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"An FM Receiver".

The present invention relates to an FM receiver for controlling stereo separation.

In an FM receiver, a portion of the carrier waves, which is phase-modulated by noise waves is detected by an FM detector and is converted into a noise output. The magnitude by which the carrier waves are phase-modulated by noise waves varies depending upon a difference in the carrier wave frequency and the noise frequency. When the noise waves are uniformly distributed, the magnitude increases in proportion to the frequency. This characteristic is referred to as triangular noise characteristic in the frequency modulation.

In FM stereo demodulation, there is greater deterioration in the signal-to-noise ratio (S/N ratio) by the noise contained in a frequency band of sub-channel signals in which stereo composite signals have frequencies

of 23 KHz to 53 KHz, than in the monaural demodulation in which a portion surrounded by a small triangle of up to 15 KHz in an audible range produces a noise output.

When the receiver is placed in an electromagnetic field established by a weak input in which the amplitude limiting effect is diminished, the signal-to-noise ratio is reduced by the amplitude modulation component and the phase modulation. During the period of stereo demodulation, therefore, the signal-to-noise ratio is very substantially reduced by noise which is distributed over the above-mentioned wide ranges.

Japanese Laid-Open Patent Specification No. 17604/1976 discloses a method of preventing the sound quality from deterioration by automatically switching between FM stereo and monaural demodulation depending upon the noise level in the output of the FM detector, or by automatically switching between the FM stereo and monaural demodulation by detecting the intensity of the input field strength relying upon the output level of the FM intermediate-frequency amplification.

According to the above-mentioned known method, switching between the FM stereo and monaural demodulation is automatically accomplished by forming a variable filter using a resistor, a capacitor and a control transistor, by

controlling the conductive state of the control transistor, and by controlling the amount of attenuation of the high-frequency components. However, since the above conventional FM receiver requires the capacitor to form the variable filter, difficulty is encountered when it is attempted to construct the FM receiver in the form of a monolithic semiconductor integrated circuit.

When switching between the stereophonic reproduction and monaural reproduction in an FM receiver which will be subjected to great and frequent changes in the input electric field strength such as in the case of car radios, however, instantaneous and frequent change between the stereophonic reproduction and the monaural reproduction results in the reproduction of offensive sounds. In order to eliminate such a defect, therefore, we have previously disclosed in our British Patent Application No. 79.41976 (Serial No. 2040145....) a method to continuously change the stereo separation by continuously changing the level of 38 KHz switching signals applied to an FM stereo demodulator in the switching system, depending upon the intensity in the input electromagnetic field.

With reference to the control system, disclosed in our Patent Application No. 79.41976 referred to above it

should be noted that the stereo separation varies irrespective of the change in the noise level of FM demodulated signals due to dispersion in the FM front end characteristics and dispersion in the gain of an
5 intermediate-frequency amplifier circuit, and the signal-to-noise ratio of the signals reproduced under an input field strength which is expected to attain a predetermined stereo separation, varies responsive to the dispersion. In the above-proposed control system, it is difficult to
10 control the stereo separation so that the signal-to-noise ratio of the resulting signals becomes greater than a predetermined value.

Furthermore, beat components which fall outside the audible range and which are caused by signal interference
15 between the two FM broadcasting signals of close frequencies are contained in the FM detection signals, such beat components often interfere with harmonics of switching signals of 38 KHz which are employed for the FM stereophonic demodulator, to produce beat signals having
20 audible frequencies. The system disclosed in our British Patent Application No. 79.41976 is not capable of avoiding such disadvantages.

It is an object of the present invention to provide an FM receiver which is capable of reducing noise due to

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interference with harmonics in the FM stereo demodulator.

According to the present invention there is provided an FM receiver including: an FM detector; a stereo demodulator which receives a main-channel signal and a sub-channel signal of a stereo composite signal obtained from the output terminal of said FM detector, as well as a sub-carrier signal; a gain-controlled circuit which transmits said sub-carrier signal to said stereo demodulator; a high-pass filter for obtaining high-frequency components in the output signal from said FM detector; and a level detector for detecting the level of said high-frequency components which are obtained from said high-pass filter; wherein:-

(a) the output signal of said level detector is transmitted to said gain-controlled circuit;

(b) the amplitude level of said sub-carrier signal applied by said gain-controlled circuit to said stereo demodulator is gradually lowered with the rise in the level of said high-frequency components that are obtained from said high-pass filter; and

(c) a cut-off frequency of said high-pass filter is selected to such a value that said level detector is not substantially affected by the sub-channel signal of the stereo composite signal.

The present invention will now be described in greater detail by way of example with reference to the accompanying drawing, wherein the sole figure is a circuit diagram of one preferred form of an FM receiver.

Referring to the drawing, the FM receiver includes

an FM detector 1 which produces an FM detection signal at a nodal point N_1 upon receipt of an FM intermediate-frequency signal which is supplied from an intermediate-frequency amplifier that is not shown. When a stereophonic broadcast is received, the FM detection signal consists of a composite signal made up of a main-channel signal, a sub-channel signal which is modified by a 38 KHz sub-carrier signal, and a 19 KHz pilot signal, and when a monaural broadcast is received, the FM detection signal consists of the main-channel signal alone.

The FM receiver also includes an amplifier 2 for amplifying the FM detection signal, and a phase-lock loop circuit 3 comprises a phase detector 31, a voltage-controlled oscillator 32 having a free-running oscillation frequency of approximately 76 KHz, and three dividers 33, 34 and 35 each having a frequency-dividing ratio of one-half. When the stereophonic broadcast is received, the PLL circuit 3 operates in synchronism with pilot signals of 19 KHz in the FM detection signals applied to a nodal point N_2 and produces 38 KHz sub-carrier signals of opposite phases at nodal points N_4 and N_5 and a 19 KHz signal at a nodal point N_6 . When the monaural broadcast is received, signals of a frequency determined by the oscillation frequency of the voltage-controlled oscillator

32 are produced at the nodal points N_4 to N_6 .

The FM receiver also includes a phase detector 4 which detects pilot signals reproduced during the reception of a stereophonic broadcast upon receipt of the 19 KHz signal from the nodal point N_6 of the PLL circuit 3 and upon receipt of the FM detection signal from the nodal point N_2 of the amplifier 2.

The circuit further includes a stereo/monaural switching control circuit 5 which is responsive to the output signals from the phase detector circuit 4 and produces a control signal to render a transistor Q_6 conductive when the monaural broadcast is being received, and to render the transistor Q_6 non-conductive when the stereophonic broadcast is being received.

Full details of the PLL circuit 3 have been disclosed in "ELECTRONICS", pp. 62-66 published in November, 1971.

To control the stereo separation, the FM receiver further includes a high-pass filter 6, a level detector 7 and a gain-controlled circuit 8, such that the level of 38 KHz sub-carrier signals supplied to a stereo demodulator 9 of the switching system is controlled.

The high-pass filter 6 comprises capacitors C_1 to C_3 and resistors R_1 to R_3 . The filter 6 selects high-

frequency components in the FM detection signals introduced from the nodal point N_1 , and produces outputs at a nodal point N_7 . In order that the level detector 7 is not affected by the sub-channel signals in the 23 KHz to 53 KHz band, the high-pass filter 6 has a cut-off frequency which is greater than 53 KHz which is the upper-limit frequency of the sub-channel signals. Although there is no particular limitation, the cut-off frequency of the high-pass filter 6 is set at about 60 KHz.

The detector 7 comprises a coupling capacitor C_4 , rectifier diodes D_1 and D_2 , a smoothing capacitor C_5 and a resistor R_4 . The resistor R_4 and the smoothing capacitor C_5 are connected in parallel between a nodal point N_8 and a nodal point N_{10} . The anode of the diode D_1 is connected to the nodal point N_8 , the cathode of the diode D_1 is connected to one terminal of the coupling capacitor C_4 and to the anode of the diode D_2 , and the cathode of the diode D_2 is connected to the nodal point N_{10} which is connected to a D.C. bias source E_1 .

Therefore, the D.C. potential appearing at the nodal point N_8 is at a negative potential relative to the D.C. potential at the nodal point N_{10} by a value corresponding to the amplitude of high-frequency noise signals supplied to the nodal point N_7 . When the level of high-frequency

noise signals supplied to the nodal point N_7 is substantially zero, the potentials at the nodal points N_8 and N_{10} become substantially equal to each other as determined by the D.C. bias source E_1 .

5 The gain-controlled circuit 8 comprises resistors R_5 to R_{12} , and transistors Q_1 to Q_5 .

 The base electrode of the transistor Q_1 is connected to the nodal point N_5 of the PLL circuit 3, and its collector electrode is connected to a nodal point N_{12} .

10 The base electrode of a transistor Q_2 is connected to the nodal point N_4 of the PLL circuit 3, and its collector electrode is connected to a nodal point N_{13} . Emitter electrodes of the transistors Q_1 and Q_2 are connected to the collector electrode of a transistor Q_3 so that the

15 transistors Q_1 and Q_2 operate in a differential manner.

 The resistors R_5 and R_6 are connected between each of the nodal points N_{12} and N_{13} and a power supply terminal V_{cc} , the base electrode of the transistor Q_3 is connected to the nodal point N_8 , and the emitter electrode of the

20 transistor Q_3 is connected to one end of a resistor R_9 via a resistor R_7 .

 Base electrodes of the transistors Q_4 and Q_5 are commonly connected to the nodal point N_9 , and their emitter electrodes are connected to each other. The commoned

emitter electrodes are connected to one end of the resistor R_9 via a resistor R_8 .

Collector electrodes of the transistors Q_4 and Q_5 are connected to their corresponding nodal points N_{13} and N_{14} , respectively.

The transistors Q_4 and Q_5 have the same construction so that they will permit equal collector current to flow responsive to a bias across the common base and the common emitter electrodes.

The transistors Q_3 , Q_4 and Q_5 operate in a differential manner responsive to a potential difference between the nodal point N_8 and the nodal point N_9 .

Resistors R_{10} and R_{11} are connected in series between the nodal point N_{10} and earth to constitute a voltage-dividing circuit. A resistor R_{12} is connected between a nodal point N_{11} to which the resistors R_{10} , R_{11} are connected and the nodal point N_9 .

If the resistance ratio of the resistor R_{10} to the resistor R_{11} is suitably selected, the nodal point N_{11} produces a D.C. bias voltage which renders the transistors Q_4 and Q_5 non-conductive and the transistor Q_3 conductive when the level of high-frequency noise signals at the nodal point N_7 is approximately zero.

The stereo demodulator 9 comprises resistors R_{13} to

R_{17} , transistors Q_7 to Q_{12} , and a D.C. bias source E_2 , and is of the type disclosed in IEEE TRANSACTIONS ON BROADCAST AND TELEVISION RECEIVERS, Vol. BTR-14, No. 3, pp. 58-73, issued October, 1968.

5 Switching signals of 38KHz are supplied from the nodal points N_{12} and N_{13} to the base electrodes of the transistors Q_7 to Q_{10} , and FM detection signals are supplied from the nodal point N_2 to the base electrode of the transistor Q_{11} .

 With this arrangement, the transistor Q_6 is
10 rendered non-conductive when the stereophonic broadcast is being received.

 Therefore, a D.C. bias voltage determined by the resistors R_{10} and R_{11} is supplied to the nodal point N_9 of the gain-controlled circuit 8.

15 When the level of the high-frequency noise signals produced by the high-pass filter 6 appearing at the nodal point N_7 is so small that it can be regarded as being almost zero, the potential at the nodal point N_8 is approximately equal to the potential at the nodal point N_{10} .

20 Accordingly, the transistor Q_3 is rendered conductive, and the transistors Q_4 and Q_5 are rendered non-conductive.

 When the transistor Q_3 is conductive, a sufficient operation current is allowed to flow into the transistors

Q_1 and Q_2 the base electrodes of which are supplied with 38 KHz switching signals as sub-carrier signals.

Due to the presence of the transistors Q_1 and Q_2 , 38 KHz switching signals of a sufficiently high level are generated at the nodal points N_{12} and N_{13} .

Therefore, the stereo demodulator 9 produces stereo demodulation signals of a sufficiently large degree of separation through its pair of output terminals OUT_1 and OUT_2 .

A D.C. potential at the nodal point N_8 decreases with the increase in the level of high-frequency noise signals at the nodal point N_1 .

A current starts to flow into the transistors Q_4 and Q_5 with the decrease in the D.C. potential at the nodal point N_8 , whereby the current through the transistor Q_3 starts to decrease. Consequently, the amplitude of the sub-carrier switching signals of 38 KHz which are generated by the transistors Q_1 and Q_2 and generated at the nodal points N_{12} , N_{13} is decreased.

The degree of separation of the stereo demodulation signals produced from the stereo demodulator 9 decreases with the decrease in the level of switching signals at the nodal points N_{12} and N_{13} . The D.C. potentials at the nodal points N_{12} and N_{13} are maintained nearly constant,

since voltage drops develop across the resistors R_6 and R_5 due to the currents of the transistors Q_4 and Q_5 .

As the level of high-frequency noise signals becomes sufficiently great at the nodal point N_7 , the D.C. potential at the nodal point N_8 is decreased correspondingly, whereby
5 the transistor Q_3 is rendered non-conductive.

When the transistor Q_3 is rendered non-conductive, the operation currents of the transistors Q_1 and Q_2 become zero. Hence, 38 KHz switching signals do not substantially
10 appear at the nodal points N_{12} and N_{13} .

Therefore, the stereo demodulator 9 no longer produces the stereo demodulation function. In other words, monaural signals are reproduced at the output terminals OUT_1 and OUT_2 .

15 When the monaural broadcast is being received, the transistor Q_6 is rendered conductive as mentioned earlier.

The potential at the nodal point N_9 of the gain-controlled circuit 8 is maintained at a relatively large value owing to the transistor Q_6 which is rendered
20 conductive. Therefore, the transistor Q_3 is rendered non-conductive, and switching signals of 38 KHz cease to appear on the nodal points N_{12} and N_{13} exactly as in the above-mentioned case.

The level of high-frequency noise signals at which the degree of separation starts to decrease, will be obvious

from the above description of operation. The level, however, can also be changed by varying the voltage dividing ratio of the resistor R_{10} to the resistor R_{11} .

The rate of decrease in separation with respect to the level of high-frequency noise signals can be determined by the resistances of the resistors R_7 and R_8 .

In the above described circuit since noise in the band of signal frequencies and noise of higher frequencies establish a correlation as determined by the FM triangular noise characteristics, noise in the band of signal frequencies can be detected by detecting the high-frequency noise.

Since the separation degree is controlled by directly detecting the magnitude of noise contained in the FM detection outputs, therefore, it is possible to control the degree of separation maintaining accuracy without being affected by the dispersions in the FM front end and the intermediate-frequency amplifier.

With the degree of separation being decreased by decreasing the level of 38 KHz sub-carrier switching signals which are fed to the stereo demodulator 9, even when harmonic components of a frequency of, for example 100 KHz are contained in the FM detection signals, beat signals, which are produced by the multiplication of the sub-carrier

switching signals by the harmonic components, in the band of audible frequencies can be attenuated.

Beat components in the high-frequency 150 KHz to 450 KHz frequency band appear in the outputs of the FM detector due to the interference of primary signal interference between the two FM broadcasting stations of very close broadcasting frequencies. Also, offensive beat signals in the band of audible frequencies are produced in the outputs of the stereo demodulator due to the secondary signal interference between the beat components in the high-frequency band and harmonic components of the order of odd numbers (i.e., 114 KHz, 190 KHz,.....) in the 38 KHz sub-carrier signals.

In the above described circuit, these beat signals and secondary signal interference is suppressed since the gain-controlled circuit 8 decreases the amplitude level of the 38 KHz sub-carrier switching signals fed to the stereo demodulator 9 with the increase in the level of high-frequency components of frequencies of greater than 100 KHz in the outputs of the FM detector 1.

Furthermore, signals are transmitted from PLL circuit 3 through gain-controlled circuit 8 to stereo demodulator 9 in a D.C. coupling manner. Therefore, the PLL circuit 3, gain-controlled circuit 8 and stereo

demodulator 9 can be easily formed in a single semiconductor silicon chip of a monolithic semiconductor integrated circuit.

5 In modified forms the high-pass filter 6 may be a band-pass filter such as a mechanical filter, and signals from the amplifier 2 may be supplied to the high-pass filter 6.

Furthermore, the detector circuit 7, and the gain-controlled circuit 8 may be replaced by the circuits
10 which have similar functions.



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CLAIMS.

1. An FM receiver including; an FM detector; a stereo demodulator which receives a main-channel signal and a sub-channel signal of a stereo composite signal obtained from the output terminal of said FM detector,
5 as well as a sub-carrier signal; a gain-controlled circuit which transmits said sub-carrier signal to said stereo demodulator; a high-pass filter for obtaining high-frequency components in the output signal from said FM detector; and a level detector for detecting
10 the level of said high-frequency components which are obtained from said high-pass filter; wherein:-
 - (a) the output signal of said level detector is transmitted to said gain-controlled circuit;
 - (b) the amplitude level of said sub-carrier
15 signal applied by said gain-controlled circuit to said stereo demodulator is gradually lowered with the rise in the level of said high-frequency components that are obtained from said high-pass filter; and
 - (c) a cut-off frequency of said high-pass
20 filter is selected to such a value that said level detector is not substantially affected by the sub-channel signal of the stereo composite signal.



2. An FM receiver according to Claim 1, wherein said gain-controlled circuit includes a first transistor, a second transistor and a third transistor, the emitter electrode of said first transistor and the emitter electrode of said second transistor being commonly connected to the collector electrode of said third transistor, at least either the base electrode of said first transistor or the base electrode of said second transistor being driven by said sub-carrier signal, the base electrode of said third transistor being supplied with the output signal of said level detector, and said stereo demodulator being supplied with the sub-carrier signal which is produced on at least either the collector electrode of said first transistor or the collector electrode of said second transistor.

3. An FM receiver according to Claim 1 or 2, further including a phase-lock-loop circuit which is so constructed as to generate said sub-carrier signal which is substantially in synchronism with pilot signal of said stereo composite signal.

4. An FM receiver according to any one of the preceding claims, wherein the frequency of said sub-carrier signal is 38KHz.

5. An FM receiver according to Claims 3 and 4, wherein the frequency of said pilot signal is 19KHz.

An FM receiver constructed and arranged to operate substantially as herein described with reference to and as illustrated in the accompanying drawing.