

Description

Background of the Invention

This invention relates to an improvement in frequency modulated (FM) receivers and more specifically is directed to improving the audio sound quality by reducing the magnitude of audible pops that occur during input signal minimums caused by Rayleigh faded received signals. This invention is especially effective for FM systems which utilize peak deviations of less than 5.0 kilohertz (kHz).

In order to appreciate this invention the concept of a Rayleigh faded signal should be understood. Rayleigh fading refers to rapid fluctuations in the magnitude and/or phase of the received signal. A Rayleigh faded signal is most objectionable to a listener when the magnitude of a fade is large enough to cause a substantial momentary decrease in the signal-to-noise ratio. This results in the listener hearing an objectionable noise burst or "pop". A common example of Rayleigh fading occurs when a mobile radio user travels down a highway while receiving a signal having rapid and substantial magnitude fluctuations in field strength. Such fluctuations may be caused by the vehicle passing relatively nearby objects such as telephone poles or buildings which result in field strength variations at the vehicle's mobile antenna.

The undesired audio responses due to Rayleigh fading become more objectionable as the peak transmitted deviation decreases and the carrier frequency increases. Deviation is a factor in determining the signal-to-noise ratio. In order to achieve a given level of audio output, more audio gain will be required in a system having smaller peak deviation. Because this greater gain also amplifies the undesired noise burst, the pop is louder relative to the desired audio in a system having smaller deviation and hence is rendered more objectionable. Since wavelength decreases as frequency increases, a larger number of signal strength nulls exist to be encountered by a mobile radio operating at higher frequencies. Thus, more frequent audio pops are likely at higher frequencies.

Since the available frequency spectrum is limited and there continues to be an increasing demand for wireless communication channels, it is apparent that better utilization of the current available communication channels is desired. One way to increase the available channels is to divide the current channel bandwidths and provide more narrowband channels. For example, if an existing 25 kHz channel is divided in half, two 12.5 kHz channels could exist. Obviously, narrower channels require that transmitted signals occupy less bandwidth. Decreasing the peak deviation from 5kHz to

2.5 kHz in an FM system is one way to reduce the bandwidth of the transmitted signal in order to create more communication channels. New communication channels are becoming available at higher frequencies. Thus, the likelihood of having smaller deviation systems which operate at higher frequencies makes the audio pop problem associated with Rayleigh fades a significant problem.

In the field of single sideband receivers, US-A-4466129, describes an impulse noise reduction circuit.

Summary of the Invention

It is an object of this invention to minimize the noise burst problems associated with a Rayleigh faded signal in an FM receiver.

According to the invention, there is provided a method for improving the audio response of an FM receiver as claimed in claim 1 and an FM receiver as claimed in claim 7.

This invention is especially, but not exclusively, suited for minimizing noise pops due to Rayleigh fading in an FM system utilizing a peak deviation of less than 5 kHz.

The present invention, at least in its preferred embodiment, minimizes Rayleigh generated noise pops by using a controllable attenuator in series with the audio output, i.e. between the discriminator and speaker. The amount of attenuation may be controlled by a control signal which corresponds to the magnitude of the received signal for signal levels which are below a given clipping level and may be a constant when the received signal magnitude is above the given clipping level. Significant Rayleigh fades will cause the control signal amplitude to decrease below the clipping level. This causes the amount of attenuation to increase as the amplitude of the received signal decreases below the clipping level. The increased attenuation results in lower audio output and thus mutes the magnitude of the pop generated during the fade. A suitable choice for the clipping level has been found to be 5-20dB below the average magnitude of the received signal.

Preferably the control signal includes another component signal which is utilized only during received signal conditions where low signal-to-noise ratios exist. This component signal is derived by peak detecting only the high frequency signal components of either the amplified IF signal or of the discriminator output signal which correspond to noise so that the peak detection does not respond to desired audio frequencies. Since the magnitude of such high frequencies are low except at threshold signal conditions, the additional component to the control signal does not normally contribute except at such threshold conditions where it aug-

ments the control signal so as to provide additional muting by the attenuator. It has been found that this additional muting contributes to the intelligibility of marginal signals at threshold conditions by reducing the prominent noise content.

Brief Description of the Drawings

The same reference numbers used in different figures of the drawings denote like elements.

Figure 1 is a block diagram illustrating an improved FM receiver according to the present invention.

Figure 2 is a block diagram of an alternative embodiment of an improved receiver according to the present invention.

Figure 3 is a graph illustrating the average tone-to-noise ratio relative to carrier level for an FM receiver employing the concepts of the present invention and for a conventional FM receiver.

Figure 4 is a graph which illustrates the output of the clipper versus signal magnitude of the embodiment of Figure 1.

Figure 5 is a graph illustrating the amount of attenuation provided in response to the signal magnitude embodiment of Figures 1 and 2.

Figure 6 is a graph illustrating the output of the clipper versus signal magnitude of the embodiment shown in Figure 2.

Figure 7 is a block diagram of another embodiment of the present invention which utilizes a received signal strength indicator (RSSI) signal.

Figure 8 is a graph which illustrates waveforms associated with the embodiment shown in Figure 7.

Figure 9 is a schematic diagram illustrating selective portions of the invention as shown in Figure 7.

Figure 10 illustrates a log-to-linear converter which is used in a modified embodiment of the invention as shown in Figure 7.

Figure 11 is a block diagram of an FM transmitter in which companding is used.

Figure 12 illustrates an FM receiver for receiving a companded signal.

Figure 13 is a partial block diagram of an FM receiver for receiving a companded signal which incorporates noise reduction in accordance with the present invention.

Detailed Description

Figure 1 illustrates an improved FM receiver in accordance with the present invention. Antenna 10 couples signals to bandpass filter 12 which couples the filtered signals to mixer 14. The output of local oscillator 16 provides the other input to mixer 14 which has its output coupled via bandpass filter 18 to IF amplifier 20. The gain of amplifier 20 is

controlled by means of an input 22. The output of amplifier 20 is coupled through bandpass filter 24 to amplifier 25 which further amplifies and limits the signal before it is coupled to discriminator 26.

The unprocessed baseband audio output 28 from the discriminator can be used to provide a squelch signal to a conventional squelch circuit or an output to a digital signal demodulator, and also provides an input to attenuator 30. The output of the attenuator provides a voice output which can be coupled to a speaker 32. It will be apparent to those skilled in the art that the output of the attenuator can also be amplified by an audio amplifier (not shown) rather than directly driving speaker 32.

The output of bandpass filter 24 is also coupled to an amplifier 34 which preferably has its gain controlled means of an input 36. The output of amplifier 34 is coupled to a linear envelope detector 38 which detects the peak magnitude of its input signal. The output 40 of the detector is coupled to a lowpass filter 42 which has its output coupled to amplifiers 44 and 46. These amplifiers function as comparators and provide outputs when the input from lowpass filter 42 exceeds VR1 and VR2, respectively. The output from amplifier 46 serves as the input 36 to control the gain of amplifier 34. The output of amplifier 44 provides the input 22 to control the gain of amplifier 20.

The output 40 from envelope detector 38 is also coupled to a clipper 48 which has a selected voltage level at which clipping begins so that its output, which is coupled to summation network 50, is limited to a predetermined value even if the input continues to increase. The output 40 is also coupled to a highpass filter 52 which highpass filters the signal and couples same to amplifier 54 which amplifies the signal and provides an input to envelope detector 56. The detector detects the peak envelope of the magnitude of the signal from amplifier 54. The detector's output is smoothed by a lowpass filter 58 which may consist of a RC time constant circuit which has its output coupled as an input to summation network 50. The output of summation network 50 provides an input to attenuator stage 60 which attenuates the magnitude of the audio signal in response to the control signal provided from the network 50. The output of stage 60 is coupled to the input of attenuator stage 62 which also has its attenuation controlled in response to an input provided from clipper 48. The output of stage 62 consists of the audio output.

It will be apparent to those having skill in the art that elements 10-28 are a standard FM receiver circuits with the exception that the IF gain associated with amplifier 20 is controlled by an automatic gain control (AGC) circuit. The AGC circuitry consists of elements 34, 38, 42, 44, 46 and 20. The

purpose of the AGC circuitry is to control the gain of amplifiers 34 and 20 by means of the output of amplifiers 46 and 44 to keep amplifiers 34 and 20 operating in a linear region for all magnitudes of input signals.

Figure 4 illustrates the transfer characteristic of clipper 48 by the solid line 66. The response curve 66 has a so-called "knee" 68 so that the clipper output is a constant level for input signal levels greater than that corresponding to the knee.

The clipping action provided by clipper 48 is important to the present invention. the point indicated by numeral 70 in Figure 4 represents the operational point of the clipper for a preferred predetermined limiting level such as at 15 dB. The time constant associated with lowpass filter 42 is such that the AGC control signals 22 and 36 do not respond rapidly enough to follow a typical Rayleigh fade. The purpose of the AGC is to follow the average input signal magnitude and thereby control the gain for slowly changing signal conditions which are much longer in duration than Rayleigh fades. Thus, a time constant associated with filter 42 could be on the order of one second for UHF radio systems where Rayleigh fades have time durations on the order of a few milliseconds. The significance of the operational point 70 as shown in Figure 4 is that a Rayleigh fade of significant magnitude will cause the clipper output to fall below the knee 68 for part of the duration of the fade and hence increase the attenuation by attenuator 30 during this time.

Figure 5 illustrates the attenuation provided by attenuator 30 as a function of the output of clipper 48. Each attenuation stage may consist of an operation transconductance amplifier such as a CA3280E. The curve 72 illustrates that the attenuation characteristic exhibits a knee 74 which corresponds to knee 68. For clipper inputs greater than the level at the knee 74, the attenuation is a constant. At clipper outputs below knee 74 the attenuation is inversely proportional to the square of the clipper output, that is, attenuation increases at a greater than linear rate as the clipper output decreases. This characteristic is due to the two cascaded attenuator stages 60 and 62 each having its attenuation controlled in response to the clipper output. The operational point 70 in Figure 4 corresponds to operational point 76 in Figure 5. Thus, during a fade as the operational point moves below knee 68 on curve 66 and to the left of knee 74 on curve 72, it will be apparent that increasing attenuation is provided which mutes or reduces the audio gain thereby minimizing noise bursts or pops corresponding to the Rayleigh fade.

If attenuator 30 had only a single attenuator stage, the attenuation characteristic to the left of knee 74 would be linear. While such a single stage

attenuator would provide an audio reduction during Rayleigh fading, attenuation increasing at a greater than a linear rate provides a greater rate of muting. It will be apparent to those skilled in the art that more than two attenuation stages or attenuators having a controllable transfer characteristic could be utilized to provide an even greater rate of attenuation below a given knee. However, it will be appreciated that a complete or total muting of the audio during the fade may be perceived by the listener to be as objectionable as a noise burst. Therefore, an empirical determination of the best rate of attenuation can be selected based upon a subjective evaluation of the audio output.

In narrow deviation FM systems, i.e., below 5 kHz peak deviation, it is desirable at threshold or low signal-to-noise conditions to provide additional muting. Elements 52-58 provide an implementation to accomplish this function. Highpass filter 52 passes the high frequency or noise content above the audio range which is amplified by amplifier 54 before being peak detected by detector 56. It will be noted that the amount and presence of the higher frequency noise increases rapidly near threshold conditions. Time constant 58 is preferably selected to be on the order of a few milliseconds so that rapid fluctuations with respect to the noise content can be followed. Attenuation is provided by means of attenuation stage 60. This type of attenuation functions for very low level received signals such as approximately 12 dB SINAD or below because moderate and strong signal levels have little high frequency noise content. This enhances the ability of a listener to attempt to understand low level signals by providing audio attenuation which tracks rapidly changing noise levels as opposed to an average signal level.

Figure 3 is a graph which visually illustrates an improved audio response achieved by the present invention in response to Rayleigh faded received signals. The graph shows the average tone-to-noise ratio versus relative carrier level for a conventional full limiting FM receiver by curve 78 and for an FM receiver embodying the concepts of the present invention by curve 80. The knee of curve 78 occurs at an average tone-to-noise ratio of approximately 20 and at a relative carrier level of approximately 22 dB. The knee of curve 80 occurs at slightly above an average tone-to-noise ratio of 36 and at a relative carrier level of approximately 35 dB. For relative carrier levels of approximately 15 dB and less, a receiver according to the present invention has an tone-to-noise ratio of approximately 8 better than the conventional receiver. At a relative carrier level of 40 dB and above, a receiver according to the present invention has an average tone-to-noise ratio of approximately 16 dB greater than that of a conventional radio.

The curves in Figure 3 represent a 2.5 kHz peak deviation receiver measured at 1.5 kHz peak deviation with a 1 kHz audio tone modulation. Simulated Rayleigh fading having a maximum Doppler frequency of approximately 54 Hz was utilized to simulate the fading which might be encountered by a vehicle travelling at approximately 40 miles per hour while receiving a signal at 900 MHz.

The curves presented in Figure 3 are intended to merely provide a visual representation of the improved audio response achieved by utilization of the present invention. While Figure 3 does illustrate the benefits of the present invention, it is difficult to fully represent the subjective improvement in audio quality and listening comfort achieved by the present invention by purely visual means.

Figure 2 illustrates an FM receiver in which the concept of the present invention is implemented by a different embodiment. It should be noted that many of the same elements referenced in Figure 1 are also present in the diagram shown in Figure 2.

The embodiment in Figure 2 illustrates that additional circuitry 82 could be added to a conventional FM receiver to achieve the improved results of the present invention. A single attenuation stage 84 is utilized instead of the two stages 60 and 62 as shown in Figure 1. A square law detector 86 is utilized instead of the linear detector 38. Detector 86 has a square law transfer characteristic instead of a linear transfer function. For example, a properly biased diode could be utilized as the detector 86. The general purpose of the detector 86 is similar to that of detector 38, that is, it follows the peak magnitude envelope of the amplified input signal except that it has a square law transfer function.

Figure 6 illustrates the output of clipper 48 as embodied in circuitry 82 versus the signal magnitude. It should be noted that below the knee 88 on curve 90 the response is a square law response representing the output of detector 86. Above the clipper input voltage corresponding to knee 88, the clipper output is a constant. Point 92 as shown on curve 90 represents operation at a preferred clipping level such as 15 dB of clipping. During a Rayleigh fade in which the received signal magnitude momentarily becomes less than the level of clipping, the clipper's output will decrease. The attenuator stage 84 responds to this change in level by increasing the attenuation thereby decreasing the audio gain during the Rayleigh fade to minimize the objectionable noise burst. For moderate and strong signal level conditions, the receiver shown in Figure 2 will perform substantially equivalent to the receiver as shown in Figure 1. In this embodiment detector 86 provides the square law characteristic instead of the two cascaded attenuation stages 60 and 62 of the embodiment

shown in Figure 1. Although the receiver in Figure 2 does not show additional audio muting due to low level received signals near threshold, it will be apparent that elements 50, 52, 54, 56 and 58 could also be utilized with the embodiment as shown in Figure 2.

Lowpass filter 42 and amplifiers 46 and 44 derive AGC signals that are coupled to inputs 36 and 22 of amplifiers 34 and 20 to maintain the amplifiers in a linear region for various average input signal levels. The time constant associated with this AGC action is substantially longer than the duration of a Rayleigh fade, such as approximately one second.

Figure 7 illustrates another embodiment of the present invention utilized with a conventional FM receiver. Discriminator 26, attenuator 30 and speaker 32 operate in the same manner as previously described with respect to the embodiment shown in Figure 1.

A received signal strength indicator (RSSI) signal is provided at terminal 100 and is coupled through capacitor 102 to a variable threshold clipper 104. The generation of RSSI signals is well known. For example, FM receivers used in cellular telephone mobile radios generate an RSSI signal. The RSSI signal is preferably proportional to the mathematical log of the magnitude of the received signal in order to compress large signal level variations into a smaller range of RSSI signals.

A DC bias voltage VR3 is summed with the AC coupled RSSI signal through resistor 106. The magnitude of voltage VR3 sets the threshold level at which clipper 104 begins to clip. The RC time constant of resistor 106 and capacitor 102 is selected so that only the relatively rapid Rayleigh fades reflected in the RSSI signal are coupled to clipper 104. The functioning of clipper 104 will be further described below.

A circuit 108 receives a source of signal noise at terminal 110 and provides an output signal voltage V_N which is proportional to the amplitude of noise being received. The unprocessed audio output 28 from discriminator 26 may be used as the noise source. The circuit 108 includes a highpass filter 112, an envelope detector 114, a lowpass filter 118, and an amplifier 116. The envelope detector and amplifier are biased by a reference voltage VR4. The highpass filter 112 filters out audio frequencies and passes higher frequencies. These higher frequency signals are envelope or amplitude detected by detector 114 whose output is lowpass filtered by filter 118 and amplified by 116. The voltage VR4 provides a reference which corresponds to the magnitude at which noise signals will be detected and amplified by detector 114 and amplifier 116. An output V_N of circuit 108 is provided only during low signal to noise conditions.

The purpose of output V_N is to provide additional attenuation of the audio output during weak signal levels. This action results in a more pleasing audio output as the audio message grows weaker relative to the noise level.

Figure 8 is a composite graph showing three waveforms: reference DC level VR3, waveform 120 which corresponds to the magnitude of the received signal as determined by the RSSI, and waveform V_C (shown in solid line) from clipper 104 which controls the amount of attenuation to be provided by attenuator 30. It should be understood that waveform V_C is superimposed over portions of waveform 120. The portions of waveform 120 which coincide with signal V_C illustrate Rayleigh fading nulls which have a magnitude sufficient to cause attenuation to be provided by attenuator 30. Bias voltage VR3 is preferably selected so that Rayleigh fades having a level 5-20 dB below the average magnitude of the received signal will cause attenuation of the audio output. The magnitude at which attenuation is provided is illustrated graphically in Figure 8. The portion of waveform 120 above waveform V_C represents signal levels above the attenuation threshold; the threshold corresponds to the straight horizontal line portion of waveform V_C .

The schematic diagram in Figure 9 illustrates a particular embodiment of circuit 108 and clipper 104. Amplifiers 122 and 124 and the associated capacitors and resistors comprise highpass filter 112. Amplifier 126 and diode 128 comprise envelope detector 114; resistor 130 and capacitor 132 comprise lowpass filter 118.

The variable clipper circuit 104 comprises an amplifier 134 whose output is clipped by diode 136. The control signal V_N is summed through resistor 138 with the output V_C to provide additional attenuation during low signal level conditions.

A conventional FM receiver can incorporate the embodiment of the present invention as illustrated in Figures 7-9 without modification of the other receiver circuitry. For example, there is no requirement for automatic gain control of intermediate frequency amplifiers. Thus, this embodiment of the present invention can be easily added to existing FM receivers.

It is preferred that attenuator 30 in the embodiment illustrated in Figure 7 provide the same attenuation characteristics as previously described. That is, the attenuation provided when the received signal falls below the predetermined threshold is preferably greater than one dB of attenuation for one dB in reduced signal strength; a two dB increase in attenuation for one dB loss in signal strength has proved satisfactory. With the two attenuator stages 60 and 62 in series, a signal V_C corresponding to a linear change of received signal strength would provide the 2:1 attenuation change

assuming each attenuation stage contributes one dB of attenuation. However, if the RSSI signal corresponds to a logarithmic variation of the received signal strength, the rate at which the attenuation will change varies with the signal strength. An attenuation change of approximately 2:1 can be achieved despite the logarithmic response of the RSSI by making an appropriate choice of the bias voltage VR3.

Figure 10 illustrates a log-to-linear converter 140 which can be utilized with the embodiment of the present invention as shown in Figure 7 by connecting the output of the clipper 104 to its input and connecting its output to attenuator 30. By providing a logarithmic to linear conversion of signal V_C and by operating the clipper 104 and attenuator 30 in a linear region, a logarithmic RSSI signal is compensated for by the converter 140 such that the control signal to attenuator 30 is substantially linear with respect to received signal strength. Thus, an attenuation versus received signal strength variation of 2:1 (during fades below the predetermined threshold) can be precisely achieved. It will also be apparent to those skilled in the art that other ratios of attenuation versus received signal strength can be achieved by varying the control signal applied to attenuator 30. Alternatively, additional series attenuator stages in addition to attenuator 60 and 62 could be utilized to achieve different ratios.

Figures 11 and 12 illustrate a typical transmitter and receiver, respectively, in which "syllabic companding" is utilized to improve the effective signal-to-noise ratio. In a communications system using syllabic companding, the amplitude of the voice input signal is compressed by a compressor 142 in the transmitter and the receiver utilizes an expander 144 to expand the received audio amplitude back to its original characteristics. Much of the improvement due to companding in FM communication systems is due to the expansion provided at the receiver. The expander gain increases during audio envelope maxima and decreases during audio envelope minima. This produces an improvement in the average signal-to-noise ratio of a signal which has a fluctuating amplitude, such as speech, assuming that the amplitude of a noise signal is below the amplitude of the desired received signal. During a Rayleigh fade which produces a noise burst with an amplitude greater than the desired signal, the expander in the receiver tends to track the increasing noise amplitude and increases the gain of the noise signal. Thus, such fading will "talk up" the expander in the same manner as a voice signal so as to produce an undesired audio output. This problem is especially apparent when trying to receive a signal having a relatively low signal strength. During such con-

ditions, a Rayleigh fade produces a noise signal output from the FM receiver which has a greater amplitude than the desired signal. This noise signal causes the expander to increase gain, thereby amplifying the noise burst and producing an audio output which sounds worse than a system without companding.

The partial block diagram of the receiver shown in Figure 13 illustrates that the prior embodiments of the present invention represented by noise reduction block 146 can be inserted between a conventional discriminator 26 and circuitry 148 which is part of the conventional circuitry utilized in a companding system. It was not readily apparent that the combination of noise reduction circuitry 146 in an FM receiver which utilizes an expander 144 would provide an improved result. Although the noise reduction circuitry 146 will reduce the noise output of the conventional receiver by reducing the magnitude of the noise pops, it was thought that its use with an expander might produce an undesirable system in which the expander would follow the reduced magnitude level produced by the noise reduction circuits during fading and introduce undesirable amplitude fluctuations in the received signal.

Actual testing of the noise reduction circuitry 146 in a companding receiver showed that the overall receiver system did not respond undesirably according to the above prediction. The time duration during which audio attenuation is provided by the noise reduction circuitry for Rayleigh fades is shorter than the normal time constant associated with the expander 144. For example, a typical time constant of approximately 20 milliseconds associated with an expander is substantially longer than the typical time intervals of audio muting provided in response to the noise reduction circuitry 146 of the present invention. Thus, the expander does not follow the brief audio level reductions caused by the noise reduction circuit 146 and hence the expander does not introduce undesirable amplitude fluctuations in the received signal.

Incorporation of the noise reduction circuitry 146 according to the present invention in a narrow deviation FM system which utilizes companding provides a significant improvement in the quality of received audio signals at all signal levels. The improvement provided by this combination is most apparent at relatively low signal levels where there is a tendency of conventional FM companding receivers to be talked up in response to noise bursts which occur during Rayleigh fades.

Although embodiments of the invention have been described and shown in the drawings, the scope of the present invention is defined in the appended claims.

Claims

1. A method for improving the audio response of an FM receiver for Rayleigh faded received signals comprising the steps of:
 - amplifying (20,25) the received signal;
 - limiting (25) the amplified received signal;
 - converting (26) the limited FM signal into an audio signal; and
 - attenuating (30) the audio signal so that a substantially constant amount of attenuation is provided for received signals greater than a predetermined level below an average signal corresponding to the average magnitude of the received signal and so that increasing attenuation is provided as the magnitude of the received signal decreases below said predetermined level.
2. The method according to claim 1 wherein said predetermined level is within the range of 5-20 dB.
3. The method according to claim 2 wherein said predetermined level is within the range of 10-15 dB.
4. The method according to claim 1 further comprising the steps of generating a control signal (40, 100) corresponding to the magnitude of the received signal, producing an average signal which corresponds to the average magnitude of the received signal, clipping (48, 104) said control signal so that the control signal is substantially a constant for received signals greater than a predetermined level below said average signal and so that the control signal decreases below said predetermined level as the received signal decreases, and attenuating (30) said audio signal in an inverse relationship to said clipped control signal.
5. The method according to claim 1 further comprising the step of providing additional attenuation in response to the high frequency components above the audio frequencies associated with said received signal, whereby additional attenuation is provided when the received signal is near the noise threshold of the receiver.
6. The method according to claim 1 wherein the Rayleigh faded received signals are companded, and further characterized by the step of expanding said attenuated audio signals to yield an audio output signal.
7. An FM receiver having an improved audio re-

ditions, a Rayleigh fade produces a noise signal output from the FM receiver which has a greater amplitude than the desired signal. This noise signal causes the expander to increase gain, thereby amplifying the noise burst and producing an audio output which sounds worse than a system without companding.

The partial block diagram of the receiver shown in Figure 13 illustrates that the prior embodiments of the present invention represented by noise reduction block 146 can be inserted between a conventional discriminator 26 and circuitry 148 which is part of the conventional circuitry utilized in a companding system. It was not readily apparent that the combination of noise reduction circuitry 146 in an FM receiver which utilizes an expander 144 would provide an improved result. Although the noise reduction circuitry 146 will reduce the noise output of the conventional receiver by reducing the magnitude of the noise pops, it was thought that its use with an expander might produce an undesirable system in which the expander would follow the reduced magnitude level produced by the noise reduction circuits during fading and introduce undesirable amplitude fluctuations in the received signal.

Actual testing of the noise reduction circuitry 146 in a companding receiver showed that the overall receiver system did not respond undesirably according to the above prediction. The time duration during which audio attenuation is provided by the noise reduction circuitry for Rayleigh fades is shorter than the normal time constant associated with the expander 144. For example, a typical time constant of approximately 20 milliseconds associated with an expander is substantially longer than the typical time intervals of audio muting provided in response to the noise reduction circuitry 146 of the present invention. Thus, the expander does not follow the brief audio level reductions caused by the noise reduction circuit 146 and hence the expander does not introduce undesirable amplitude fluctuations in the received signal.

Incorporation of the noise reduction circuitry 146 according to the present invention in a narrow deviation FM system which utilizes companding provides a significant improvement in the quality of received audio signals at all signal levels. The improvement provided by this combination is most apparent at relatively low signal levels where there is a tendency of conventional FM companding receivers to be talked up in response to noise bursts which occur during Rayleigh fades.

Although embodiments of the invention have been described and shown in the drawings, the scope of the present invention is defined in the appended claims.

Claims

1. A method for improving the audio response of an FM receiver for Rayleigh faded received signals comprising the steps of:
 - amplifying (20,25) the received signal;
 - limiting (25) the amplified received signal;
 - converting (26) the limited FM signal into an audio signal; and
 - attenuating (30) the audio signal so that a substantially constant amount of attenuation is provided for received signals greater than a predetermined level below an average signal corresponding to the average magnitude of the received signal and so that increasing attenuation is provided as the magnitude of the received signal decreases below said predetermined level.
2. The method according to claim 1 wherein said predetermined level is within the range of 5-20 dB.
3. The method according to claim 2 wherein said predetermined level is within the range of 10-15 dB.
4. The method according to claim 1 further comprising the steps of generating a control signal (40, 100) corresponding to the magnitude of the received signal, producing an average signal which corresponds to the average magnitude of the received signal, clipping (48, 104) said control signal so that the control signal is substantially a constant for received signals greater than a predetermined level below said average signal and so that the control signal decreases below said predetermined level as the received signal decreases, and attenuating (30) said audio signal in an inverse relationship to said clipped control signal.
5. The method according to claim 1 further comprising the step of providing additional attenuation in response to the high frequency components above the audio frequencies associated with said received signal, whereby additional attenuation is provided when the received signal is near the noise threshold of the receiver.
6. The method according to claim 1 wherein the Rayleigh faded received signals are companded, and further characterized by the step of expanding said attenuated audio signals to yield an audio output signal.
7. An FM receiver having an improved audio re-



sponse to Rayleigh faded received FM signals comprising:

means (26) for converting said received FM signals into amplitude varying audio signals;

means for generating a first signal (40,100) which is proportional to the strength of said received FM signals;

means (30) for attenuating said audio signals in response to a second signal; and

means (48,104) for generating said second signal in response to said first signal so that said audio signals are attenuated during a Rayleigh fade when said first signal decreases below a predetermined threshold, said predetermined threshold set relative to the average value of said first signal, whereby improved audio is provided in response to Rayleigh fading of the received signal regardless of the strength of the received signal.

8. The receiver according to claim 7 wherein said predetermined threshold is within the range of 5-20 dB below the average value of said first signal.

9. The receiver according to claim 7 wherein said second signal generating means (48,104) generates a second signal during a Rayleigh fade which causes said attenuating means to increase audio signal attenuation at a ratio of X/Y greater than 1, where Y is the change in the amplitude of the received signal and X is the corresponding change in attenuation, whereby the amount of attenuation increases at a greater rate than the decrease in amplitude of the received signal during a Rayleigh fade.

10. The receiver according to claim 7 wherein said second signal generating means comprises means for detecting the average noise present in the received signal, said second signal changing in response to said detected noise exceeding a predetermined level to cause said attenuating means to attenuate to the audio signals.

Revendications

1. Un procédé pour améliorer la réponse audio d'un récepteur à modulation de fréquence pour des signaux reçus affectés par l'évanouissement de Rayleigh, comprenant les étapes suivantes :

on amplifie (20, 25) le signal reçu;

on limite (25) le signal reçu amplifié;

on convertit (26) le signal à modulation de fréquence limité en un signal audio; et

on atténue (30) le signal audio, de façon à introduire une valeur d'atténuation pratiquement constante pour des signaux reçus supérieurs à un niveau prédéterminé au-dessous d'un signal moyen correspondant à l'amplitude moyenne du signal reçu, et de façon à introduire une atténuation croissante lorsque l'amplitude du signal reçu diminue au-dessous du niveau prédéterminé.

2. Le procédé selon la revendication 1, dans lequel le niveau prédéterminé est compris dans la plage de 5 à 20 dB.

3. Le procédé selon la revendication 2, dans lequel le niveau prédéterminé est compris dans la plage de 10 à 15 dB.

4. Le procédé selon la revendication 1 comprenant en outre les étapes suivantes : on génère un signal de commande (40, 100) correspondant à l'amplitude du signal reçu, on produit un signal moyen qui correspond à l'amplitude moyenne du signal reçu, on écrête (48, 104) le signal de commande de façon que le signal de commande soit pratiquement constant pour des signaux reçus supérieurs à un niveau prédéterminé au-dessous du signal moyen, et de façon que le signal de commande diminue au-dessous du niveau prédéterminé lorsque le signal reçu diminue, et on atténue (30) le signal audio en relation inverse du niveau du signal de commande écrêté.

5. Le procédé selon la revendication 1, comprenant en outre l'étape qui consiste à introduire une atténuation supplémentaire sous la dépendance des composantes de fréquence élevée, situées au-dessus des fréquences audio associées au signal reçu, grâce à quoi une atténuation supplémentaire est introduite lorsque le signal reçu est proche du seuil de bruit du récepteur.

6. Le procédé selon la revendication 1, dans lequel les signaux reçus affectés d'évanouissement de Rayleigh sont soumis à une compression-expansion, et caractérisé en outre par l'étape qui consiste à effectuer une expansion des signaux audio atténués pour donner un signal de sortie audio.

7. Un récepteur à modulation de fréquence ayant une réponse audio améliorée pour des signaux à modulation de fréquence reçus affectés d'évanouissement de Rayleigh, comprenant :

des moyens (26) destinés à convertir les signaux à modulation de fréquence reçus en



signaux audio d'amplitude variable;

des moyens (40, 100) destinés à générer un premier signal qui est proportionnel au niveau des signaux à modulation de fréquence reçus;

des moyens (30) destinés à atténuer les signaux audio sous la dépendance d'un second signal; et

des moyens (48, 104) destinés à générer le second signal sous la dépendance du premier signal, de façon que les signaux audio soient atténués pendant un évanouissement de Rayleigh lorsque le premier signal diminue au-dessous d'un seuil prédéterminé, ce seuil prédéterminé étant fixé par rapport à la valeur moyenne du premier signal, grâce à quoi on obtient un signal audio amélioré en présence d'un évanouissement de Rayleigh du signal reçu, indépendamment du niveau du signal reçu.

8. Le récepteur selon la revendication 7, dans lequel le seuil prédéterminé est compris dans la plage de 5 à 20 dB au-dessous de la valeur moyenne du premier signal.

9. Le récepteur selon la revendication 7, dans lequel les moyens de génération du second signal (48, 104) génèrent, pendant un évanouissement de Rayleigh, un second signal sous l'effet duquel les moyens d'atténuation augmentent l'atténuation du signal audio dans un rapport de X/Y supérieur à 1, en désignant par Y le changement d'amplitude du signal reçu et par X le changement d'atténuation correspondant, grâce à quoi la valeur de l'atténuation augmente plus rapidement que l'amplitude du signal reçu ne diminue pendant un évanouissement de Rayleigh.

10. Le récepteur selon la revendication 7, dans lequel les moyens de génération du second signal comprennent des moyens qui sont destinés à détecter le bruit moyen présent dans le signal reçu, et le second signal change lorsque le bruit détecté dépasse un niveau prédéterminé, pour commander aux moyens d'atténuation d'atténuer les signaux audio.

Patentansprüche

1. Verfahren zum Verbessern der Hörsignale eines mit Frequenzmodulation arbeitenden Empfängers, wenn Signale mit Rayleigh-Schwund empfangen werden, bei dem die Schritte vorgenommen werden:

das empfangene Signal zu verstärken (20, 25),

das empfangene und verstärkte Signal zu begrenzen (25),

das begrenzte, frequenzmodulierte Signal in ein Hörsignal umzuwandeln (26), und

das Hörsignal zu dämpfen (30), so daß ein im wesentlichen konstantes Dämpfungsmaß für die empfangenen Signale vorgesehen wird, die größer als ein vorgegebenes Niveau unterhalb eines Durchschnittssignals sind, das der durchschnittlichen Größe des empfangenen Signals entspricht, und eine zunehmende Dämpfung erzielt wird, wenn die Größe des empfangenen Signals unter das vorherbestimmte Niveau abnimmt.

2. Verfahren gemäß Anspruch 1, bei dem das vorherbestimmte Niveau innerhalb des Bereiches von 5 bis 20 db liegt.

3. Verfahren gemäß Anspruch 2, bei dem das vorherbestimmte Niveau innerhalb des Bereiches von 10 bis 15 db liegt.

4. Verfahren gemäß Anspruch 1 ferner mit den folgenden Schritten, nämlich ein Steuersignal (40, 100) entsprechend der Größe des empfangenen Signals zu erzeugen, ein Durchschnittssignal hervorzubringen, das der durchschnittlichen Größe des empfangenen Signals entspricht, das Steuersignal zu beschneiden (48, 104), so daß es im wesentlichen eine Konstante für die empfangenen Signale ist, die unterhalb des Durchschnittssignals größer als ein vorherbestimmtes Niveau sind, so daß das Steuersignal bei einer Abnahme des empfangenen Signals unter das vorherbestimmte Niveau abfällt, und das Hörsignal umgekehrt zu dem beschnittenen Steuersignal zu dämpfen (30).

5. Verfahren gemäß Anspruch 1 ferner mit dem Schritt, eine zusätzliche Dämpfung in Abhängigkeit von hochfrequenten Komponenten vorzusehen, die oberhalb der Hörfrequenzen dem empfangenen Signal zugeordnet sind, wenn sich das empfangene Signal nahe bei dem Rauschschwellenwert des Empfängers befindet.

6. Verfahren gemäß Anspruch 1, bei dem die mit Rayleigh-Schwund empfangenen Signale verdichtet werden, dadurch gekennzeichnet, daß die gedämpften Hörsignale für ihre Ausgabe gedehnt werden.

7. Mit Frequenzmodulation arbeitender Empfänger mit einer verbesserten Hörreaktion auf mit Rayleigh-Schwund empfangene, frequenzmo-



dulierte Signale

mit einem Hilfsmittel (26) zur Umwandlung der empfangenen, frequenzmodulierten Signale in sich mit der Amplitude ändernde Hörsignale,

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mit Hilfsmitteln zur Erzeugung eines ersten Signals (40, 100), das zu der Stärke der empfangenen, frequenzmodulierten Signale proportional ist,

mit einer Vorrichtung (30) zur Dämpfung der Hörsignale in Abhängigkeit von einem zweiten Signal und

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mit Hilfsmitteln (48, 104) zur Erzeugung des zweiten Signals in Abhängigkeit von dem ersten Signal, so daß die Hörsignale während des Rayleigh-Schwundes gedämpft sind, wenn das erste Signal unter einen vorherbestimmten Schwellenwert abnimmt, der in bezug auf den Durchschnittswert des ersten Signals festgesetzt ist, wobei ein verbessertes Hörsignal bei einem Rayleigh-Schwund des empfangenen Signals unabhängig von der Stärke des empfangenen Signals vorgesehen ist.

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8. Empfänger gemäß Anspruch 7, bei dem der vorherbestimmte Schwellenwert innerhalb des Bereiches von 5 bis 20 db unter dem Durchschnittswert des ersten Signals liegt.

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9. Empfänger gemäß Anspruch 7, bei dem die das zweite Signal erzeugenden Hilfsmittel (48, 104) ein zweites Signal während eines Rayleigh-Schwundes erzeugen, wodurch die dämpfende Vorrichtung die Dämpfung des Hörsignals in einem Verhältnis von X/Y größer als 1 vergrößert, wobei Y die Amplituden-Änderung des empfangenen Signals und X die entsprechende Dämpfungsänderung darstellt und das Dämpfungsmaß schneller als die Amplitudenabnahme des empfangenen Signals während eines Rayleigh-Schwundes zunimmt.

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10. Empfänger gemäß Anspruch 7, bei dem die das zweite Signal erzeugenden Hilfsmittel einen Detektor für das in dem empfangenen Signal vorhandene Durchschnittsrauschen enthält, wobei das zweite Signal in Abhängigkeit von dem wahrgenommenen, ein vorherbestimmtes Niveau übersteigenden Rauschen verändert wird, um die Vorrichtung zur Dämpfung der Hörsignale zu veranlassen.

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