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[54] **DIGITAL MODULATION METHOD FOR STANDARD BROADCAST FM SUBCARRIER**

[75] Inventors: **Jing J. Young,** Indianapolis, Ind.; **Richard L. Stuart,** Columbia, Md.

[73] Assignee: **Regency Electronics, Inc.,** Indianapolis, Ind.

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[51] **Int. Cl.**[4] **H04J 9/00**

[52] **U.S. Cl.** **370/11;** 455/45; 381/4

[58] **Field of Search** 370/11, 122, 110.4, 370/76; 381/4; 375/39; 455/45

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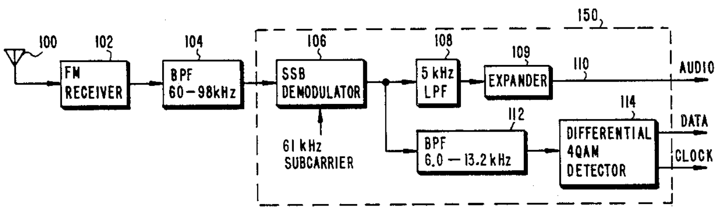
Primary Examiner—Douglas W. Olms
Assistant Examiner—M. Huseman
Attorney, Agent, or Firm—Woodard, Weikart, Emhardt & Naughton

[57] **ABSTRACT**

A digital transmission system using standard FM broadcast stations employs an SCA subcarrier which is amplitude modulated with a second subcarrier modulated to have different phase orientations representative of digital data. Bits are separated from a digital data stream in groups and are differentially encoded into one of at least four phase orientations of the second subcarrier. The amplitude modulated SCA subcarrier is combined with the stereo signal output of a stereo multiplexer to form the modulating signal for the station FM modulator. The receiver includes a differential phase detector for reconstruction of the differentially encoded digital data.

A system which additionally includes means for modulating the SCA subcarrier with a composite signal having an audio signal in addition to the differentially encoded second subcarrier is disclosed.

16 Claims, 6 Drawing Figures



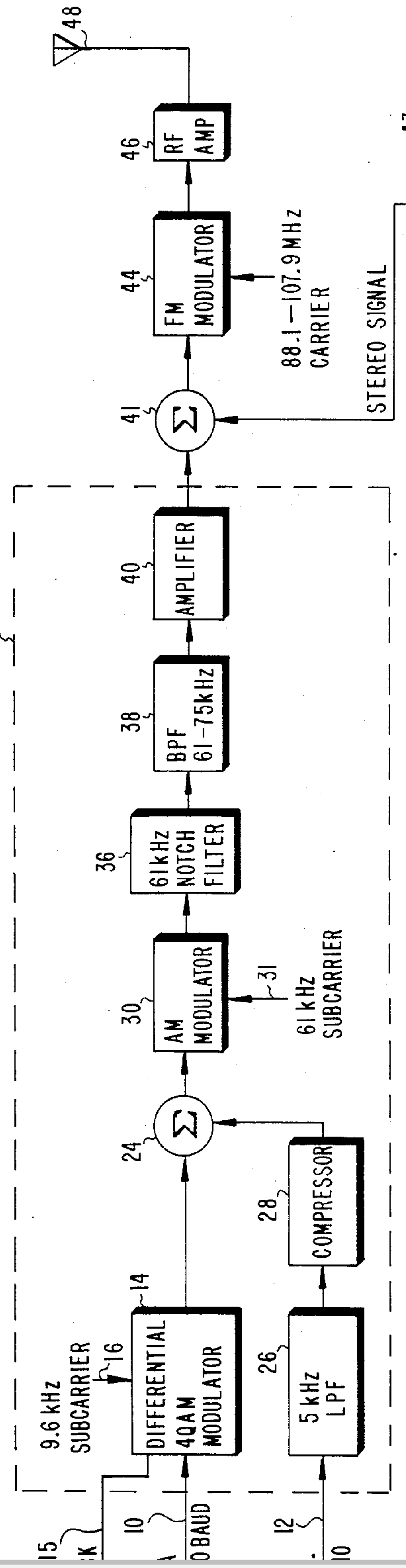
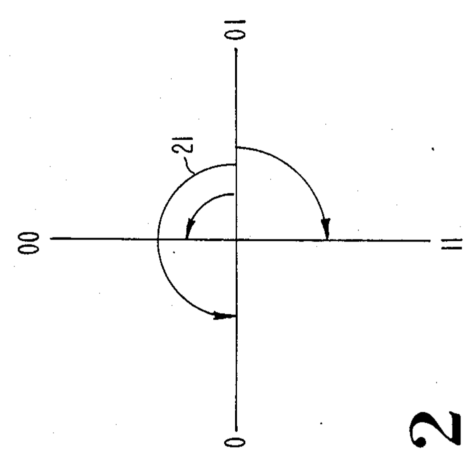


Fig.1



IT PAIR	PHASE CHANGE
01	0°
00	90°
10	180°
11	-90°

Fig.2

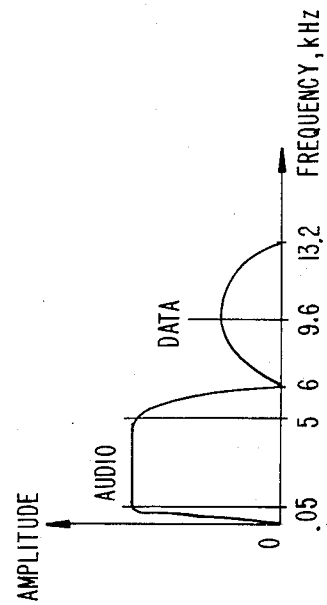


Fig.3

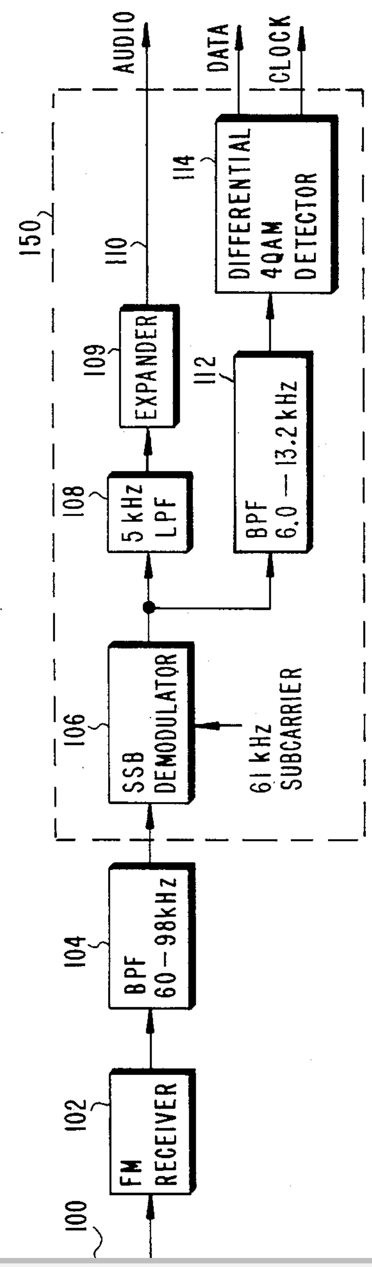


Fig.5

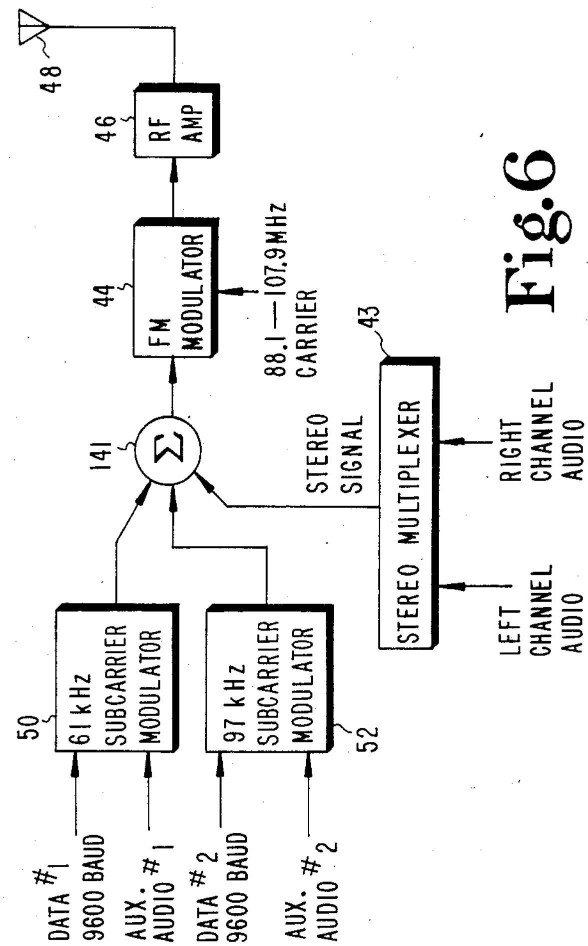


Fig.6

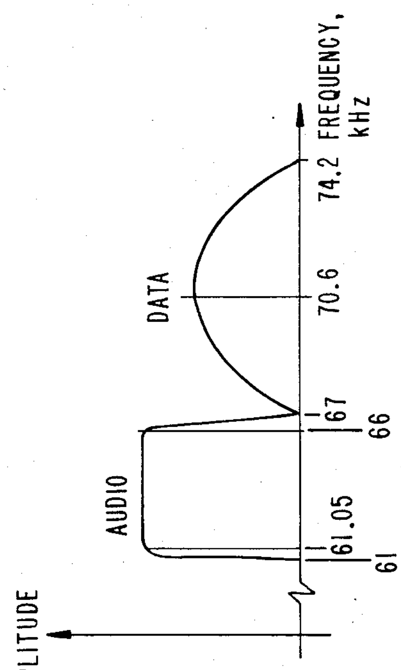


Fig.4

DIGITAL MODULATION METHOD FOR STANDARD BROADCAST FM SUBCARRIER

FIELD OF THE INVENTION

The invention relates to a method for modulating a subcarrier with digital signals in connection with a standard FM broadcast station.

BACKGROUND OF THE INVENTION

In the past, some standard broadcast FM stations (operating from 88.1 to 107.9 MHz) have incorporated a subcarrier at, for example, 67 kHz which was frequency modulated to incorporate audio information, such as background music (Muzak). This subcarrier has sometimes been referred to as the SCA subcarrier (subsidiary communications authorization). Additionally, digital systems utilizing the SCA subcarrier were developed which transmitted data by frequency shift keyed modulation of the subcarrier. Since the frequency swing of the composite signal had to be restricted to avoid adjacent channel interference, the amplitude of the subcarrier has been required to be restricted to a level which would produce not more than 7.5 kHz deviation.

Several systems have been proposed to use the SCA subcarrier for both digital and audio use. One such system, proposed by Mutual Broadcasting, frequency modulated the SCA subcarrier with a composite signal. This composite signal included an audio signal plus a signal obtained from digital information modulating a second 4QAM (four-level quadrature amplitude modulation) modulated subcarrier. While this sytem was an improvement over earlier systems, it was unable to accommodate the digital baud rate desired.

SUMMARY OF THE INVENTION

Standard broadcast (88.1 to 107.9 MHz) FM transmitters conventionally carry an audio signal (either monaural or, if stereo, the sum of right and left audio channels for stereo) and, if stereo, a multiplexed signal representing the difference between the right and left channel. The invention relates to a system having a standard broadcast FM tranmitter and receiver which additionally utilizes an SCA subcarrier (above 60 kHz) by amplitude modulating and demodulating the subcarrier (such as with full amplitude modulation or with single-sideband or double-sideband suppressed-carrier) with a signal which includes a second subcarrier which has been modulated to have different phase orientations for digital data.

Preferably the second subcarrier incorporates 4-phase quadrature phase-shift-keyed modulation or the equivalent 4-level quadrature double-sideband suppressed-carrier amplitude modulation. Alternatively, higher order modulation techniques may also be used, such as 8-phase PSK or 16-ary QAM. Also, preferably, an audio signal additionally amplitude modulates the SCA subcarrier directly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a digital transmission system using standard FM broadcast stations according to the preferred embodiment of the present invention.

FIG. **2** illustrates the phase coding relationship for the differential encoding and decoding of data as performed by the system according to the preferred embodiment of the present invention.

FIG. **3** is a graph of the baseband spectrum of the composite signal comprised of 4QAM data and auxiliary audio found at the input to the AM modulator of FIG. **1**.

FIG. **4** is a graph of the spectrum of the single-sideband, suppressed-carrier modulated signal at the output of amplifier **40** of FIG. **1**.

FIG. **5** is a block diagram of a receiver according to the present invention.

FIG. **6** is a block diagram of an alternative embodiment of the present invention in which two SCA subcarriers are employed.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, a digital transmission system using standard FM broadcast stations is shown in block diagram form. Digital data at 9600 baud is received on input line **10**, and an auxiliary audio signal is received on line **12**. The digital data on line **10** is clocked into differential 4QAM (4-level quadrature amplitude modulation) modulator **14** under control of a clock signal generated therein and supplied to the data source (not shown) on line **15**. 4QAM modulator **14** is a phase oriented modulator which removes data from the digital data stream in pairs of bits and differentially encodes each pair into one of four quadrature-amplitude-modulated signals. Differential encoding of the data conveys the information by carrier phase changes from the previously sent phase, rather than by the absolute phase of the carrier with respect to a reference signal.

The phase change of the carrier is determined by pairs of bits which are sequentially taken from the digital data stream. FIG. **2** shows the phase change relationship for differential encoding of received bit pairs, in tabular and graphical form. As an example, if the bit pair **10** is received by differential 4QAM modulator **14**, the 4QAM signal generated by modulator **14** shifts in phase by 180 degrees with respect to the phase of the previous 4QAM signal, as indicated at **21** in FIG. **2**.

Differential 4QAM modulator **14** operates in conventional fashion and the details of its operation are not shown. In general, however, it phase-divides the 9.6 kHz subcarrier signal received on line **16** into an in-phase (I) subcarrier and a quadrature (Q) subcarrier shifted 90 degrees with respect to the I subcarrier, in conventional quadrature modulation fashion. The I and Q subcarriers are supplied respectively to I and Q AM modulators each of which also receives one bit of a modulating signal bit pair as a modulating signal. The current modulating signal bit pair is different from the previous modulating signal bit pair by an amount dependent on the bit pair received on line **10**. The in-phase and quadature modulated signals are added to produce a 4QAM signal.

It will be appreciated that the four possible 4QAM signals are separated in phase from each other by an integral multiple of 90 degrees. Further, it will be understood by those skilled in the art that a 4QAM signal as described hereinabove is identical to that produced in a 4-phase phase-shift-keying (4PSK) modulator. Reference to one form of modulation herein is intended to encompass the other.

4QAM modulator **14** includes a raised cosine band-pass filter, with a passband from 6.0 to 13.2 kHz, to shape the 4QAM signal spectrum prior to transmission. 4QAM modulator **14** also has an internal scrambler of conventional design which introduces changes into the bit stream to guarantee phase changes of sufficient frequency in the transmitted signal to enable the receiver to recover a clock signal from the transmitted signal.

The 4QAM output signal of modulator **14** is coupled to summing amplifier **24**. The audio signal input on line **12** is limited to frequencies below 5 kHz by low pass filter **26**, and the high-amplitude excursions of the filtered signal are compressed in compressor **28**. The compressed audio signal and the 4QAM signal are combined in summing amplifier **24** to form a composite signal having audio and digital components in adjacent portions of the baseband spectrum, as illustrated in FIG. **3**.

The composite signal is supplied to AM modulator **30** which effects the modulation of the 61 kHz subcarrier signal received on line **31**. AM modulator **30** partially suppresses the carrier, 61 kHz notch filter **36** provides further carrier suppression, and bandpass filter **38** eliminates the lower sideband, resulting in a single-sideband, suppressed-carrier signal having a spectrum bandwidth from 61 kHz to 74.2 kHz, as shown in FIG. **4**. After further amplification in amplifier **40**, the composite AM signal is supplied to summing amplifier **41**, where it is added to a stereo signal generated by stereo multiplexer **43**. Stereo multiplexer **43** operates in a conventional manner, generating the sum of left and right channel audio signals as well as the difference between those same signals, and multiplexing the sum and difference signals into one stereo signal. The output signal from summing amplifier **41** is the FM modulating signal which is fed to FM modulator **44**. FM modulator **44** generates a frequency-modulated signal on a selected carrier frequency in the standard broadcast FM band of 88.1 MHz to 107.9 MHz. The resulting FM signal is amplified in RF amplifier **46** and transmitted from antenna **48**.

The voice and digital information carried on the SCA subcarrier may be detected using a receiver such as that shown in FIG. **5**. Referring now to FIG. **5**, an incoming RF signal is received on antenna **100** and supplied to receiver **102** which is tuned to the appropriate main FM channel frequency. Receiver **102** demodulates the received FM signal and produces modulated SCA subcarrier as well as any multiplexed stereo or other audio signal which may be present on the main channel frequency. Bandpass filter **104**, with corner frequencies of 60 kHz and 98 kHz, provides attenuation of stereo signals, including the 19 kHz and 38 kHz reference signals, which may be 20 db higher than the SCA signal. The output spectrum of bandpass filter **104** is substantially the same as that shown in FIG. **4**.

The 61 kHz subcarrier is reinserted at SSB demodulator **106** which detects the audio and digital modulation on the 61 kHz subcarrier. The output spectrum of SSB demodulator **106** includes the original baseband spectrum shown in FIG. **3** as well as a subcarrier frequency component at 61 kHz and a higher-frequency band at 122 kHz.

The recovered composite signal is applied in parallel to audio and digital signal recovery circuits. Low pass filter **108**, with a corner frequency of 5 kHz, filters out the digital data portion of the spectrum, and expander **109** provides nonlinear gain inversely corresponding to that of compressor **28** (FIG. **1**), thereby restoring the original relative amplitudes in the auxiliary audio signal. Expander **109** supplies the recovered auxiliary audio signal on line **110** for audio amplification and connection to speakers (not shown). Similarly, bandpass filter **112**, with a passband from 6.0 to 13.2 kHz, rejects the audio signal portion of the spectrum and passes the 4QAM signal to differential 4QAM detector **114**. Differential 4QAM detector **114** operates in conventional fashion and the details of its operation are not shown. In general, however, it decodes phase changes in the received waveform into one of four levels according to the relationship shown in FIG. **2**. 4QAM detector **114** incorporates a descrambler in conventional form corresponding with the scrambler in 4QAM modulator **14**. Continuing with the same example as before, when 4QAM detector **114** detects the phase change of 180 degrees in one interval with respect to the previous interval, it decodes the change into the original bit pair **10**. 4QAM detector **114** outputs the decoded bit pair on the data line.

Differential phase detection is preferred over fixed-reference phase detection because the latter is susceptible to phase jitter and other channel disturbances (such as those resulting from multipath radio interference). These disturbances create the problem of both establishing the fixed reference and maintaining it in its fixed phase. Once the receiver loses synchronization, the time required to reestablish synchronization is often much longer than the duration of the disturbance. In contrast, with differential phase detection, an error burst affects only data decoded during the error burst and one interval following the burst. That is, if a channel disturbance results in a phase shift during one interval, the detected phase changes between that interval and the previous interval and between that interval and the following interval will both be incorrect. However, the second decoded bit pair following the error burst will be correct, because by that time two 4QAM signals will have been correctly received.

A Gray code, as shown in FIG. **2**, is preferred for differential encoding to minimize bit errors due to phase shifts caused by channel disturbances. Phase errors of 90 degrees are more likely than errors of 180 degrees, thus with the Gray code errors are more likely to effect only one bit per bit pair. When used with an appropriate error-correcting code, such as the Golay (23, 12) code, in which errors of up to three bits in two consecutive bit pairs of a 23-bit word can be corrected, the Gray code reduces the overall probability of error.

4QAM detector **114** also includes circuitry for recovering the original clock frequency for use in later synchronizing other circuitry (not shown) to the digital data. 4QAM detector **114** recovers this frequency from the transmitted waveform irrespective of the phase shift, if any, and supplies the resulting clock signal on the clock line. Scrambling and descrambling of the bit stream guarantees that the 4QAM signal carries sufficient phase changes to enable clock recovery by detector **114**.

One alternative embodiment, shown in block diagram form in FIG. **6**, employs two subcarries, one at 61 kHz and the other at 97 kHz. 61 kHz subcarrier modulator **50**, also shown inside dotted lines in FIG. **1**, has already been described. 97 kHz subcarrier modulator **52** contains the same functional blocks as modulator **50** but operates with a 97 kHz subcarrier and is designed to generate the lower sideband instead of the upper sideband as in modulator **50**, the notch and bandpass filters being designed accordingly. The outputs of modulators **50** and **52** are combined in summing amplifier **141** along with a stereo signal generated, as already described, by stereo multiplexer **43**. The output signal from summing amplifier **141** is the FM modulating signal for FM modulator **44**, which generates an FM signal as described

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