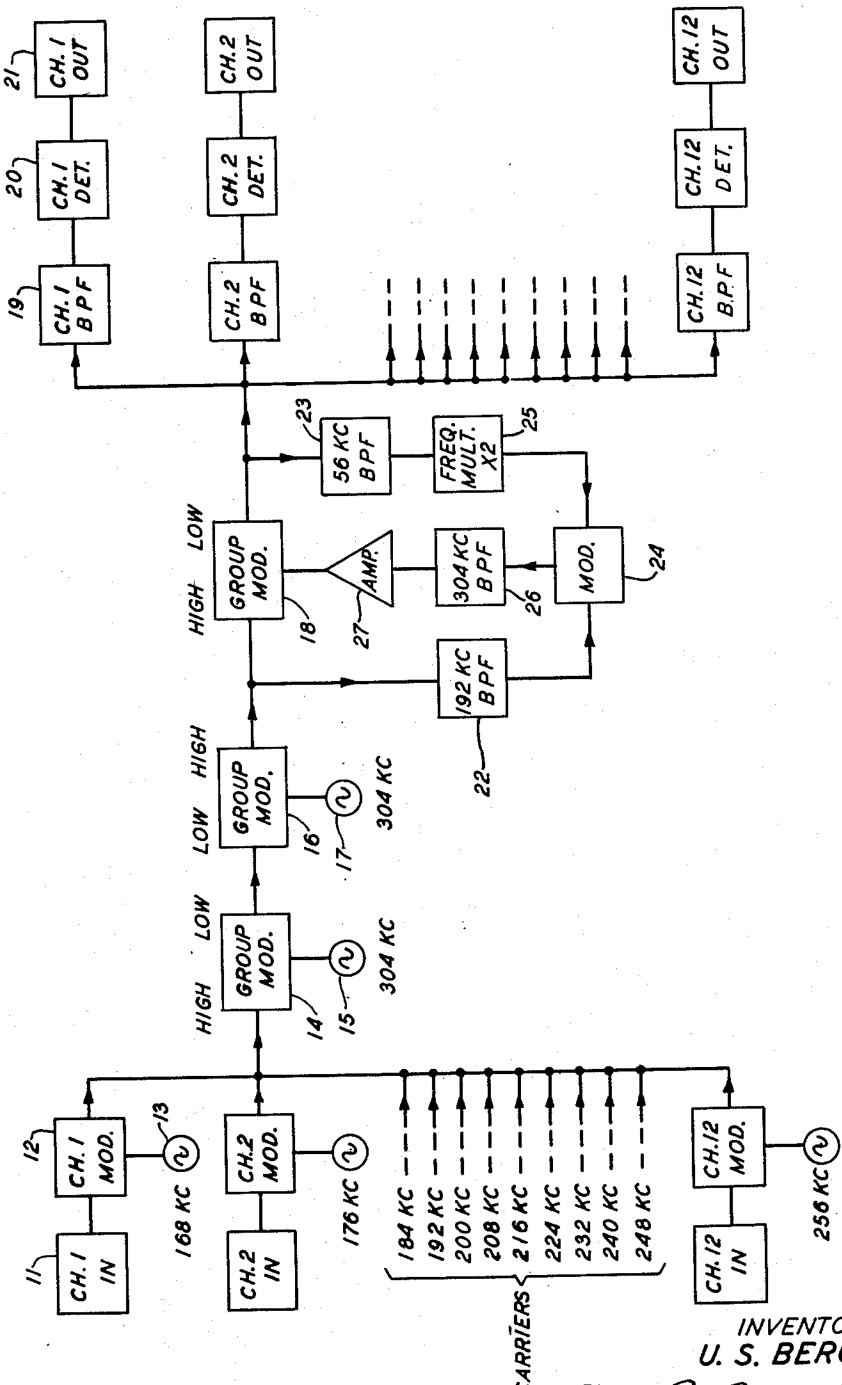

FIG. 1

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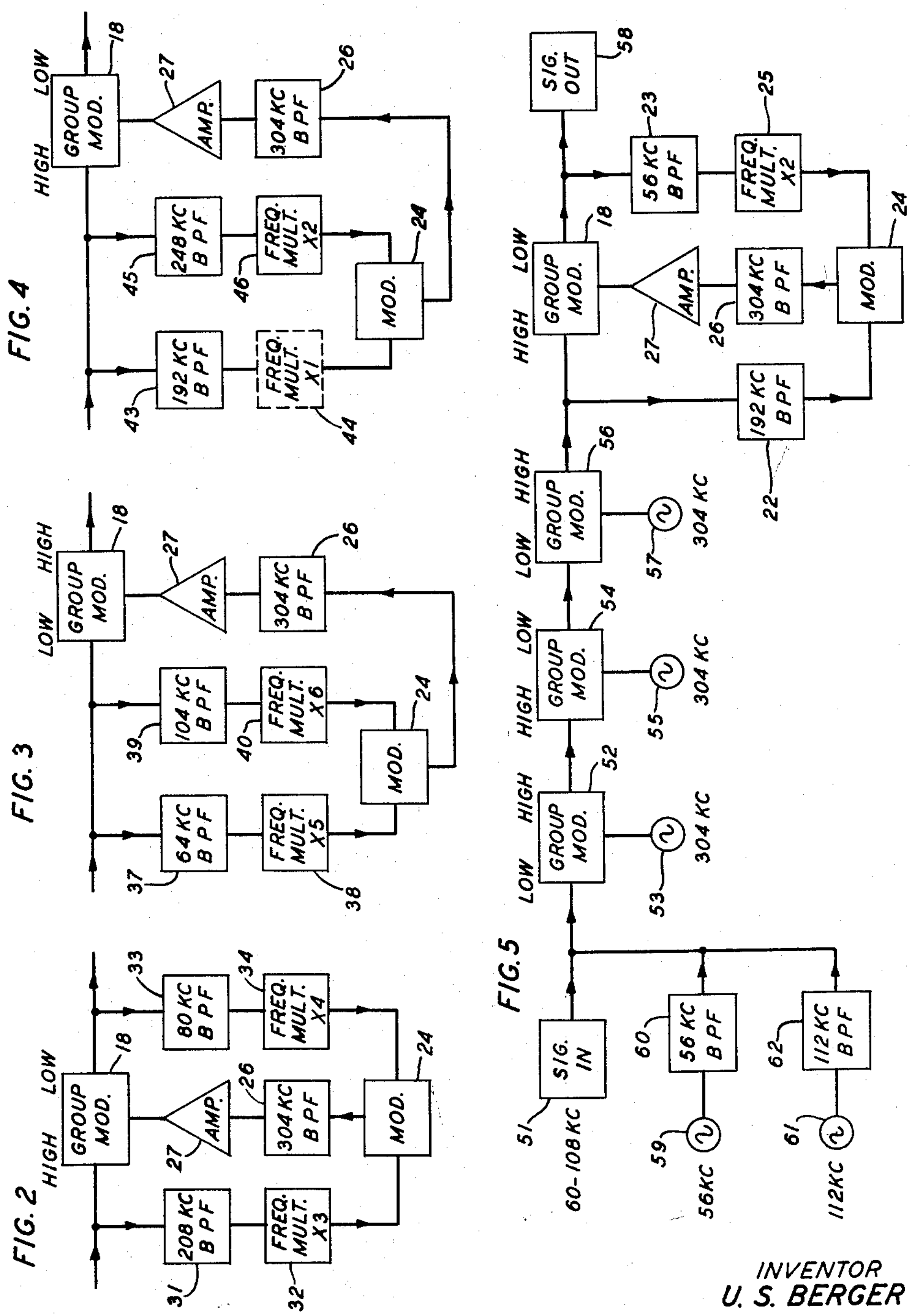

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ELIMINATION OF FREQUENCY SHIFT IN SUPPRESSED CARRIER SYSTEMS

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3 Claims. (Cl. 325—49)

This invention relates generally to the transmission of signals by amplitude modulation techniques and more particularly to suppressed-carrier amplitude modulation signal transmission over media which tend to introduce uncontrolled frequency shifts.

When either or both of the sidebands of an amplitude modulated wave are transmitted over a medium which introduces a frequency shift, the received signal is likely to be distorted if a carrier wave equal to the original carrier wave in frequency is used to accomplish demodulation. Under such conditions, the sidebands may undergo frequency changes not shared by the carrier and the demodulated signal is likely to incur not only frequency error but also quality degradation due to misalignment with receiving band filters. In the past, such distortions have been avoided by transmitting the carrier at full or reduced amplitude along with the sidebands, by manual adjustment of the demodulating carrier to cancel the frequency shift, or by taking special measures to keep the amount of frequency shift introduced by the transmission system within narrow limits.

There are, however, a number of reasons why none of these expedients may be desirable. Transmission of carrier at full amplitude may, for example, overload repeaters in the transmission system or cause crosstalk between adjacent lines, while transmission of carrier at reduced amplitude may lead to filtering difficulties in separating the carrier at the receiving end of the system for amplification prior to demodulation. Manual adjustment of the demodulating carrier frequency, on the other hand, requires a separate adjustment for every change in operating conditions. Controlling the frequency shift introduced by the transmission system within narrow limits, finally, tends to require relatively complex and expensive apparatus and is subject to failure in the event of failure of any portion of the controlling mechanism.

A principal object of the invention is, therefore, to eliminate frequency errors in the transmission of suppressed-carrier amplitude modulated waves without requiring either manual adjustments or measures to limit the amount of frequency shift in the transmitting medium.

A closely related object is to eliminate frequency error in the transmission of suppressed-carrier amplitude modulated waves in as simple and reliable a manner as possible.

A typical amplitude modulation transmission system which tends occasionally to introduce a small amount of frequency deviation is the standard short-haul Bell System carrier telephone transmission system known as type N carrier. This system, shown in outline form, for example, in United States Patent 2,695,332, which issued November 23, 1954, to R. S. Caruthers, uses suppressed-carrier single-sideband techniques to transmit whole groups of double-sideband carrier-transmitted channel signals. Repeaters are spaced periodically throughout the system and, at each repeater point, a local group carrier frequency is generated to modulate (or demodulate, depending upon the point of view) the group either from a low frequency band to a higher frequency band or vice versa. Such alternation and inversion of channel groups between low and high frequency bands is known in the art as frequency frogging and tends to equalize noise and crosstalk in the individual signal channels. Any instability or inaccuracy in the locally generated group carrier frequencies, however, will result in a frequency shift that is cumulative throughout the system. If it reaches an order of magnitude of 100 cycles per second, it can result in degradation of channel frequency characteristics because of misalignment of the received frequency spectrum with respect to the receiving channel band filters. In addition, while the frequency shift may be otherwise tolerable for normal transmission of carrier-transmitted channel signals, it may not be acceptable for program and certain types of data signals which are not accompanied by their own carrier and hence require more faithful reproduction of frequency.

In accordance with the invention, the final group demodulating carrier in such a system as the type N carrier system is derived, not from a local oscillator, but rather by frequency multiplication and intermodulation techniques from a pair of pilot frequencies which are within the pass band of the system. When the system is used to transmit groups of double-sideband carrier-transmitted channel signals, these pilot frequencies may be and preferably are two of the individual channel carriers. At the final group demodulator, which is otherwise like the preceding group modulators except that it is the last one in the system, the demodulating carrier derived from these pilot frequencies in accordance with the invention has exactly the frequency required to eliminate all of the frequency error accumulated at previous repeater points.

In completely eliminating accumulated frequency error on the final group demodulator, the invention thus eliminates any need either for transmitting the group carrier frequencies or for employing elaborate control schemes for holding frequency shift to an acceptable level. In practice, the invention is simple in that it requires a minimum amount of additional circuitry and reliable in that it does not rely upon elaborate control apparatus which is subject to failure. It is, moreover, self-correcting in that it insures the correct demodulating group carrier frequency at all times and does not require manual adjustments. It provides, in short, the advantages of actual transmission of the carrier frequency without incurring the usual penalties.

In a number of important embodiment of the invention, the pilot frequencies which are used to derive the final demodulating group carrier are harmonically related to one another when in either the high group or the low group, in the sense that they are harmonics of a common fundamental frequency, and the received pilot frequencies are multiplied in frequency by the factors m and n in deriving the demodulating carrier, where m and n are integers greater than zero and satisfy the relation

$$m=n+1$$

The greatest simplicity in deriving the final group demodulating carrier is thereby assured.

A more complete understanding of the invention, along with other objects and features, may be obtained from a study of the following detailed description of several specific embodiments. In the drawings:

FIG. 1 is a block diagram of a typical N carrier system embodying the invention arranged to transmit a group of twelve carrier-transmitted double-sideband channel signals;

FIGS. 2, 3, and 4 are block diagrams of alternative final repeaters for the embodiment of the invention illustrated in FIG. 1; and

FIG. 5 is a block diagram of a typical N carrier system embodying the invention arranged to transmit a single broadband signal channel.

FIG. 1 illustrates one direction of transmission of a typical type N carrier system modified to operate in accordance with the principles of the invention. The type N system operates on a four-wire basis, requiring a similar arrangement for transmission in the reverse direction. The circuitry required to provide the second path is not illustrated, however, since it would merely be a substantial duplication of that shown. In addition, some filters, amplifiers, and other component circuits are not separately illustrated where separate illustration is not necessary for an understanding of the invention. It is to be understood, however, that in reality they are included within appropriate ones of the blocks termed "modulator," "input circuit," and "output circuit."

For normal telephone message transmission, the type N is, as shown, a twelve channel system. The first channel includes, for example, an appropriate input circuit **11** which supplies voice-frequency signal waves occupying a band of approximately 300 to 3100 cycles to a channel modulator **12**. Modulator **12** is supplied with its carrier frequency by a carrier source **13**. The other channels are similar, except for the channel carrier frequency employed, and will not be separately described.

Through the use of different carrier frequencies, the twelve channels are combined for transmission on a frequency-division multiplex basis. In the type N system, the carriers are spaced at 8-kilocycle intervals. These may be spaced, as illustrated, from 168 to 256 kilocycles to form a so-called high group or from 48 to 136 kilocycles to form a so-called low group. In each channel, the carrier and both upper and lower sidebands are transmitted.

Repeaters in the type N system employ suppressed carrier single-sideband techniques to alternate the transmitted frequencies between a high band of from 164 to 260 kilocycles and a low band of from 44 to 140 kilocycles at successive repeater points and invert the frequency order at each point. As pointed out previously, this combination of frequency reversal and inversion is known as frogging and serves to equalize noise and crosstalk in the various signal channels. The repeaters are spaced at regular intervals in the system, the particular spacing employed depending principally upon cable gauge. Each repeater normally includes a group modulator (so-called to distinguish it from the channel modulators), a local source of carrier current having a nominal frequency of 304 kilocycles, and the appropriate amplifiers and filters. Three repeaters are shown in FIG. 1 by way of example. The first is shown comprising a group modulator **14** and a local nominal 304 kilocycle carrier source **15** and the second is shown comprising a group modulator **16** and a local 304 kilocycle carrier source **17**. As explained previously, each block labeled "group modulator" includes the appropriate filters and amplifiers for single-sideband carrier-suppressed transmission of the group frequencies. At the last repeater point in FIG. 1, the group modulator **18** accomplishes the final step of frequency frogging prior to detection of the various channel signals and, hence, can be said to perform the function of group demodulation. In accordance with the present invention, group modulator **18** has its demodulating carrier frequency derived in such a manner that all frequency shift due to inaccuracies of group carrier oscillators **15** and **17** is eliminated.

The first type N carrier signal channel in FIG. 1 is completed, to the right of final group modulator **18**, by an appropriate bandpass channel filter **19**, a channel detector **20**, and a channel output circuit **21**. The remaining channels are completed in a similar manner, differing in the pass bands of their chanel filters in order to separate the various signal channels. Since the carrier and both sidebands of the signal channels are received, no local demodulating carrier source is required.

Unwanted frequency deviation creeps into a type N carrier system whenever one or more of the group carrier oscillators at repeater points drifts from its assigned nominal frequency of 304 kilocycles. As one of these carrier oscillators drifts, the sideband frequencies transmitted from the associated group modulator drifts in the same direction. Successive carrier deviations along the repeatered line cause successive frequency errors in the transmitted sidebands which, if they combine additively, can introduce a substantial frequency error in the group frequencies supplied to the receiving channel filters from the final repeater. This frequency error tends to cause degradation in channel frequency characteristics because of misalignment of the incoming frequency spectrum with respect to the receiving channel filters.

In the embodiment of the invention illustrated in FIG. 1, such frequency errors are canceled completely at the final repeater point by deriving the final demodulating carrier frequency for group modulator **18** from two of the received channel carriers. In the arrangement shown, the two channel carriers used are 192 kilocycles from the high group and 56 kilocycles from the low group. Since the 192 kilocycle carrier has a frequency of 112 kilocycles in the low group, these two carriers are in a 2 to 1 harmonic relationship when in that band. A narrow band 192 kilocycle filter **22** is bridged across the line on the input or high group side of group modulator **18** and a narrow band 56 kilocycle filter **23** is similarly bridged across the line on the output or low group side. Both filters have pass bands wide enough to pass the chosen channel carriers even if shifted in frequency by the maximum anticipated amount but narrow enough to exclude as many other frequencies as possible. Both filters **22** and **23** are connected to a local modulator **24**, filter **22** directly and filter **23** through a frequency multiplying circuit **25**. Circuit **25** doubles the frequency of the wave applied to it by filter **23**. The sum modulation product of modulator **24** is selected by a 304 kilocycle band-pass filter **26** and amplified by an amplifier **27** before it is applied as the demodulating group carrier frequency to group modulator **18**.

The effectiveness of the frequency error cancellation afforded by the invention can be illustrated by a numerical example. The normal group demodulating wave frequency is 304 kilocycles and the selected channel carrier frequencies are 56 and 112 kilocycles. Since group modulator **18** is shown to be one providing a transition from the high band to the low band rather than vice versa, these carriers on the input side of group modulator **18** are $(304-56+D)$ and $(304-112+D)$ or $(248+D)$ kilocycles and $(192+D)$ kilocycles, where D is the accumulated frequency deviation from the preceding repeaters. The frequency $(192+D)$ kilocycles is selected by filter **22** and applied to modulator **24**. On the output side of group modulator **18**, the frequency $(P-248-D)$ kilocycles is selected by filter **23**, where P is the demodulating frequency applied to group modulator **18** from amplifier **27**. Modulator **24** combines these two frequencies to yield the sum product $(192+D+2P-496-2D)$ kilocycles or $(2P-D-304)$ kilocycles. Since this is the frequency selected by filter **26** and applied as the demodulating carrier to group modulator **18**,

$$P=2P-D-304$$

Solved for P, this equation yields

$$P=304+D$$

A demodulating carrier is thus applied to group modulator **18** which includes the precise frequency deviation D that has been acquired by the selected channel carriers and by all of the other transmitted frequencies. In this example, the two channel carriers of interest are demodulated by group modulator **18** as follows:

$$(304+D)-(248+D)=56 \text{ kilocycles}$$

$$(304+D)-(192+D)=112 \text{ kilocycles}$$

All of the accumulated frequency deviation D has been canceled in the final group modulator **18**, whether it was 1 cycle or 100 cycles.

Although the selected low band channel carrier frequencies in the embodiment of the invention illustrated in FIG. 1 are 56 and 112 kilocycles, other combinations may be used as well. Examples are 40 and 80 kilocycles, 48 and 96 kilocycles, 64 and 128 kilocycles, and 52 and 104 kilocycles.

The particular arrangement illustrated in FIG. 1, in which the 192 kilocycle high band channel carrier is applied directly to modulator **24** is, of course, a special case. The 192 kilocycle wave is, in a sense, multiplied in frequency by the factor 1. A somewhat more general case is illustrated in FIG. 2, which shows a final type N carrier repeater embodying the invention in which a 208 kilocycle channel carrier in the high group is multiplied in frequency by 3 and an 80 kilocycle channel carrier in the low group is multiplied in frequency by 4. As illustrated, a 208 kilocycle bandpass filter **31** is bridged across the input side of final group modulator **18** and connected to modulator **24** through a frequency multiplying circuit **32** arranged to multiply the selected wave in frequency by the factor 3. On the output side of group modulator **18**, an 80 kilocycle band filter **33** is connected from the line to modulator **24** by a frequency multiplying circuit **34** arranged to multiply by the factor 4. The 304 kilocycle filter **26** connected to the output of modulator **24** selects the difference product to provide the correct demodulating frequency for canceling accumulated frequency error.

It is, furthermore, not essential to the invention that the two channel carriers be selected from opposite sides of final group modulator **18**. FIGS. 3 and 4 illustrate embodiments of the invention where both channel carriers are selected from the input side of group modulator **18**. For purposes of illustration, the repeater in FIG. 3 is of the low-high type while in FIG. 4 it is of the high-low type.

In the low-high repeater shown in FIG. 3, the selected channel carriers are in the low group and have normal frequencies of 64 and 104 kilocycles. A 64 kilocycle band filter **37** and a frequency multiplying circuit **38** for multiplying an incoming frequency by a factor of 5 are connected in tandem between the line and modulator **24** Similarly connected are a 104 kilocycle band filter **39** and a frequency multiplying circuit **40** for multiplying the incoming frequency of a factor of 6. The output 304 kilocycle filter **26** selects the difference frequency to provide a demodulating carrier which contains the frequency deviation of the two channel carriers and is exactly correct in frequency to cancel all accumulated frequency error in the transmitted group signals.

The high-low repeater illustrated in FIG. 4 can be used as a basis for a large number of different channel carrier frequencies and frequency multiplying factor examples. Two channel carriers from the high group are used and the multiplying factors can be taken as m and n, which are any integers greater than zero satisfying the relation

$$m=n+1$$

A first band filter **43** and frequency multiplier **44** combination is connected from the input side of group modulator **18** to one input of modulator **24**. Frequency multiplier **44** is shown only in dashed outline form for the reason that the multiplying factor is unity in that path for the particular combination of channel carrier frequencies illustrated in FIG. 4. A second band filter **45** and frequency multiplier **46** combination is connected from the same side of group modulator **18** to the other input of modulator **24**.

If the high band channel carrier frequency selected by filter **45** is designated A, the frequency multiplying factor of frequency multiplier **46** is m, the high band channel carrier frequency selected by filter **43** is designated B, and the factor of frequency multiplier **44** is n, a number of effective combinations are shown in the following table:

A	m	B	n	mA	nB
Kc.		*Kc.*		*Kc.*	*Kc.*
240	3	208	2	720	416
232	4	208	3	928	624
240	2	176	1	480	176
248	2	192	1	496	192
256	2	208	1	512	208
252	2	200	1	504	200

The last four examples are particularly attractive because they require only a single frequency doubler in addition to the filters and modulator **24** to generate the demodulating carrier.

While the basic embodiment of the invention illustrated in FIG. 1 makes use of the channel carriers already transmitted in the standard type N carrier telephone system, the principles underlying the invention are of sufficient breadth that their applicability is much greater. It is occassionally desirable, for example, to transmit a different type of signal over a repeatered type N carrier transmission line. FIG. 5 illustrates an embodiment of the invention in which the transmitted signal does not include channel carriers and in which a pair of pilot frequencies are used to generate the demodulating carrier wave instead. The transmitted signal may be, for example, a broadband data signal or a group of suppressed-carrier single sideband channels. As in FIG. 1, only one direction of transmission is shown.

In FIG. 5, a signal input circuit **51** supplies a broadband signal occupying a band extending from 60 to 108 kilocycles to a repeatered N carrier line. The first repeater contains a low-high group modulator **52** supplied with carrier from a local nominal 304 kilocycle source **53**. The second repeater contains a high-low group modulator **54** and a carrier source **55**, while the third contains a low-high group modulator **56** supplied from a carrier source **57**. A larger or smaller number of repeaters may be employed, of course, depending upon the length of the line and the gauge of the cable, but these are shown by way of example. The final repeater contains a high-low group modulator **18** supplied with a demodulated carrier wave in accordance with the invention and furnishes the original 60 to 108 kilocycle signal to a signal output **58**.

In accordance with the invention, a pair of pilot frequencies outside of the signal band but still within the pass band of the transmission system are introduced along with the signal band. In the embodiment illustrated in FIG. 5, the two pilot frequencies are 56 and 112 kilocycles. As illustrated, a 56 kilocycle source **59** is coupled to the line through a 56 kilocycle bandpass filter **60** and a 112 kilocycle source **61** is coupled to the line through a 112 kilocycle bandpass filter **62**. These pilot frequencies are frogged up and down in frequency along with the main signal at each repeater point and accumulate the same frequency shift as the signal. At the final repeater, the demodulating carrier is supplied to group modulator **18** by a circuit combination substantially identical to the one shown in FIG. 1. The 56 kilocycle pilot frequency from the low group side of group modulator **18** is doubled in frequency and supplied to modulator **24** along with the 192 kilocycle pilot from the high group side. The output filter **26** selects the sum product from modulator **24** and supplies it, through amplifier **27**, to group modulator **18** as the demodulating carrier. As has already been explained, this carrier is precisely the frequency required to cancel all of the accumulated frequency error.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In a suppressed-carrier amplitude modulation signal transmission system having a transmitting end and a receiving end, an arrangement for eliminating frequency error which comprises means to transmit a pair of pilot frequencies over said system along with the regular signal from the transmitting end to the receiving end, said pilot frequencies being harmonically related to one another, a demodulator at the receiving end of said system, means to select said pilot frequencies at the receiving end of said system, means to multiply one of said pilot frequencies in frequency by the factor m and the other by the factor n, where m and n are integers greater than zero satisfying the relation $m=n+1$, a second order modulator and a means to derive a demodulating carrier for said demodulator by intermodulating said pilot frequencies with one another in said second order modulator subsequent to multiplication.

2. In a suppressed-carrier amplitude modulation system for transmitting a group of double-sideband carrier-transmitted signals from a transmitting station to a receiving station, an arrangement for eliminating frequency error which comprises a demodulator at said receiving station, means to select a pair of signal carrier frequencies at said receiving station, said selected signal carrier frequencies being substantially harmonically related to one another, means to multiply one of said selected carrier frequencies in frequency by the factor m and the other

by the factor n, where m and n are integers greater than zero satisfying the relation $m=n+1$, a second order modulator, and means to derive a demodulating carrier for said demodulator by intermodulating said selected carrier frequencies with one another in said second order modulator to multiplication.

3. In a suppressed-carrier amplitude modulation signal transmission system for transmitting signals having a predetermined frequency band from a transmitting station to a receiving station, an arrangement for eliminating frequency error which comprises means to transmit a pair of pilot frequencies outside of said predetermined frequency band but within the pass band of said system over said system along with the regular signals from the transmitting end to the receiving end, a demodulator at said receiving station, means to select said pilot frequencies at said receiving station, means to multiply one of said pilot frequencies in frequency by the factor m and the other by the factor n, where m and n are intergers greater than zero satisfying tht relation $m=n+1$, a second order modulator, and means to derive a demodulating carrier for said demodulator by intermodulating said selected pilot frequencies with one another in said second order modulator subsequent to multiplication.

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DAVID G. REDINBAUGH, *Primary Examiner.*