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DETECTING AND MEASURING INTERFERENCE CONTAINED WITHIN A DIGITAL CARRIER

[0001] This application claims the benefit of U.S. Provisional Application
Serial No. 60/361,493, filed March 4, 2002, the contents of which are hereby
5 incorporated by reference.

FIELD OF THE INVENTION

[0002] The invention relates to detection of interference and noise in a transmitted
signal.

DESCRIPTION OF THE RELATED ART

10 [0003] Interference (including noise) showing up in-band to a transmitted carrier is a
common problem in wireless communication systems. For example, in satellite
communication systems, interference can be caused by, but is not limited to, isolation
degradation of cross-polarized signals, adjacent satellite traffic, locally received
terrestrial signals, or an unauthorized transmission. In many cases, interference can be
15 very difficult to detect, however, its impact on the receive quality of the transmitted
digital carrier can be significant.

[0004] The most common approach to determining the presence of interference is to
temporarily remove the service (the transmitted carrier) and inspect the received power
spectrum with a frequency analysis device such as a spectrum analyzer. Although this
20 approach can be effective, it causes a service interruption that can last for many hours. In
some cases, interference is not the problem, and the service was interrupted
unnecessarily.

BRIEF SUMMARY OF THE INVENTION

[0005] The invention includes a method of and an apparatus for detecting and measuring noise and interference, which is in-band to a received communications carrier. To alleviate drawbacks to conventional approaches, the applicant has developed a non-intrusive interference detection and noise measurement approach. With this approach, interference and noise can be detected and measured without taking the carrier out of service. Rather, the measurements are made while the communications circuit (the transmitted carrier) is active.

[0006] In one aspect, in-band interference in a carrier signal in a communication system is detected. A signal is acquired including the carrier signal and an interfering signal. The interfering signal is extracted from the carrier without interrupting the carrier.

[0007] In another aspect, a signal is received, filtered, and digitized. Decimation is then performed and the signal resampled. Blind equalization and demodulation are performed thereby forming an error vector that is representative of the interference signal.

[0008] In yet another aspect, a receiver acquires a digital signal. A signal processor conditions the digital signal, and a blind equalizer demodulator forms an error vector that is representative of an interference signal included in the carrier signal.

[0009] These and other aspects are described in more detail herein.

BRIEF DESCRIPTION OF DRAWINGS

[0010] FIG. 1 illustrates a flow diagram showing the main processing associated with this invention;

[0011] FIG. 2 shows a detailed flow diagram of the processing associated with this invention; and

[0012] FIG. 3 illustrates a system in accordance with an embodiment of the present invention; and

[0013] FIG. 4 shows a graphical display that might be displayed to a user of this invention.

DETAILED DESCRIPTION OF INVENTION

[0014] FIG. 1 shows a flow diagram of a process 100 in accordance with an aspect of the present invention. A signal, which contains noise and interference, is received in a step 101. The signal is down-converted to an intermediate frequency (IF) and then digitized by a sampling device, in an acquisition step 102. The digital samples are stored in memory for further processing, also in the acquisition step 102. Using the stored samples, the signal is processed to create a re-sampled baseband version of the received signal, in a digital formatting step 103. Using this re-sampled baseband signal, an equalized error signal is created, in an interference processing step 104. This error signal is further processed to create a power spectrum of the underlying noise and interference contained in the received carrier, also in the interference processing step 104. This power spectrum of the noise and interference can be measured for interfering signals as well as displayed to the user, in an output step 105.

[0015] FIG. 2 is a more detailed flow diagram of a process 200 in accordance with an embodiment of the present invention. An input signal may be a radio frequency (RF) signal from an antenna. Alternatively the input signal may be any communication signal in any frequency band i.e. RF, IF, microwave or optical.

[0016] FIG. 3 illustrates a system 400 in accordance with an embodiment of the present invention. The system 400 detects and measures in-band interference and noise in an input signal 407 in accordance with the method of FIG. 2. An input signal 407 is received from a satellite 401 by a satellite dish 402. The input signal 407 may be transmitted by means other than the satellite 401, including but not limited to a radio transmitter, a cable transmitter, a cell tower, a microwave transmitter, or an optical transmitter. The input signal 407 may be received by means other than the satellite dish 402, including but not limited to an antenna, a microwave dish, or an optical receiver.

The present invention is applicable to any system that communicates a digital signal from a transmitter to a receiver, regardless of the medium or the carrier frequency.

[0017] Referring to FIGS. 2 and 3, a receiver 403 may convert the input signal 407 from an RF input signal 407 to an IF signal in a step 201. The IF signal may be at any
5 frequency that makes the following detection simpler, cheaper, or more accurate. The receiver 403 may further filter and adjust the level of a signal, which is representative of the input signal 407 in a step 202. The receiver 403 may filter the input signal 407 with a band-pass filter to limit the input signal 407 or its representative to the carrier and its modulation. An amplifier with automatic gain control may adjust the level of the filtered
10 input signal 407 or its representative, also in the step 202. The input signal 407 may be amplified to take full advantage of an A/D converter in the receiver 403. The A/D converter is expected to perform best when the full amplitude bandwidth is used.

[0018] The A/D converter, in the step 203, produces a digitized version of the filtered IF signal. The A/D converter may sample the IF signal at a frequency at least twice the
15 frequency of the highest frequency of interest in accordance with Nyquist's theorem, though another sampling frequency may be used. The digitized version of the IF signal is then stored as a snapshot 408 in a step 204. The above steps 201-204 may comprise the acquisition step 102 of FIG. 1.

[0019] A signal processor 404 may analyze the snapshot 408 to calculate parameters
20 representative of the input signal 407 including, a bandwidth of the input signal 407, a center frequency of the input signal 407, a symbol rate of the input signal 407, amplitudes of the carrier lines, frequencies of the carrier lines, and maximums of the carrier lines.

[0020] In a next step 205 of the process 200, a power spectrum of the snapshot 408 is calculated by the signal processor 404. Multiple power spectrums may be calculated and
25 averaged together, to create a spectral density periodogram. The power spectrum may be calculated using conventional Fast-Fourier Transform (FFT) methods, for converting the IF signal from time space to complex frequency space. Other methods beside FFT may be used to convert the IF signal to frequency space. The power spectrum or the spectral density periodogram may be displayed to user at this time.

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[0021] The input signal may be a modulated carrier. The center frequency and bandwidth (BW) of the carrier may be calculated by a signal processor 404 in a step 206 using the power spectrum or the spectral density periodogram of the IF signal from step 205. If the center frequency and the bandwidth are already known, however, then the steps 205 and 206 may be skipped.

[0022] Once the center frequency of the carrier is known, down-converting of snapshot 408 to the baseband of the carrier may be performed in step 207 by the signal processor 404. The snapshot 408 may be further filtered such that the signal is limited in bandwidth to that of the baseband signal, also in step 207. Further, the snapshot 408 may be decimated also in a step 207. Decimation may be performed at a frequency at least twice the frequency of the highest frequency of interest in accordance with Nyquist's theorem.

[0023] The carrier signal may have multiple carrier lines. In a step 208, information about the carrier such as symbol rate, and estimates of the amplitude and frequency of the carrier lines may be calculated. This information may be calculated by performing magnitude, square, cube and quad power transforms on the signal and recovering the maximums.

[0024] The estimates of the amplitude and frequency of the carrier lines may be used to determine the modulation of the digital carrier and the frequency in a step 209. By inspecting maximums of the carrier lines, the modulation of the carrier may be determined. Using information about the carrier frequency, any down-conversion error in the decimated signal may be removed in a step 210. For example if the baseband signal is offset, it may be recentered such that any offset in the carrier frequency is removed.

[0025] In a step 211, the carrier signal may be re-sampled by the signal processor 404, such as at a sample rate of two samples per symbol, and a resampled signal may be an output. This sample rate may be determined from the symbol rate calculated in the step 208. The above steps 205-211 may be performed in the digital formatting step 103 of FIG. 1.

[0026] A blind equalizer demodulator 405 may calculate an error vector that is representative of the interference signal in the input signal 407 in a step 212. This step produces an error vector that may be used to calculate the interference signal that is in the input signal 407. A digital communication system modulates a carrier wave for transmitting symbols to a receiver. In such a digital system, each symbol has discrete levels of amplitude and/or phase at which the carrier is modulated. A goal of the demodulator 405 is to determine the levels at which the carrier is modulated. It does this by making a first initial guess of the modulation levels and then calculating an error vector that represents the difference between the initial guess and the measured signal.

Then the guessed modulation levels are adjusted to minimize an error function based on the error vectors. The guessed modulation levels are continuously adjusted until the error function has been minimized, at which point the modulation has converged. There are many ways to adjust the levels, including decision directed least mean square (DD-LMS) and constant modulus algorithm (CMA), both of which are well known in the literature.

Conventionally the blind equalizer demodulator 405 is used to calculate the symbols in the input signal 407. Here, the output of interest is the error vector as opposed to the prior art where the output of interest is the symbols.

[0027] In a step 213, a first M samples are removed from the error vector to produce a new error vector. Depending on the quality of the initial first guess, the first M samples may have large error vectors that do not truly represent the noise and interference in the input signal 407. Before the blind equalizer demodulator 405 converges in the step 212, the first M samples of the error vector may contain errors. The DC bias of the new error vector is removed in a step 214, by subtracting the mean of the new error vector from the new error vector to produce an in-band vector that is representative of noise and interference in-band to the carrier. Any processing artifacts may also be removed in the step 214. The power spectrum of the in-band vector is calculated to convert the complex time representation of the in-band vector into a frequency domain representation, in a step 215. In a step 216 the spectral properties of the in-band vector are measured such as center frequency, BW, power, C/N and detected interference energy. The above steps 212-216 may comprise the interference processing step 104 of FIG. 1 performed by signal processor 405.

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[0028] A power spectrum of the error vector, such as a trace 302 in a FIG. 4, may be sent to a display 406 for presentation to a user in a step 105. A power spectrum of the input signal 407, such as trace 301 in FIG. 4, may also be sent to the display 406 also in step 105. Furthermore, the spectral properties of the error vector may be sent to the display 5 406. Other calculations regarding the digital signal may also be sent to the display 406.

[0029] The system described in FIG. 3 may also implement all the steps in the flowchart 200 of FIG. 2 and Table 1 as follows. The system may be implemented in hardware and/or software. The system may be implemented in a standard PC and/or may be implemented with custom electronics.

10 [0030] Table 1 presents the method of FIG. 2 in tabular format.

TABLE 1

Functional Block	Input	Description	Output
RF Down-conversion (201)	From Antenna	Convert RF signal to IF Frequency	IF representation of signal
Filtering and Gain Control (202)	IF Signal	Band-limit signal and adjust signal level for A/D Converter	Filtered and amplified signal
A/D Conversion (203)	Filtered IF Signal	Convert analog signal at IF to digital samples	Samples of IF signal
Snapshot Memory (204)	Samples of IF Signal	Store IF samples	Samples of IF signal
PSD Computation (205)	Samples of IF Signal	Convert time domain representation of signal to frequency domain representation.	Power spectrum
Spectral Detection and Measurement (206)	Power Spectrum	Detect and measure carrier of interest	Center frequency and BW of carrier to analyze
Down-convert and decimate (207)	Samples of IF signal, center frequency and BW estimation	Down-convert carrier to baseband, filter and decimate	Decimated signal (complex signal representation) and decimated sample rate
Carrier and Baud Recovery (208)	Decimated Signal	Perform magnitude, square, cube and quad power transforms on signal. Recover maximums	Symbol rate, estimates of amplitude and frequency of carrier lines
Modulation Identification (209)	Estimates of amplitude and frequencies of carrier lines	Determine Modulation of digital carrier by inspecting carrier line maximums	Modulation of digital carrier and Carrier frequency
Carrier Correction (210)	Decimated signal and Carrier frequency	Remove down-conversion error from decimated signal	Decimated signal

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Re-sampler (211)	Decimated signal, Decimated sample rate and symbol rate of carrier	Re-sample carrier to 2 samples/symbol	Re-sampled signal
Equalizer/Demodulator (212)	Resampled Signal	Equalize and demodulate signal using blind equalizer/demodulator approach	Estimated symbols and Error vector
Remove M Initial samples (213)	Error Vector	Remove first M samples from Error vector. First M samples contain errors from matched filter error	New Error Vector
DC bias removal (214)	New Error Vector	Remove mean from New Error Vector	In-band vector (represents noise and interference in-band to carrier)
PSD Computation (215)	In-band vector	Convert complex time domain in-band vector to a frequency domain representation	In-band spectrum
Spectral detection and measurement (216)	In-band Spectrum	Detect and measure any spectral energy	In-band spectral measurements (Center frequency, BW, power, and C/N of any detected interference energy)
Display (217)	In-band Spectrum and In-band spectral measurements	Display spectrum and measurement results to user	Done

[0031] FIG. 4 shows a graphical display 300 of data that the invention may present to a user. The trace 301 represents the power spectrum of the received carrier, and the trace 302 represents the power spectrum of the noise and interference, which are in-band to the received carrier. In this example, an interfering signal can be seen in the trace 302, which
5 is not visible in the received carrier trace 301.

[0032] Thus, a technique has been described for detecting and measuring interference within a digital carrier. The process can be completely blind, meaning that the process described above will work even when the digital carrier's RF and modulation parameters are unknown. The process described detects the RF carrier, measures its RF and
10 modulation parameters, equalizes and demodulates the digital carrier, extracts an error vector, converts this error vector into a complex baseband estimate of the noise and interference. From this estimate, a power spectrum of the in-band noise and interference is created. This power spectrum is analyzed for spectral energy. The in-band spectrum and measurement results are displayed for a user.

15 [0033] While the foregoing has been with reference to particular embodiments of the invention, it will be appreciated by those skilled in the art that changes in these embodiments may be made without departing from the principles and spirit of the invention, the scope of which is defined by the appended claims.

CLAIMS

1. A method of detecting in-band interference in a carrier signal in a communication system comprising the steps of:
 - acquiring a signal including the carrier signal and an interfering signal having a source that is independent from that of the carrier signal; and
 - extracting the interfering signal from the carrier without interrupting the carrier.
2. The method according to claim 1, being performed without knowledge of RF or modulation parameters of the carrier signal.
3. The method according to claim 1, being performed with knowledge of RF or modulation parameters of the carrier signal.
4. The method according to claim 1, further comprising extracting noise from the acquired signal.
5. The method according to claim 1, wherein the communication system performs as a wireless communication system.
6. The method according to claim 1, wherein the communication system performs as a satellite communication system.
7. The method according to claim 1, wherein the carrier comprises an RF signal.
8. A method of detecting in-band interference in a carrier signal in a communication system comprising the steps of:
 - acquiring a digital signal comprising the carrier signal and an in-band interference signal having a source that independent from that of the carrier signal,

said acquiring including receiving the signal, filtering the signal and digitizing the signal;

formatting the digital signal including filtering the digital signal, and performing decimation and re-sampling of the digitized signal; and

performing blind equalization and demodulation thereby forming an error vector that is representative of the in-band interference signal.

9. The method according to claim 8, wherein the step of formatting the digital signal is performed without knowledge of the carriers RF or modulation parameters.

10. The method according to claim 8, wherein the step of formatting the digital signal is performed with knowledge of the carriers RF or modulation parameters.

11. The method according to claim 8, further comprising extracting noise from the digital signal.

12. The method according to claim 8, wherein the communication system performs as a wireless communication system.

13. The method according to claim 8, wherein the communication system performs as a satellite communication system.

14. The method according to claim 8, wherein the carrier comprises an RF signal.

15. The method according to claim 8, wherein acquiring the digital signal includes converting the carrier signal into an IF signal, wherein the IF signal is representative of the carrier signal.

16. The method according to claim 8, wherein filtering the digital signal includes filtering the carrier signal to limit the bandwidth to a signal of interest.

17. The method according to claim 8, wherein acquiring a digital signal includes storing a digitized filtered signal into memory.
18. The method according to claim 8, wherein formatting the digital signal includes calculating a center frequency and a bandwidth of the carrier signal.
19. The method according to claim 8, wherein filtering the digital signal includes down-converting the digital signal to the baseband of the carrier signal.
20. The method according to claim 8, wherein the re-sampling of the digital signal occurs at twice the frequency of interest.
21. The method according to claim 8, including removing a M initial samples of the error vector, wherein the M initial samples occur while the blind equalization and demodulation is still converging.
22. The method according to claim 8, including removing a DC bias from the error vector.
23. A system of detecting in-band interference in a carrier signal in a communication system comprising:
 - a receiver for acquiring a digital signal, the digital signal including a carrier signal and an in-band interference signal having a source that independent from that of the carrier signal, a signal processor for conditioning the digital signal and a blind equalizer demodulator forming an error vector that is representative of the in-band interference signal included in the digital signal and wherein the signal processor is further configured to process the interference signal to obtain one or more spectral properties of the interference signal.

24. The system according to claim 23, wherein the signal processor is without knowledge of the carriers RF or modulation parameters.
25. The system according to claim 23, wherein the signal processor knows of the carriers RF or modulation parameters.
26. The system according to claim 23, wherein the digital signal further comprises noise.
27. The system according to claim 23, wherein the communication system performs as a wireless communication system.
28. The system according to claim 23, wherein the communication system performs as a satellite communication system.
29. The system according to claim 23, wherein the carrier comprises an RF signal.
30. The system according to claim 23, wherein the receiver is further configured to convert the carrier signal into an IF signal, wherein the IF signal is representative of the carrier signal.
31. The system according to claim 23, wherein the receiver is further configured to filter the carrier signal to limit the bandwidth to a signal of interest.
32. The system according to claim 23, wherein the receiver is further configured to store a digitized filtered signal in memory.
33. The system according to claim 23, wherein the signal processor is further configured to calculate a center frequency and a bandwidth of the carrier signal.

34. The system according to claim 23, wherein the signal processor is further configured to down-convert the digital signal to the baseband of the carrier signal.
35. The system according to claim 23, wherein the signal processor is further configured to decimate the digital signal at twice the symbol rate.
36. The system according to claim 23, wherein the signal processor is further configured to remove M initial samples of the error vector, wherein the M initial samples occur while the blind equalization and demodulation is still converging.
37. The system according to claim 23, wherein the signal processor is further configured to remove a DC bias from the error vector.
38. The system according to claim 23, wherein the signal processor is further configured to receive the signal, filter the signal and digitize the filtered signal.
39. The method according to claim 1, further comprising processing the interfering signal to obtain one or more spectral properties of the interfering signal.
40. The method according to claim 39, wherein the spectral properties are selected from a group consisting of a power spectrum of the interfering signal and a detected energy of the interfering signal.
41. The method according to claim 39, wherein the spectral properties are selected from a group consisting of a center frequency of the interfering signal and a bandwidth of the interfering signal.
42. The method according to claim 39, further comprising displaying the one or more spectral properties.

43. The method according to claim 8, further comprising processing the error vector to obtain one or more spectral properties of the interference signal.
44. The method according to claim 43, wherein the spectral properties are selected from a group consisting of a power spectrum of the interference signal and a detected energy of the interference signal.
45. The method according to claim 43, wherein the spectral properties are selected from a group consisting of a center frequency of the interference signal and a bandwidth of the interfering signal.
46. The method according to claim 43, further comprising displaying the one or more spectral properties.
47. The system according to claim 23, wherein the spectral properties are selected from a group consisting of a power spectrum of the interference signal and a detected energy of the interference signal.
48. The system according to claim 23, wherein the spectral properties are selected from a group consisting of a center frequency of the interference signal and a bandwidth of the interference signal.
49. The system according to claim 23, further comprising a display that displays the one or more spectral properties.