

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
11 June 2009 (11.06.2009)

PCT

(10) International Publication Number
WO 2009/073302 A1

(51) International Patent Classification:
H04B 7/24 (2006.01) **H04B 7/00** (2006.01)

(21) International Application Number:
PCT/US2008/082409

(22) International Filing Date:
5 November 2008 (05.11.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/946,734 28 November 2007 (28.11.2007) US

(71) Applicant (for all designated States except US): **MOTOROLA, INC.** [US/US]; 1303 E. Algonquin Road, Schaumburg, Illinois 60196 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **CORKE, Robert J.** [US/US]; 97 Brandon Avenue, Glen Allyn, Illinois 60137

(US). **PSYSBY, Daniel G.** [US/US]; 722 Jamestowne Road, Sleepy Hollow, Illinois 60118 (US).

(74) Agents: **DOUTRE, Barbara R.** et al.; 1303 East Algonquin RD, Schaumburg, Illinois 60196 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR COMPLEMENTARY CUMULATIVE DISTRIBUTION DRIVEN LEVEL CONVERGENCE FOR SPECTRUM SENSING

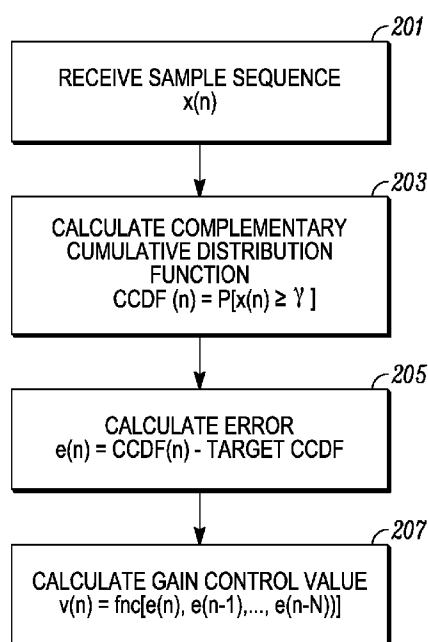


FIG. 2

(57) Abstract: A method for use in a digital communications receiver for controlling an input signal level (200) into an analog-to-digital converter (ADC) initially receives a sample sequence (201) where a threshold crossing rate is measured as a percentage samples of an input signal that exceed the threshold (203). The error between the measured threshold crossing rate and a desired reference threshold crossing rate is calculated (205) and an error signal is then utilized in a feedback loop to control the receiver gain such that the error is reduced (207).



FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL,
NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG,
CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— *before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments*

Published:

— *with international search report*

**METHOD AND APPARATUS FOR COMPLEMENTARY CUMULATIVE
DISTRIBUTION DRIVEN LEVEL CONVERGENCE
FOR SPECTRUM SENSING**

Field of the Invention

[0001] The present invention relates generally to digital communications systems and more particularly to the control of signal input levels in a digital communications receiver for the purpose of sensing the presence of a plurality of different waveforms.

Background

[0002] In general, a typical digital communications receiver is designed for use in connection with a particular type of input waveform. When the waveform is received, an analog-to-digital converter (ADC) input signal is maintained at a power level in order to maximize ADC's dynamic range. This ultimately works to minimize quantization noise and clipping induced noise for enhanced receiver performance over a range of input signal levels. In other words, the power level into the ADC is constrained to maximize the signal-to-noise ratio (SNR) of the particular digitized waveform. In that the receiver is designed for one type of input waveform, these types of power level control methods minimize the error in ADC input power relative to some reference power level, which is selected based on apriori knowledge of the input waveform characteristics.

[0003] One example of this type arrangement is where the power of a matched filter output is compared to a reference power determined by the signal of interest,

the ADC dynamic range, RF front end parameters, etc. The front end gain is adjusted to minimize the difference between the power of the matched filter output and the reference power. This type of matched filter design is based on the known signal waveform such as a pseudo-random noise (PN) sequence, packet preamble, pilot tone, or the like. Often, the reference power is selected according to the peak-to-average characteristic of the waveform to be detected. Accordingly, the reference power for an orthogonal frequency division multiplexing (OFDM) signal will differ from that of a single tone (sine wave) or a direct sequence spread spectrum (DSSS) waveform. Note that for most useful waveforms (excepting a single tone) a certain amount of clipping is typically permissible in order to maximize SNR, where the percentage of clipping is dependent on the input waveform.

[0004] Gain control stages as used in the prior art are not adequate for spectrum sensing in cognitive radio applications. In cognitive radio, the signal or waveform input to the ADC is, in general, random and unknown. Also, there may be several superimposed waveforms present on the scanned channel which are then input to the ADC. In this case, the a priori waveform characteristics required to determine an optimal reference power for level control are absent.

[0005] Hence, there is a need to provide a means to achieve a desired level of clipping which is acceptable for spectrum sensing in the absence of apriori knowledge of waveform characteristics.

Brief Description of the Figures

[0006] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to further illustrate various embodiments and to explain various principles and advantages all in accordance with the present invention.

[0007] FIG. 1 a block diagram illustrating the complementary cumulative distribution driven level convergence system in accordance with an embodiment of the invention.

[0008] FIG. 2 is a flowchart diagram illustrating high level steps in the complementary cumulative distribution driven level convergence method in accordance with an embodiment of the invention.

[0009] FIG. 3 is a flowchart diagram illustrating a detailed description of the complementary cumulative distribution driven level convergence method in accordance with an embodiment of the invention.

[0010] Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

Detailed Description

[0011] Before describing in detail embodiments that are in accordance with the present invention, it should be observed that the embodiments reside primarily in combinations of method steps and apparatus components related to a complementary cumulative distribution driven level convergence system and method. Accordingly, the apparatus components and method steps have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments of the present invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

[0012] In this document, relational terms such as first and second, top and bottom, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms “comprises,” “comprising,” or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element preceded by “comprises . . . a” does not, without more constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element.

[0013] It will be appreciated that embodiments of the invention described herein may be comprised of one or more conventional processors and unique stored program instructions that control the one or more processors to implement, in conjunction with certain non-processor circuits, some, most, or all of the functions of a complementary cumulative distribution driven level convergence system as described herein. The non-processor circuits may include, but are not limited to, a radio receiver, a radio transmitter, signal drivers, clock circuits, power source circuits, and user input devices. As such, these functions may be interpreted as steps of a method to perform a complementary cumulative distribution driven level convergence. Alternatively, some or all functions could be implemented by a state machine that has no stored program instructions, or in one or more application specific integrated circuits (ASICs), in which each function or some combination of certain of the functions are implemented as custom logic. Of course, a combination of the two approaches could be used. Thus, methods and means for these functions have been described herein. Further, it is expected that one of ordinary skill, notwithstanding possibly significant effort and many design choices motivated by, for example, available time, current technology, and economic considerations, when guided by the concepts and principles disclosed herein will be readily capable of generating such software instructions and programs and ICs with minimal experimentation.

[0014] Turning now to the drawings, FIG. 1 is a block diagram illustrating the complementary cumulative distribution driven level convergence (CCDDLCL)

control loop system in accordance with an embodiment of the invention. The system 100 includes an input signal $x(n)$ 103. This is input to a variable gain amplifier 105 in receiver 101. The output of the variable gain amplifier 105 is directed to an ADC 107 whose digital sample sequence is sent to a function representing the complementary cumulative distribution function (CCDF), $P(x(n)) > \gamma$ 109, where γ is the absolute maximum output value supported by the ADC, known as the clipping level.

[0015] The output of the of the CCDF 109 is represented as the function $P(n)$ 111. This is applied to a mathematical subtraction function 113 with a target CCDF represented by P_r 115. The output of the subtraction, $P(n) - P_r$, provides a signal $e(r)$ 117 which is provided to a multiplication function 119 where it is multiplied with a value 121 representing the loop gain. The output of the multiplication function 119 is input to a loop filter 123 which sums the multiplication function 119 output and the previous value 125 of the gain control value 126. The output is the new gain control value, $v(n)$ 126, which is in turn input to a function 127 which generates the variable gain amplifier's gain value $G(n)$, according to the variable gain amplifier's gain response characteristic where $G(n) = 10[G_{\text{max}} - av(n)/20]$ where G_{max} is the maximum gain in decibels (dB) and 'a' is a predetermined constant of proportionality (e.g. dB/bit) used in connection with the control value $v(n)$. Thereafter, $G(n)$ is then used to control the gain of the variable gain amplifier 105. Thus, this invention controls an ADC input signal power level to yield a desired probability of clipping without prior

consideration of waveform characteristics. Those skilled in the art will recognize that this technique is appropriate for spectrum sensing applications where the use of a waveform dependent, predetermined reference power as a set point is not feasible.

[0016] Rather than using ADC input signal power as used in prior art topologies, the system 100 uses the complementary cumulative distribution function, $CCDF_x(\gamma) = P(X > \gamma)$, of the input waveform as the comparative statistic. The CCDF at the n^{th} ADC sample is estimated as:

$$ccdf(n) = \frac{1}{N} \sum_{k=n-N+1}^n I_x(k)$$

where

$$I_x(k) = \begin{cases} 0 & \text{for } |x(k)| \leq \gamma \\ 1 & \text{for } |x(k)| > \gamma \end{cases}$$

is the indicator function;

and γ is the clipping level of the ADC.

[0017] As seen in FIG. 1, the CCDF statistic is the input to an exemplary (PI) control loop where P_r represents the target CCDF, $P(n)$ is the CCDF at sample n , β is the loop gain and $G(n)$ is the programmable gain amplifier gain for a control value, $v(n)$.

[0018] For this non-linear system, an idealized linear approximation using perturbation (small signal) analysis can be used to characterize the performance (e.g., convergence time, stability) and obtain qualitative insight.

[0019] Let $P(n) = CCDF_x(\gamma)$ at time n ,

$P_r = \text{targetCcdf}$

[0020] Assume the CCDF is a function of control value, $v(n)$, and the signal power, $P_x(n)$:

$P(n) = f(v(n), P_x(n))$ where this idealized model assumes no delay in the programmable gain amplifier.

[0021] If the equilibrium values of $v(n)$, $P_x(n)$ and $P(n)$ is v_{ST} , P_{xST} , and $P_{ST} = P_r$, respectively; and the deviation from steady state is:

$$\hat{v}(n) = v(n) - v_{ST}(n)$$

$$\hat{P}_x(n) = P_x(n) - P_{xST}(n)$$

$$\hat{P}(n) = P(n) - P_r(n)$$

[0022] Then

$$\begin{aligned} \hat{P}(n) &= \frac{\partial f(v_{ST}, P_{xST})}{\partial v} \hat{v}(n) + \frac{\partial f(v_{ST}, P_{xST})}{\partial P_x} \hat{P}_x(n) \\ &= K_1 \hat{v}(n) + K_2 \hat{P}_x(n) \end{aligned} \quad (\text{Eq. 1})$$

$$\begin{aligned} \hat{v}(n) &= \beta \hat{P}(n) + \hat{v}(n-1) \\ &= \beta [K_1 \hat{v}(n) + K_2 \hat{P}_x(n)] + \hat{v}(n-1) \end{aligned} \quad (\text{Eq. 2})$$

or, taking the Z transform,

$$\hat{V}(z) = \frac{\beta K_2 \hat{P}_x(z)}{(1 - \beta K_1) - z^{-1}}$$

[0023] Also from (Eq. 2)

$$\hat{P}(z) = \frac{1}{\beta} \hat{V}(z)(1 - z^{-1})$$

$$= \frac{K_2 \hat{P}_x(z) [1 - z^{-1}]}{[1 - K_1 \beta] - z^{-1}} \quad (\text{Eq. 3})$$

[0024] It is shown below that $K_1 \leq 0$. Then, given the pole at $\frac{1}{[1 - K_1 \beta]}$, the loop is stable for $\beta > 0$.

[0025] Also for a step deviation from equilibrium on input signal power, the deviation from the CCDF equilibrium point is

$$\begin{aligned} \hat{P}_{step}(z) &= \frac{1}{1 - z^{-1}} \frac{K_2 [1 - z^{-1}]}{[1 - K_1 \beta] - z^{-1}} \\ &= \frac{K_2}{[1 - K_1 \beta]} \frac{1}{1 - \frac{1}{[1 - K_1 \beta]} z^{-1}} \end{aligned} \quad (\text{Eq. 4})$$

so

$$\hat{p}_{step}(n) = K_2 \left(\frac{1}{[1 - K_1 \beta]} \right)^{n+1} \quad (\text{Eq. 5})$$

which illustrates that the CCDF converges to 0 when $\beta > 0$, $K_1 \leq 0$.

[0026] Also,

$$\lim_{z \rightarrow 1} (z - 1) \hat{P}_{step}(z) = \lim_{z \rightarrow 1} (z - 1) \frac{K_2}{[1 - K_1 \beta] - z^{-1}} = 0 \quad (\text{Eq. 6})$$

confirming convergence for a step input change in input signal power.

[0027] Finally, the number of samples required for $\hat{p}_{step}(n)$ to go from 0.95 to 0.05, relative to maximum deviation due to a step change in input signal power (i.e., the response time) is:

$$\Delta n = \frac{3}{\ln[1 - K_1 \beta]} \quad \text{samples} \quad (\text{Eq. 7})$$

[0028] In general, the exact pole location and hence the response time are difficult to determine analytically due to the dependence on $K_1 = \frac{\partial f(v_{ST}, P_{xST})}{\partial v}$. The slope of the CCDF vs. control value, v , curves can be examined empirically.

[0029] Insight, can be obtained by examining the case of a sinusoidal input signal

$$x(n) = A \cos(2\pi f_o n T_s)$$

where $f_o < F_s/2$ is the waveform frequency, $T_s = 1/F_s$ is the sample time duration.

[0030] A clipping event occurs when the output of the variable gain amp exceeds the ADC maximum input level, i.e.,

$$Gx(n) = GA \cos(2\pi f_o n T_s) > \gamma$$

where

$$G \text{ (dB)} = G\_MAX - sv$$

or

$$G = 10^{\frac{G\_MAX - sv}{20}}.$$

[0031] The CCDF is given by

$$\begin{aligned} CCDF(v, A) &= 2 \frac{f_o}{F_s} \max \left[0, 2 \text{ceil} \left\{ \frac{F_s}{2\pi f_o} \cos^{-1} \left(\frac{\gamma}{GA} \right) \right\} - 1 \right] \\ &= 2 \frac{f_o}{F_s} \max \left[0, 2 \text{ceil} \left\{ \frac{F_s}{2\pi f_o} \cos^{-1} \left(\frac{\gamma}{A} 10^{\frac{-G\_MAX}{20}} 10^{\frac{sv}{20}} \right) \right\} - 1 \right] \quad (\text{Eq. 8}) \end{aligned}$$

Note, the max function is required to cover the case of $\frac{\gamma}{GA} = 1$. For G such that $\frac{\gamma}{GA} \geq 1$, no clipping occurs and the CCDF = 0

[0032] Determination of K_1 , requires taking the partial derivative of CCDF(v,A) with respect to v. However, CCDF(v,A) is a non-linear function of v, with discontinuities due to the ceil() function. However, a linear approximation to CCDF(v,A) can provide a qualitative and fairly accurate quantitative result for K_1 . The partial derivative of

$$CCDF_{lin}(v, A) = \frac{2}{\pi} \cos^{-1} \left(\frac{\gamma}{A} 10^{\frac{-G_{MAX}}{20}} 10^{\frac{sv}{20}} \right) - 1 \quad (\text{Eq. 9})$$

yields the equation:

$$K_1 = \frac{\partial CCDF_{lin}(v, A)}{\partial v} = \frac{-s \ln(10)}{10\pi} \frac{1}{\left(\frac{A^2}{\gamma^2} 10^{\frac{G_{MAX}-sv}{10}} - 1 \right)^{1/2}} \quad (\text{Eq. 10})$$

[0033] The response time (at a given control value v) is given as

$$\Delta n = \frac{3}{\ln[1 - K_1 \beta]}$$

[0034] FIG. 2 is a flow chart diagram illustrating high level steps in the complementary cumulative distribution driven level convergence method in accordance with an embodiment of the invention. The convergence method 200 includes receiving a sample sequence x(n) 201, where the complementary cumulative distribution function $CCDF(n) = P[x(n) \geq \gamma]$ is calculated 203. The

error $e(n) = CCDF(n) - \text{target CCDF}$ is calculated 205 and the finally a gain control value $v(n) = \text{fnc}[e(n), e(n-1), \dots, e(n-N)]$ is determined 207 for applications with a particular amplifier stage and/or device. Thus, the function can be a scaling function, a linear combination function of $e(n)$, $e(n-1)$, ... such as a filter; a non-linear function, or any combination thereof.

[0035] FIG. 3 is a flowchart diagram illustrating a detailed description of the complementary cumulative distribution driven level convergence method in accordance with an embodiment of the invention. As seen in FIG. 3, the convergence method 300 includes the steps of receiving a clip indicator $I(n)$ 301. Those skilled in the art will recognize that the clip indicator is a “clip” or sample of the input waveform into a device such as an ADC. Once a signal is received indicating that the analog-to-digital converter (ADC) input has clipped, then a binary signal from the ADC is generated by a comparison between the ADC sample output, $x(n)$, and the clip level. The CCDF can be calculated by adding the most recent clip indicator value, $I(n)$, to the CCDF accumulator 303 and subtracting the oldest clip indicator, $I(n-D)$ 305, where the CCDF is calculated over D clip indicator samples. That is

$$CCDF(n) = \frac{1}{D} \sum_{k=0}^{D-1} I(n-k) = \frac{1}{D} [CCDF(n-1) + I(n) - I(n-D)]$$

Thereafter, the difference between $CCDF(n)$ and target CCDF $e(n)$ is calculated 309 as well as a calculation for the error power (P_e) 311 where

$$P_e(n) = \frac{1}{N} \sum_{k=0}^{N-1} |e(n-k)|^2$$

Finally, the gain control, $v(n)$, is calculated using a first function (fnc1) 315 where $v(n) = \text{fnc1}[e(n), e(n-1), \dots, e(n-N)]$, if the error power is greater than a threshold 313, otherwise a second function (fnc2) 317 where $v(n) = \text{fnc2}[e(n), e(n-1), \dots, e(n-N)]$, is used. An example first and second function is a first and second error multiplier 119 selected according to the error power. The first and second functions are associated with locked and unlocked states, respectively. When the error power exceeds a threshold, the first function associated with the unlocked state is used to cause quicker convergence to the correct gain control value 315. Once the error is below a threshold, the second function associated with the locked state is used to reduce the variation of the gain control about the correct value 316.

[0036] In the foregoing specification, specific embodiments of the present invention have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present invention. The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or

essential features or elements of any or all the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

Claims

We claim:

1. A method for use in a communications receiver for controlling an input signal level into an analog-to-digital converter (ADC) comprising the steps of:
 - measuring a threshold crossing rate as a percentage samples of an input signal that exceed the threshold;
 - computing an error between the measured threshold crossing rate and a desired reference threshold crossing rate; and
 - utilizing an error signal in a feedback loop to control the receiver gain such that the error is reduced.
2. A method for use in a communications receiver as in claim 1, wherein the percentage of samples are a predetermined number of the last samples received.
3. A method for use in a communications receiver as in claim 1, further comprising the step of:
 - determining the threshold crossing rate based a clipping rate of the input signal.

4. A method for use in a communications receiver as in claim 1, further comprising the step of:

allowing the input signal to operate over an amplitude distribution for achieving a predetermined level of clipping.

5. A digital communications receiver comprising:

at least one controllable amplifier stage; and

at least one analog-to-digital converter (ADC) for receiving a signal from the at least one controllable amplifier stage; and

at least one gain controller and

wherein the at least one gain controller operates using the steps of:

receiving at least one input sample $x(n)$;

calculating a complementary cumulative distribution function (CCDF) for sample $x(n)$ based upon the function $ccdf(n) = \frac{1}{N} \sum_{k=n-N+1}^n I_x(k)$ where $I_x(k) = 0$ for

$|x(k)| \leq \gamma$ and $I_x(k) = 1$ for $|x(k)| > \gamma$ and further where γ is the clipping level of the ADC;

calculating a difference between a CCDF(n) and a target CCDF; and

calculating a control value as a function of the error for adjusting the gain of the at least one controllable amplifier stage.

6. A digital communications receiver as in claim 5, wherein the difference is an error value $e(n)$ which equals $\text{CCDF}(n) - \text{target CCDF}$.

7. A digital communications receiver as in claim 5, wherein the at least one controllable amplifier stage further operates using the step of:

$$\text{calculating an error power } P_e(n) = \frac{1}{N} \sum_{k=0}^{N-1} |e(n-k)|^2$$

8. A digital communications receiver as in claim 5, wherein the control value is represented by the equation: $v(n) = \text{fnc1}[e(n), e(n-1), \dots e(n-N)]$ if the error power is greater than an error threshold value and fnc1 is a one from the group of scaling function, a linear combination function; a non-linear function or combinations thereof.

9. A digital communications receiver as in claim 7, wherein the control value is represented by the equation: $v(n) = \text{fnc2}[e(n), e(n-1), \dots e(n-N)]$ if the error power is lesser than an error threshold value and fnc2 is a one from the group of scaling function, a linear combination function, a non-linear function or combinations thereof..

10. A method for use in a digital communications receiver for controlling an input signal level of an amplifier before supplying the signal to an analog-to-digital converter (ADC), the method comprising the steps of:

- receiving a radio frequency (RF) input signal;
- measuring a threshold crossing rate as a percentage of a predetermined number of signal samples that exceed a predetermined threshold;
- computing an error between the measured threshold crossing rate and a desired reference value for providing an error signal; and
- using the error signal in a feed back loop to calculate a gain control value for the amplifier to reduce error in the ADC.

11. A method for use in a digital communications receiver for controlling an input signal level as in claim 10, wherein the threshold crossing rate is measured based upon the complementary cumulative distribution function (CCDF) such that $CCDF(n) = P[x(n) \geq \gamma]$ where $x(n)$ is sample sequence and γ is the clipping level of the ADC.

12. A method for use in a digital communications receiver for controlling an input signal level as in claim 10, wherein the error signal $e(n) = CCDF(n) - a$ target CCDF value.

13. A method for use in a digital communications receiver for controlling an input signal level as in claim 10, wherein the gain control value $v(n) = \text{fnc}[e(n), e(n-1) \dots e(n-N)]$ where fnc is an error multiplier based on error power.

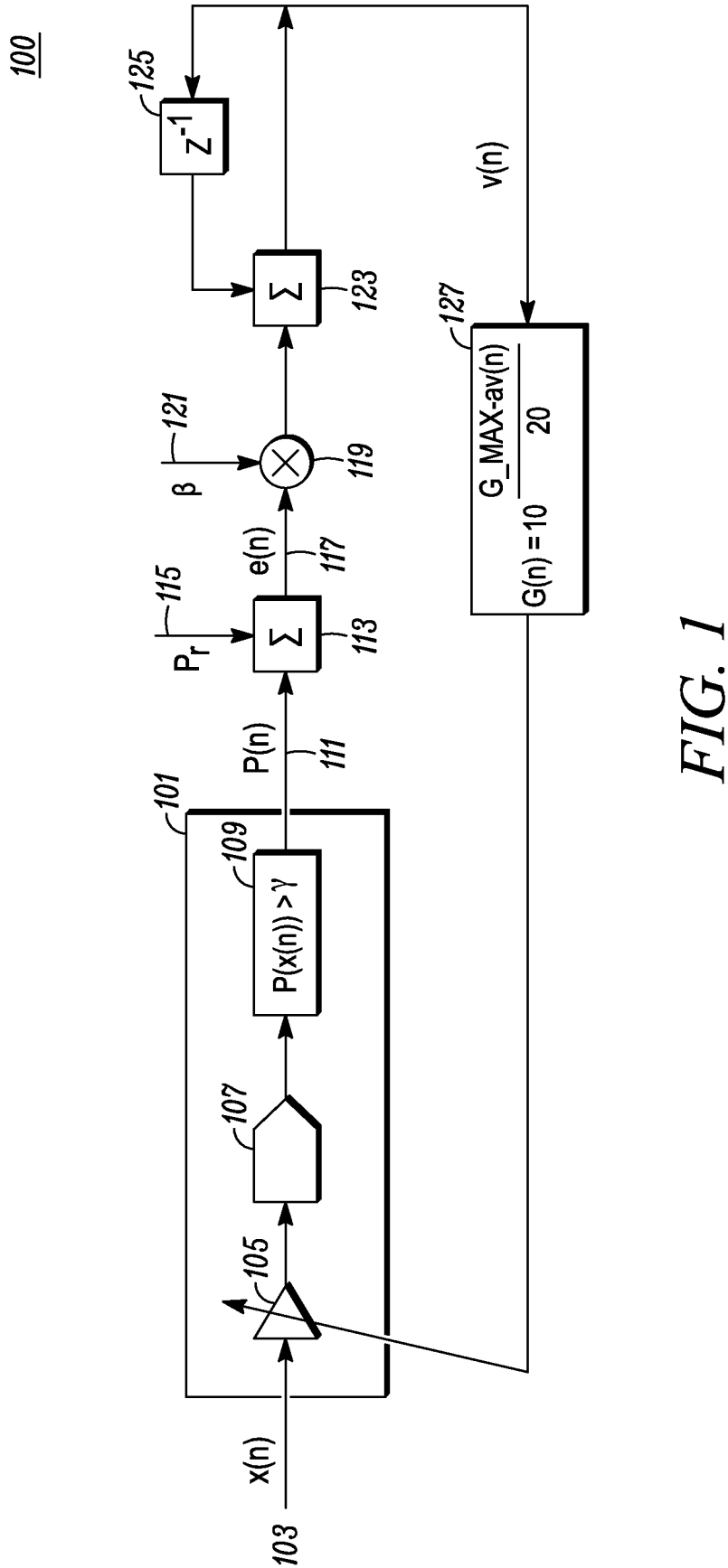
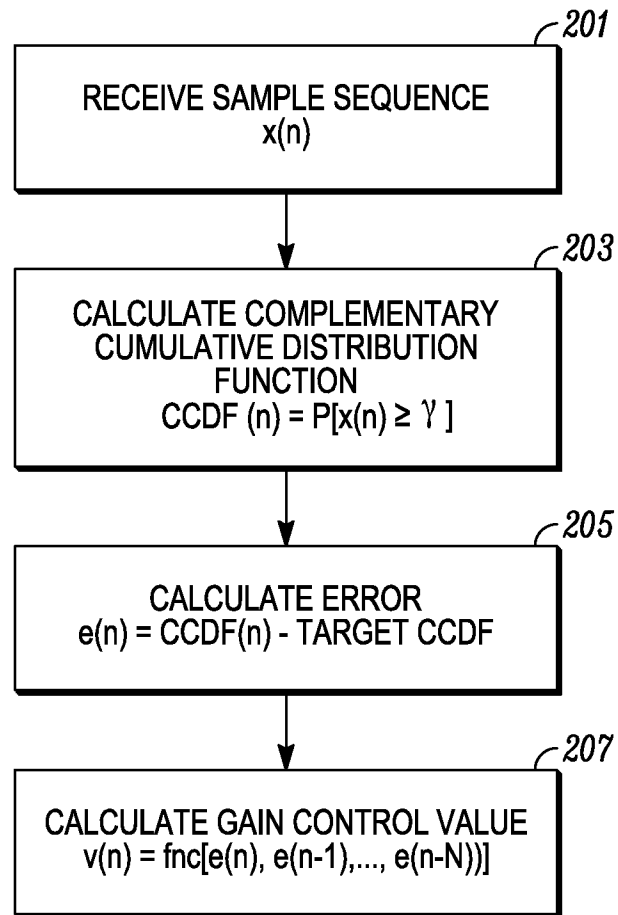


FIG. 1

*2/3*200*FIG. 2*

3/3

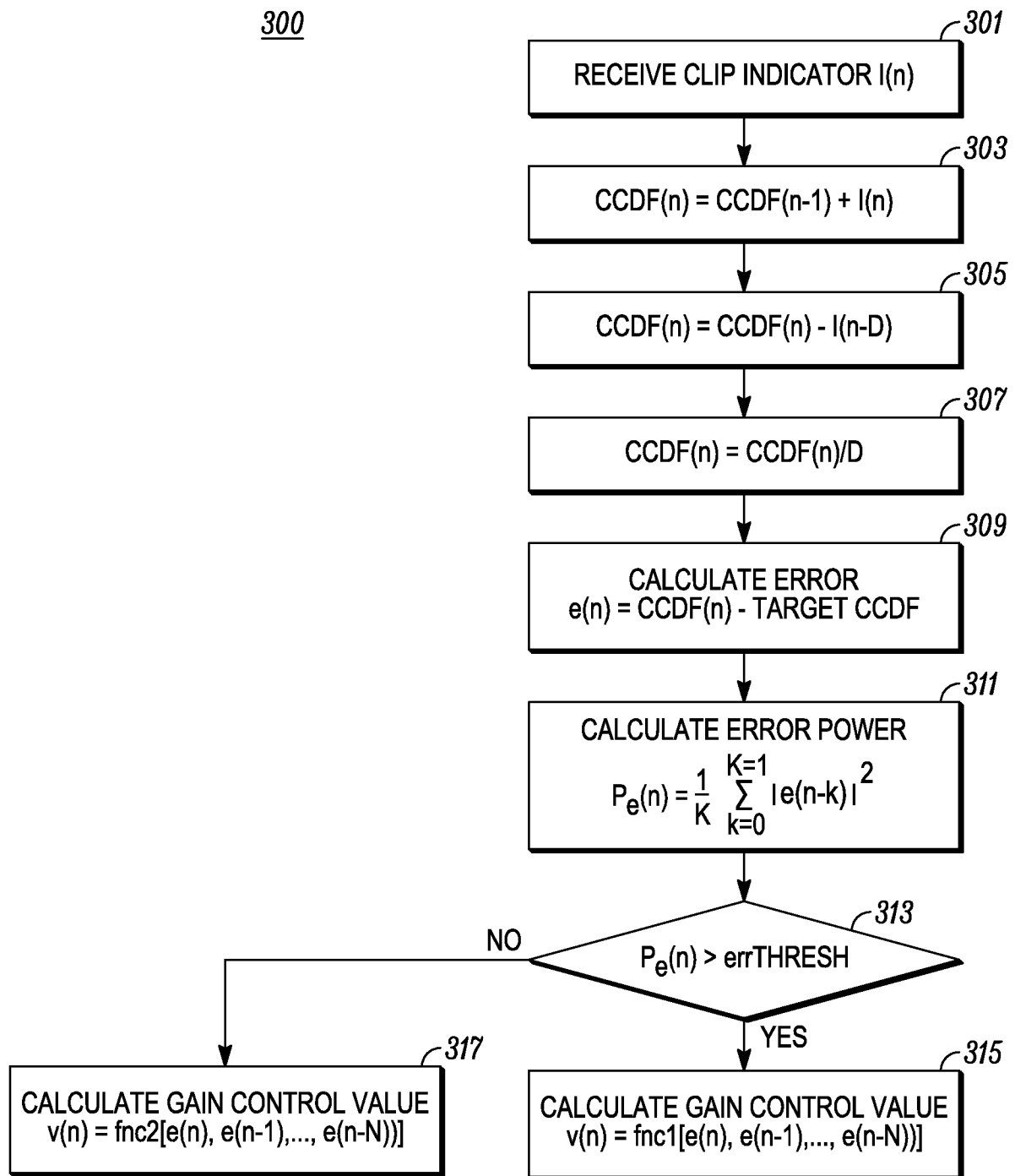


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/082409**A. CLASSIFICATION OF SUBJECT MATTER****H04B 7/24(2006.01)i, H04B 7/00(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC : H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
KOREAN UTILITY MODELS AND APPLICATIONS FOR UTILITY MODELS SINCE 1975
JAPANESE UTILITY MODELS AND APPLICATIONS FOR UTILITY MODELS SINCE 1975Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKIPASS(internal) & Keywords : automatic gain control, receiver, clipping, crossing rate**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 7127223 B2(HANG JIN et al.) 24 OCTOBER 2006 See abstract; column 2, line 60 - column 4, line 15; Fig.2	1-13
A	US 2006/0222118 A1(VINAY MURTHY et al.) 5 OCTOBER 2006 See abstract; paragraphs[0033]-[0038]; Fig.2	1-13
A	MURRAY,B.M et al. 'AGC and Quantization Effects in a Zero-Forcing MIMO Wireless System'. Vehicular Technology Conference, 2006. VTC 2006-Spring. IEEE 63rd Volume 4, 7-10 May 2006, Page(s):1802 - 1806	1-13
A	H. Wu et al. 'Energy and Spectrum Efficient TransmissionModes for the 3GPP-LTE Uplink' in Proc. of PIMRC07, Athens, Greece, September 2007, Page(s):1-5	1-13



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 APRIL 2009 (24.04.2009)

Date of mailing of the international search report

24 APRIL 2009 (24.04.2009)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seo-
gu, Daejeon 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

LEE, Hee Bong

Telephone No. 82-42-481-5686



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2008/082409

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 7127223 B2	24. 10. 2006	EP 1787398 A2	23. 05. 2007
		US 2006-0052070 A1	09. 03. 2006
		WO 2006-031573 A2	23. 03. 2006
		WO 2006-031573 A3	04. 05. 2006
US 2006/0222118 A1	05. 10. 2006	None	