(11) Application No. AU 2007200714 B2

(19) AUSTRALIAN PATENT OFFICE

(54) Title

System for determining conducted radio frequency (RF) receiver sensitivity and related methods

(51)[6] International Patent Classification(s)

H04B 17/00 (2006.01) 20060101AFI2007022

H04B 17/00 3BHAU

(21) Application No: 2007200714 (22) Application Date: 2007.02.19

(30) Priority Data

(31) Number	(32) Date	(33) Country
06251113.4	2006.03.01	EP

(43) Publication Date : 2007.09.20

(43) Publication Journal Date : 2007.09.20

(71) Applicant(s)

Research In Motion Limited

(72) Inventor(s)

Qi, Yihong; Certain, Michael; Jarmuszewski, Perry

(74) Agent/Attorney

PIZZEYS, GPO Box 1374, Brisbane, QLD, 4001

(56) Related Art

US 2004/148580

US 2004/209635

2007200714 19 Feb 2007

SYSTEM FOR DETERMINING CONDUCTED RADIO FREQUENCY (RF) RECEIVER SENSITIVITY AND RELATED METHODS

Abstract of the Disclosure

A test method for determining conducted radio frequency (RF) receiver sensitivity using an RF source coupled to an RF receiver by an RF cable may include determining a bit error rate (BER) versus traffic channel (TCH) power level function for an initial channel, determining an estimated TCH power level for a subsequent channel based upon the function and the desired BER, and measuring a BER of the subsequent channel based upon the estimated TCH power level. The measured BER may be compared to the desired BER, and a difference therebetween is used along with the function to determine a next estimated TCH power level. Measuring and comparing may be repeated if the difference may be greater than a threshold to thereby determine a TCH power level in the subsequent channel corresponding to the desired BER.

Figure 1

2007200714 19 Feb 2007

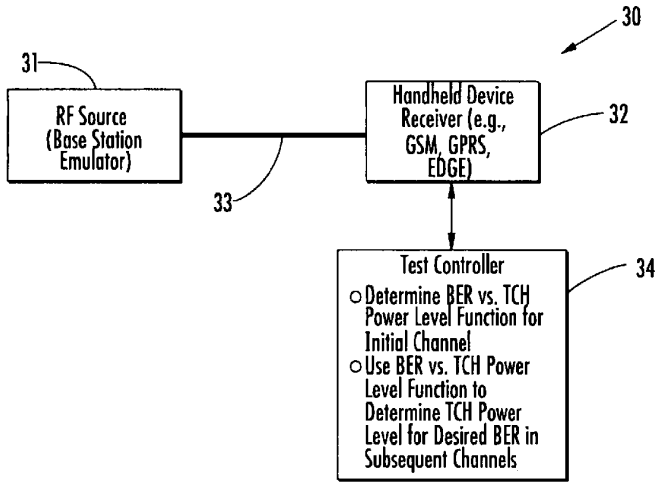


FIG. 1

2007200714 19 Feb 2007

SYSTEM FOR DETERMINING CONDUCTED RADIO FREQUENCY (RF) RECEIVER SENSITIVITY AND RELATED METHODS

Field of the Invention

[0001] The present invention relates to the field of communications systems, and, more particularly, to performance testing in mobile wireless communications systems, such as cellular communications systems, and related methods.

Background of the Invention

[0002] In cellular communications devices, radio sensitivity is a fundamental figure characterizing radio receiver performance. Conducted (i.e., via an RF cable) and radiated (i.e., via a wireless communications link) radio sensitivity measurements are performed frequently during radio design, certification, and verification. These measurements are performed by reducing the base station power transmit level until the receiver residual bit error ratio (RBER) reaches a desired level, specifically 2.44%.

[0003] For Global System for Mobile communication (GSM) mobile devices, for example, there are several communications bands each ranging from at least one hundred channels to almost four hundred. To scan every channel of a GSM mobile phone requires large amounts of time using traditional, semi-intuitive methods. Automated methods replicating manual estimation tend to be random or follow binary-tree search methodology.

[0003A] Throughout the specification the term "comprising" shall be understood to have a broad meaning similar to the term "including" and will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps. This definition also applies to variations on the term "comprising" such as "comprise" and "comprises".

2007200714 19 Feb 2007

Brief Description of the Drawings

[0004] FIG. 1 is a schematic block diagram of an exemplary test system for measuring conducted radio frequency (RF) receiver sensitivity in accordance with the invention.

[0005] FIG. 2 is a schematic block diagram of an exemplary test system for measuring radiated RF receiver sensitivity in accordance with the invention.

[0006] FIGS. 3-5 are flow diagrams of exemplary methods for RF receiver sensitivity measurement in accordance with the invention.

[0007] FIG. 6 is a flow diagram of an exemplary method for determining RF path loss in accordance with the invention.

[0008] FIGS. 7 and 8 are flow diagrams of exemplary methods for determining RF path loss between an RF source and an RF receiver with hysteresis in accordance with the invention.

[0009] FIGS. 9-13 are flow diagrams of additional exemplary methods for determining RF path loss in accordance with the invention.

[0010] FIGS. 14 and 15 are graphs of BER versus TCH power level change for different sets of data, as well as corresponding BER versus TCH power level functions therefore, in accordance with the present invention.

[0011] FIG. 16 is a graph illustrating sine waves approximated using spline fitting.

[0012] FIG. 17 is a graph illustrating handheld device hystersis switching.

[0013] FIG. 18 is a graph of BER vs. normalized TCH level function.

Detailed Description of the Preferred Embodiments

[0014] The present description is made with reference to the accompanying drawings, in which preferred embodiments are shown. However, many different embodiments may be used, and

2007200714 19 Feb 2007

thus the description should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete. Like numbers refer to like elements throughout, and prime and multiple prime notation are used to indicate similar elements in alternative embodiments.

[0015] Generally speaking, a test method is disclosed herein for determining conducted radio frequency (RF) receiver sensitivity, which is defined based upon a traffic channel (TCH) power level at a desired bit error rate (BER) for a plurality of channels extending over at least one frequency band, using an RF source coupled to an RF receiver by an RF cable. The test method may include determining a BER versus TCH power level function for an initial channel, determining an estimated TCH power level for a subsequent channel based upon the BER versus TCH power level function and the desired BER, and measuring a BER of the subsequent channel based upon the estimated TCH power level. The method may further include comparing the measured BER to the desired BER and using a difference therebetween along with the BER versus TCH power level function to determine a next estimated TCH power level, and repeating measuring and comparing if the difference is greater than a threshold to thereby determine a TCH power level in the subsequent channel corresponding to the desired BER.

[0016] More particularly, determining the BER versus TCH power level function for the initial channel may include measuring respective TCH power levels for a plurality of BERs within a target BER range, and determining the BER versus TCH power level function based upon the measured BERs in the target BER range. By way of example, the target BER range may be from about one to three percent.

[0017] The method may further include using a linear approximation to determine the TCH power level in the

2007200714 19 Feb 2007

subsequent channel corresponding to the desired BER when the difference between the measured BER and the desired BER is less than or equal to the threshold. Also, the BER versus TCH power level function may be an exponential function. Additionally, determining the BER versus TCH power level function may include determining the BER versus TCH power level function based upon a least squares algorithm.

[0018] The RF receiver may be a Global System for Mobile Communications (GSM) receiver, a General Packet Radio Service (GPRS) receiver, and/or an Enhanced Data Rates for Global System for Mobile Communications (GSM) Evolution (EDGE) receiver, for example. Moreover, the RF source may be a base station emulator.

[0019] A test system for determining conducted radio frequency (RF) receiver sensitivity may include an RF source, an RF receiver, an RF cable coupling the RF source to the RF receiver, and a test controller coupled to the RF receiver. The test controller may be for determining a BER versus TCH power level function for an initial channel, determining an estimated TCH power level for a subsequent channel based upon the BER versus TCH power level function and the desired BER, and measuring a BER of the subsequent channel based upon the estimated TCH power level. The test controller may also be for comparing the measured BER to the desired BER and using a difference therebetween along with the BER versus TCH power level function to determine a next estimated TCH power level, and repeating measuring and comparing if the difference is greater than a threshold to thereby determine a TCH power level in the subsequent channel corresponding to the desired BER.

[0020] Generally speaking, methods and test systems are provided herein for determining conducted and radiated receiver sensitivity which use a channel information-based search approach, which creates a fast sensitivity search for

2007200714 19 Feb 2007

GSM or other mobile devices. The RBER vs. normalized TCH transmit level is largely determined by the modulation method and digital signal processor (DSP) code. Measurement of a range of this data creates a curve or function showing the characteristics of the receiver near the target RBER. The compiled data for one channel applies to all channels within the same band. This curve allows predictive, rather than estimated, transmit level change within its boundaries.

[0021] The sensitivity measurement is defined as the transmit (TX) power at which the mobile reports a Class II RBER of 2.44 percent or less. Often the calibrated base station transmit power is decreased until the desired RBER is achieved. To correctly measure device sensitivity in a conducted mode, accurate cable path loss needs to be determined across the channels in question. Within the desired bands, a random channel may be selected as representative. The lower and upper limits of the RBER scan range are selected. The lower limit is selected to minimize high Gaussian and other random noise error susceptibility at very low RBER. It is preferably sufficiently low to maintain a large overall scan range. The upper limit is selected to protect against terminated mobile calls while maintaining large overall scan range. The lower RBER limit can be found through various search methods, as will be appreciated by those skilled in the art.

[0022] Bit error measurements within the above-noted limits use the highest transmit level resolution. Decreasing resolution decreases prediction accuracy over a non-linear system. The values are compiled with the TCH transmit level normalized. Random noise and bit error ratio modify the exact data curve. One approach is to apply a least-squares fitting to create the appropriate fast search curve. Because of the nature of the modulation, the normalized curve will have the form of $y = Ce^{bx}$ between the lower and upper limits, where y is

2007200714 19 Feb 2007

the bit error ratio, x is the normalized TCH transmit level, and C and b are values derived from curve fitting, as will be discussed further below.

[0023] An example of an RBER vs. normalized TCH level curve is shown in FIG. 18. The points are the measurement data, and the line is the result of the curve fitting. For all other channels, points on the normalized curve are determined using a "leapfrog" method. The leapfrog amount is within the range from the lower to the upper limit. Consecutive channel sensitivities often narrowly differ.

[0024] Within the curve range, based on the information of the least squares curve, the change in transmit level is calculated. The new transmit level is then applied to the base station emulator, and the achieved RBER target (2.44%) is confirmed through measurement. Any deviation is corrected via reapplication of the normalized curve and a successive confirmation measurement. Increasingly small target to actual deviation increases accuracy through linearity, and deviation from expected values is minimal.

[0025] Referring initially to FIG. 1, a test system **30** for measuring conducted receiver sensitivity is first described. The system **30** illustratively includes an RF test source **31** coupled to a handheld device receiver **32** to be tested via an RF cable **33**. By way of example, the handheld device receiver **32** may be a Global System for Mobile Communications (GSM) receiver, a General Packet Radio Service (GPRS) receiver, and/or an Enhanced Data Rates for Global System for Mobile Communications (GSM) Evolution (EDGE) receiver, for example. Of course, other suitable wireless receivers may also be used.

[0026] In addition, the RF source **31** may be one of a Rohde and Schwartz universal radio communication tester CMU 200 or an Agilent 8960 base station emulator, for example, although other suitable emulators and/or RF test sources may also be used. A test controller **34** is connected to the handheld device

2007200714 19 Feb 2007

receiver **32** for performing various test operations and measurements, which will be discussed in further detail below. It should be noted that while the RF source **31** and test controller **34** are illustrated as separate components in the FIG. 1, the functions of the RF source and test controller may in fact be performed by the same base station emulator, for example. Alternately, the test controller **34** could be a computer or computing device separate from the RF source **31**, as will be appreciated by those skilled in the art.

[0027] Path loss plays an important role in the accuracy of a radio conducted sensitivity measurement as will be appreciated by those skilled in the art. One difficulty of performing a path loss measurement in a test configuration, however, is that typical base station emulators only report a receiver accuracy level of ±1 dB, as noted above, even though the internal amplifier of the receiver **32** may have much greater accuracy, for example, of about ±0.1 dB. By obtaining sign change information in the receiver power level, the path loss accuracy can therefore be improved to ±0.1 dB, as will be discussed further below.

[0028] In the case of a conducted receiver sensitivity test, the path loss of the cable **33** that connects the receiver **32** and the base station emulator **31** can be well calibrated. One relatively straightforward accurate path loss measurement involves changing the internal amplification of the receiver **32** by 0.1 dB increments until the desired RSSI edge point is obtained. However, if the starting point is .9 dB from the edge point, it will take many steps and, therefore, increased measurement time to find the edge point. Accordingly, more complex test schemes may be used to reduce the number of steps that will be required on average to find the edge point and, therefore, reduce test times.

[0029] For example, one slightly more complex approach is illustrated in FIG. 9. Beginning at Block **110**, the desired TCH

2007200714 19 Feb 2007

power level is first set on the RF source **31**, at Block **111**. The internal amplification level of the receiver **32** is first changed by a coarse increment, such as the difference between the reported RSSI of the receiver and the TCH power level or other integer value, at Block **112**. The edge is then found by changing the internal amplification level of the receiver using a fine increment (e.g., 0.1 dB) until the edge transition is observed to provide the path loss, at Blocks **113-114**, at which point the internal amplification value of the receiver **32** may be set and/or recorded (Block **115**), thus concluding the illustrated method (Block **116**).

[0030] Stated alternatively, the "coarse" search changes the internal amplification by the difference between TCH level and reported RSSI. Since in the present example the reported RSSI is an integer value, this gives an accuracy of ±1 dB. The "fine" search then determines the edge between two consecutive RSSI readings.

[0031] Other variations of the coarse-fine edge point detection approach may also be used. Generally speaking, the coarse portions of these searches are fairly similar, so particular attention will be given herein to the variations in the fine search that may be used as appropriate for a given implementation. A fine search generally includes three stages. First, the RSSI is set to the desired level by adjusting the internal amplification and the TCH level of the base station emulator. Next, the internal amplification is changed in a series of successively decreasing increments to find the edge. These increments should narrow to 0.1 dB (or the accuracy of the given internal amplifier) to ensure the accuracy is also 0.1 dB. Finally, it may be necessary to "step back" to the edge point, as the measurements may have left off 0.1 dB from the desired RSSI.

[0032] Another example of a fine search is now described with reference to FIG. 10. Beginning at Block **120**, the RSSI is

2007200714 19 Feb 2007

set to the desired level, at Block **121**, and the internal amplification changed in 0.2 dB increments until the desired RSSI is no longer reported, at Blocks **122-123**. That is, after a number of steps (typically between one and five), the returned RSSI will not match the desired level since the internal amplification will have jumped the edge by 0.1 or 0.2 dB. Thus, decreasing or "stepping back" the internal amplification level in 0.1 dB increments will find the edge point either in one or two steps, at Blocks **124-125** (depending upon whether the edge was jumped by 0.1 or 0.2 dB), thus concluding the illustrated method (Block **126**).

[0033] Another fine search process is now described with reference to FIG. 11. Beginning at Block **130**, the RSSI is set to the desired level, as discussed above, and then the internal amplification is increased by 0.3 dB increments until the RSSI is no longer the desired value, at Blocks **131-133**. Once the RSSI changes, two consecutive 0.1 dB scans will yield a change in RSSI, thus locating an edge, at Blocks **136-138**, and the internal amplification is decreased by 0.1 dB (Block **139**), thus concluding the illustrated method. For example, if the sum total change is 0.1 dB (e.g. +0.2 and then -0.1 dB, totaling +0.1 dB) and this produces a change in RSSI, an edge has been found. Alternatively, if the internal amplification is changed three times (i.e., 0.9 dB) without the RSSI changing from the desired value, at Block **134**, an edge is also located, as a 1.0 dB change will change the RSSI since they are reported in integers.

[0034] Another exemplary approach is now described with reference to FIG. 12. Beginning at Block **140**, a starting actual RSSI value is -80.47 dB, and the reported RSSI is -80 db (Block **141**). The internal amplification is then increased by 0.6 dB, at Block **142**, changing the actual RSSI value to -79.87 dB, and the reported RSSI to -79 db (Block **143**), indicating that the edge has been crossed. The next step is a

2007200714 19 Feb 2007

0.3 dB decrease, at Block **144**, which changes the actual RSSI value to -80.17 dB, and the reported RSSI back to -80 db (Block **145**), indicating the edge has been crossed back over. As such, the internal amplification is increased by 0.1 dB, at Block **146**, changing the actual RSSI value to -80.07 dB, and the reported RSSI remains at -80 db (Block **147**), meaning the edge was not crossed. Accordingly, another 0.1 dB increase is performed (Block **148**), which changes the actual RSSI value to -79.97 dB, and also changes the reported RSSI to -79 dB, thus locating the edge (Block **149**), and concluding the illustrated method, at Block **150**.

[0035] It will be appreciated by those skilled in the art that many different edge location schemes may be used. The first, and each successive, jump is typically any number from 0.1 to 0.9 dB. Jump values can change or remain constant for each step. To choose an appropriate method for a given application, variation of the data and average performance are important considerations. For example, with relatively "flat" data the approach illustrated in FIG. 9 may locate the edge quicker than the approach illustrated in FIG. 10, but the opposite may be true for "sloped" data, potentially by up to three steps.

[0036] Still another approach now described with reference to FIG. 13 is a five-step path loss scheme. Beginning at Block **151**, the reported RSSI for a given TCH level is obtained, at Block **152**. The first step includes determining if the reported RSSI is the same as the TCH level, at Block **153**. If so, the method proceeds to step two. If not, the internal amplification is increased (or decreased depending upon the particular implementation) by the difference of the reported RSSI minus the given TCH level, at Block **154**. The new reported RSSI is then obtained (Block **152**), and for steps two through four the internal amplification is changed in successively

2007200714 19 Feb 2007

decreasing increments of 0.5 dB, 0.2 dB, and 0.1 dB, at Block **156**.

[0037] If the reported RSSI is not the same as the last reported RSSI after each of these changes, then the sign is changed before the next step (Block **158**) to step in the opposite direction (i.e., back toward the edge). Once the first four steps are completed, the fifth step involves once again determining if the reported RSSI is the same as the last reported RSSI, at Block **160**, and if so changing the internal amplification by 0.1 dB once again (which will be the edge) and obtaining the reported RSSI, at Blocks **161**, **162**, to conclude the illustrated method (Block **159**). This approach is advantageous in that it will converge on the edge point within five steps, which provides good overall results for different curve types.

[0038] Use of a path loss search in a test method for determining conducted radio frequency (RF) receiver sensitivity for a plurality of channels extending over one or more frequency bands will now be described with reference to FIGS. 3 and 4. As will be appreciated by those skilled in the art, receiver sensitivity is defined based upon a traffic channel (TCH) power level at a desired bit error rate (BER). BER is an "end-to-end" performance measurement which quantifies the reliability of the entire radio system from "bits in" to "bits out," including the electronics, antennas and signal path in between.

[0039] Aside from the relatively poor reporting accuracy of receiver test equipment, another difficulty in determining receiver sensitivity is that it can be a very time consuming process. That is, there are typically numerous channels within a cellular band, and a cellular device may operate over multiple bands, as noted above. Thus, a sensitivity measurement covering all of the channels used by a device may take many hours, and even days, to complete.

2007200714 19 Feb 2007

[0040] To reduce receiver sensitivity measurement times, a relatively fast sensitivity search algorithm is preferably used. Beginning at Block **40**, if the path loss of the RF cable **33** is not already known, using one of the above-described path loss searches (or others) a path loss function may advantageously be determined, at Block **48'**. More particularly, path loss associated with the RF cable **33** will be different for different channels (i.e., frequencies), but there will be a generally linear relation between these path loss values. Accordingly, by determining the path loss of two separate channels (e.g., the first and last channels in the band), a linear path loss function for the RF cable **33** can be quickly generated. This provides a quick and accurate approximation of path losses for all of the channels, although the path loss for each channel could be measured separately in some embodiments, if desired.

[0041] Furthermore, a BER versus TCH power level function is determined for an initial channel, at Block **41**. The initial channel could be any channel in the band, but for explanation purposes it will be assumed to be the first channel in the band. It has been found that given enough sampling frames, the general shape of the TCH power level vs. BER function for a given channel in a frequency band will be essentially the same for all of the remaining channels in the band. This is due to fact that the function is determined by the modulation scheme and digital signal processing (DSP) algorithm of the handheld device. By way of example, GPRS has a GMSK modulation scheme. Since the relationship for BER vs. energy per bit has an exponential form, the BER vs. TCH level function also takes the form of an exponential. Thus, once the shape of this function is found for one channel, this function can be used to rapidly locate the TCH level/target BER point for each of the following channels, as will be discussed further below.

2007200714 19 Feb 2007

[0042] In particular, the BER versus TCH power level function is determined for the initial channel by measuring respective TCH power levels for a plurality of BERs within a target BER range, and determining the BER versus TCH power level function based upon the measured BERs in the target BER range (i.e., curve fitting based upon the measured values), at Block **41'**. Typically speaking, only BER values within a particular target range will be of interest because values outside of this range will result in dropped connections, etc. By way of example, the target range may be about one to three percent, although other target ranges may be appropriate for different applications. Various curve fitting approaches, such as a least squares approach, for generating the BER versus TCH power level function will be discussed further below.

[0043] To find the edges of the BER target range, a coarse search may be used that involves stepping the TCH power level in relatively coarse negative increments (e.g., -1.5 db) when the measured BER is less than 0.5, and relatively coarse positive increments (e.g., +2.0 dB) when the measured BER is greater than 3.0. This gives a relatively close approximation of the target range edge points, and successive measurements within the target range may then be made at relatively fine TCH power level increments (e.g., 0.1 dB increments) to provide the data points for curve fitting.

[0044] Curve fitting is appropriate because BER data is often accompanied by noise. Even though all control parameters (independent variables) remain constant, the resultant outcomes (dependent variables) vary. A process of quantitatively estimating the trend of the outcomes, also known as curve fitting, therefore becomes useful. The curve fitting process fits equations of approximating curves to the raw field data, as will be appreciated by those skilled in the art.

2007200714 19 Feb 2007

[0045] As noted above, the data for the BER vs. TCH level function is generally exponential. Two exemplary curve-fitting approaches that may be used to fit an exponential curve are a least square polynomial approximation and a non-linear (i.e., exponential) least square approximation. The theory and implementation of a least square polynomial approximation is first described. Since polynomials can be readily manipulated, fitting such functions to data that does not plot linearly is common. In the following example, n is the degree of polynomial and N is the number of data pairs. If $N=n+1$, the polynomial passes exactly through each point. Therefore, the relationship $N>n+1$ should always be satisfied.

[0046] Assuming the functional relationship

$$y = a_0 + a_1 x + a_2 x^2 + \cdots + a_n x^n ,$$

with errors defined by

$$e_i = Y_i - y_i = Y_i - a_0 - a_1 x_i - a_2 x_i^2 - \cdots - a_n x_i^n ,$$

where Y_i represents the observed or experimental value corresponding to x_i, with x_i free of error, the sum of squares of the errors will be

$$S = \sum_{i=1}^{N} e_i^2 = \sum_{i=1}^{N} (Y_i - a_0 - a_i x - a_i x^2 - \cdots - a_n x_i^n)^2 .$$

At a minimum, the partial derivatives $\frac{\delta S}{\delta a_0}, \frac{\delta S}{\delta a_1}, \cdots, \frac{\delta S}{\delta a_n}$ are zero. Writing the equations for these terms gives $n+1$ equations as follows:

2007200714 19 Feb 2007

$$\frac{\delta S}{\delta a_1} = \sum_{i=1}^{N} 2(Y_i - a_0 - a_1 x_i - \cdots - a_i x_i^n)(-1)$$
$$\frac{\delta S}{\delta a_0} = \sum_{i=1}^{N} 2(Y_i - a_0 - a_1 x_i - \cdots - a_i x_i^n)(-x_i)$$
$$\vdots$$
$$\frac{\delta S}{\delta a_n} = \sum_{i=1}^{N} 2(Y_i - a_0 - a_1 x_i - \cdots - a_i x_i^n)(-x_i^n) .$$

Dividing each equation by -2 and rearranging gives $n+1$ normal equations to be solved simultaneously:

$$a_0 N + a_1 \sum x_i + a_2 \sum x_i^2 + \cdots + a_n \sum x_i^n = \sum Y_i$$
$$a_0 \sum x_i + a_1 \sum x_i^2 + a_2 \sum x_i^3 + \cdots + a_n \sum x_i^{n+1} = \sum x_i Y_i$$
$$a_0 \sum x_i^2 + a_1 \sum x_i^3 + a_2 \sum x_i^4 + \cdots + a_n \sum x_i^{n+2} = \sum x_i^2 Y_i$$
$$\vdots$$
$$a_0 \sum x_i^n + a_1 \sum x_i^{n+1} + a_2 \sum x_i^{n+2} + \cdots + a_n \sum x_i^{2n} = \sum x_i^n Y_i .$$

[0047] Putting these equations in matrix form reveals a notable pattern in the coefficient matrix:

$$\begin{bmatrix} N & \sum x_i & \sum x_i^2 & \sum x_i^3 & \cdots & \sum x_i^n \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \cdots & \sum x_i^{n+1} \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \sum x_i^5 & \cdots & \sum x_i^{n+2} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \sum x_i^n & \sum x_i^{n+1} & \sum x_i^{n+2} & \sum x_i^{n+3} & \cdots & \sum x_i^{2n} \end{bmatrix} * \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix} = \begin{bmatrix} \sum Y_i \\ \sum x_i Y_i \\ \sum x_i^2 Y_i \\ \vdots \\ \sum x_i^n Y_i \end{bmatrix}$$

This matrix equation is called the normal matrix for the least-square problem. In this equation $a_0, a_1, a_2 \cdots a_n$ are unknown coefficients while x_i and Y_i are given. The unknown coefficients $a_0, a_1, a_2 \cdots a_n$ can hence be obtained by solving the above matrix equations.

[0048] To fit the curve Y_i, it is required to know what degree of polynomial should be used to best fit the data. As the degree of polynomial is increased, the deviations of the

2007200714 19 Feb 2007

point from the curve is reduced until the degree of polynomial, n, equals $N-1$. At this point, there is an exact match. In terms of statistics, the degree of approximating the polynomial is increased as long as there is a statistically significant decrease in the variance, σ^2, which is computed by:

$$\sigma^2 = \sum \frac{e_i^2}{N-n-1}.$$

[0049] The approach illustrated above was programmed in two exemplary implementations using C++ and the normal matrix was solved using two different methods, namely the Gauss-Jordan approach and LU decomposition, as will be appreciated by those skilled in the art. Although both of these methods produced comparable results, the LU decomposition method was found to be more desirable for the least square polynomial approximation program because LU decomposition provided desired performance results.

[0050] The above noted C++ program was implemented so that it is able to calculate the coefficient of the approximated curve fitting equation of varying degree. Polynomials with degrees of 2, 3, 4 and 5 were used to fit a curve against BER data values, and it was found that third degree polynomial produced the most advantageous results. More particularly, degrees higher than three did not show any significant improvement in the fitted curve. Therefore, a third degree polynomial was used to fit the curve against BER data values.

[0051] The theory and implementation of fitting non-linear curves using a least squares approach will now be described. In many cases data obtained from experimental tests is not linear. As such, it is necessary to fit some other function than a first-degree polynomial to this data. Some common forms

2007200714 19 Feb 2007

that may be used are exponential forms of a type $y=ax^b$ or $y=ae^{bx}$.

[0052] Normal equations for these forms can again be developed by setting the partial derivatives equal to zero, but such nonlinear simultaneous equations are much more difficult to solve than linear equations. Because of this, these forms are usually linearized by taking logarithms before determining the parameters, for example, $\ln y=\ln a+b\ln x$, or $\ln y=\ln a+bx$. Then, a new variable is introduced, i.e., $z=\ln y$ as a linear function of $\ln x$ or x. In this case, instead of minimizing the sum of squares of the deviations of Y from the curve, deviations of $\ln Y$ are minimized. To find which form of curve best fits the BER data, MathCAD mathematical software was used. A BER curve was plotted using MathCAD and different forms of the curve were fitted against the BER data. It was found that an exponential curve defined by $y=ce^{ax}$ provided a desirable fit for the BER data, although other functions may provide desired results in different implementations.

[0053] Data linearization is used to fit a curve of type $y=ce^{ax}$ to the data points given as $(x_1,y_1),(x_2,y_2),\cdots(x_N,y_N)$, where x is the independent variable, y is the dependent variable, and N is the number of x,y pairs. To linearize the data, a logarithm of both sides is taken, i.e., $\ln y=\ln c+ax$. Then a change of variable is introduced, namely $X=x$ and $Y=\ln(y)$, which produces the equation $Y=aX+\ln(c)$. This equation is a linear equation in the variables X and Y, and it can be approximated with a "least square line" of the form $Y=AX+B$. However, in this case, $\ln(y)$ will be used for performing least square approximation instead of y. Comparing the last two equations, it is noticed that $A=a$ and $B=\ln(c)$. Thus, $a=A$ and $c=e^b$ are used to construct the coefficients which are then used to fit the curve $y=ce^{ax}$.

2007200714 19 Feb 2007

[0054] This approach was again programmed in C++. The normal matrix to be solved for this method was only 2x2, which was solved with a relatively high degree of accuracy. Plotted curves for two different sets of data using this approach are illustrated in FIGS. 14 and 15.

[0055] Both of the nonlinear exponential least square and least square polynomial approaches described above approximated the original data with a relatively high degree of accuracy. Generally speaking, the margin of error of the curves generated using these approaches will result in less than a 0.1 dB margin of error in the sensitivity measurement. In addition, the results provided by these methods are also very close to one another. Below are the results obtained by performing exponential and least square polynomial approximation on the two sets of data, namely data set 1 and data set 2. Here 'S' represents the standard error and 'R' represents the Correlation Coefficient.

Results for data set 1:

3rd degree Polynomial Fit: $y=a+bx+cx^2+dx^3...$

Coefficient Data:

a = 1.075334	S = 1.720
b = 0.653063	R = .99168
c = 0.097339	
d = 0.048979	

Exponential Fit: $y=ae^{bx}$

Coefficient Data:

a = 1.092514 Standard Error(S) = 1.690

b = 0.533035 correlation coefficient (R) = .99158

Results for data set 2:

3rd degree Polynomial Fit: $y=a+bx+cx^2+dx^3...$

Coefficient Data:

a = 1.192487	S = 1.101
b = 0.565984	R = .99592

2007200714 19 Feb 2007

c = 0.164962
d = 0.031628

Exponential Fit: $y=ae^{bx}$

Coefficient Data:
a = 1.1846416 S = 1.131
b = 0.5021062 R = .99588

[0056] For both sets of results, the polynomial fit had a slightly higher correlation coefficient than the exponential fit. However, the standard error for the polynomial fit in data set 2 was smaller than for the exponential fit, but in data set 1 the standard error for the exponential fit was smaller than the polynomial fit.

[0057] Based on these results, the exponential fit model was deemed to be more preferable because it did not require inclusion of as many terms as the cubic function. This is because the exponential model $y=ae^{bx}$ provides almost the same accuracy (i.e., up to about the third decimal place) as that of the polynomial method, and it also has a physical interpretation of all the terms in it. Of course, the polynomial method or other approaches may be used in various applications as appropriate, as will be appreciated by those skilled in the art.

[0058] Generally speaking, if the data to be used in curve fitting does not appear to be approximated by a straight line, then there are often equations which can be used to fit the data very well. The first thing that comes to mind when considering the type of curve to fit to the data is a polynomial. This is because polynomials can be applied without much forethought and they are typically successful in matching the shape of the graphed data. However, when a higher degree polynomial is chosen to fit the data, it may be difficult to determine a theoretical basis for the coefficients in the polynomial equation. It is preferable to have such a basis for

2007200714 19 Feb 2007

why a particular model is chosen, and that model should have some type of physical interpretation of each of the parameters in it.

[0059] Advantages of using linearizable equations to fit data are notable. Typically, curves of this type are somewhat easier to understand or predict than polynomials. That is, proper choice of the curve to fit the data can lead to insight concerning underlying mechanisms which produce the data. Secondly, manipulations of these curves such as differentiation, integration, interpolation and extrapolation can be made more confidently than can those with polynomials. Third, linearizable curves often require fewer numbers of parameters for estimation of values than do polynomials. As a result, the normal matrix may be small and can be solved with a relatively high degree of accuracy. Thus, this reduces the need to solve large sets of linear equations which often have an undesirable property of ill-conditioning. Thus, for BER data, Applicants have determined that it is generally desirable to use nonlinear forms such as logarithms, inversions, and exponentials to find the linearizable curve to match the shape of the data before resorting to a higher degree polynomial.

[0060] Having generated the BER vs. TCH power level function for the initial channel based upon measured BER values within the target range, this function may then be used to advantageously perform a fast search for the desired BER and corresponding TCH power level value in each of the subsequent channels in a given frequency band. First, an estimated or starting TCH power level for the subsequent channel is chosen based upon the BER vs. TCH power level function and the desired BER, at Block **42**. That is, an estimate of the TCH power level that will correspond to the desired BER in the subsequent channel is determined and used as a starting point to hone in on the actual TCH power level

2007200714 19 Feb 2007

for the desired BER. For purposes of the present discussion, a desired BER of 2.44% will be assumed, although other desired BERs may be appropriate based upon the given standard or carrier requirement that is to be met, as will be appreciated by those skilled in the art.

[0061] It should be noted that the estimated TCH power level may be chosen based upon the path loss function noted above. That is, one approach to determining the estimated TCH power level for the subsequent channel is to use the TCH power level for the initial channel that corresponds to the desired BER (i.e., 2.44%) and offset this value by the difference between the initial and subsequent channel path loss values on the path loss function (or actual measured values if a path loss function is not used), as will be appreciated by those skilled in the art (Block **42'**).

[0062] Once the estimated TCH power level is determined, then the BER of the subsequent channel is measured based thereon, at Block **43**. If the measured BER is not within the target BER range (e.g., 1.0 to 3.0%), then the above-described coarse step search may be used to determine a TCH power level that is within the range. If the measured BER is within the target range, it is compared with the desired BER value, and the difference (i.e., delta) therebetween is used along with the BER vs. TCH power level function to determine a next estimated TCH power level, at Block **44**. From the above discussion of the TCH power level function, it will be appreciated by those skilled in the art that the next estimated TCH power level may be estimated according to the relationship $\Delta BER = bce^{bx}\Delta TCHlevel$, since the ΔBER and the coefficient **b** are known.

[0063] If the measured BER is not within a threshold range of the desired BER (e.g., ± 0.15%), at Block **45**, the steps described above with reference to Blocks **43** and **44** are repeated until a TCH power level corresponding to the desired

2007200714 19 Feb 2007

BER (i.e., within the threshold range) is found, at Block **46**, thus concluding the method illustrated in FIG. 3. Yet, if still further accuracy is desired, a linear approximation may be used, at Block **46'**. More particularly, within a relatively small 0.3% BER range (i.e., the ± 0.15% BER threshold range), the shape of the BER vs. TCH power level curve will be approximately linear. Therefore, this linear relationship may be used to provide still further accuracy, as will be appreciated by those skilled in the art.

[0064] Turning now to FIGS. 2 and 5, a test system **30'** and method for determining RF receiver radiated sensitivity are now described. The test system **30'** includes the RF source **31'** (e.g., a base station emulator), an RF controlled enclosed environment, and the wireless handheld device receiver **32'**. As will be appreciated by those skilled in the art, an RF controlled enclosed environment is an electromagnetic (EM) wave shield environment, such as the illustrated EM anechoic chamber **37'** (which may be a full or semi-anechoic chamber), a shield room or an RF enclosure. An antenna **35'** connected to the RF source **31'** is positioned within the anechoic chamber **37'** and connected to the RF source **31'** by a coaxial cable to simulate a base station. An antenna **36'** for the wireless handheld device is also positioned within the anechoic chamber **37'** and connected to the handheld receiver **32'**. It should be noted that in typical tests the handheld receiver **32'** and antenna **36'** will be carried by a device housing, but these components may be tested without the device housing if desired.

[0065] Generally speaking, the radiated receiver sensitivity search is the same as that described above for a conducted receiver sensitivity search with the exception of the path loss determination process. More specifically, the relationship between path loss values for a plurality of wireless channels in a frequency band will typically not be a

2007200714 19 Feb 2007

linear function, as is the case for the RF cable **33**. This is because path loss can be affected by factors such as antenna gain, antenna directivity and the measurement environment. Typically the path loss will be different for different wireless channels.

[0066] Even so, a path loss function may still be determined for the frequency band using similar approaches to those described above for determining the BER vs. TCH power level function (e.g., a least squares approximation, etc.), at Block **48''**. By way of example, the five-step path loss search described above with reference to FIG. 13 may be performed on a subset of the channels within the band, such as every 10th channel. This approach advantageously allows an accurate path loss function to be determined for the entire band to provide path loss estimates for every channel, yet without taking the time to individually measure the path loss of each channel. The path loss function is then used in determining the estimated TCH power level for the subsequent channel, at Block **42''**, as described further above.

[0067] The path loss determination process will now be described in further detail with reference to FIG. 6. Beginning at Block **60**, RF path losses are measured for at least some of the RF channels within the RF frequency band, at Block **61**. Using the above-noted example, path loss is measured every M channels. By way of example, M may be 10, although other intervals may also be used. An RF path loss function is determined based upon the measured RF path losses of the at least some RF channels, at Block **62**, and an RF path loss for at least one other channel within the given RF frequency band is determined based upon the RF path loss function, at Block **63**, thus concluding the illustrated method (Block **64**).

[0068] The choice of M generally depends on the linearity of the system. That is, a linear system would only require two points to be measured, regardless of the number of the

2007200714 19 Feb 2007

channels or frequency bandwidth. As the non-linearity or order of the system increases, the order of a single curve fitting equation should correspondingly increase to obtain a proper fitting. A least squares method, or other non-linear fitting methods, may be used. Many methods use matrices inversion where size is relative to the order of the equation. An inversion is increasingly complex and error prone as its dimensions increase. The least squares method requires a matrices inversion. Due to the nature of radio systems over large frequency spans, higher order path loss responses can exist.

[0069] Path loss curve fitting may also be performed using a plurality of splines. That is, many partial equations replace one complete equation. Sets of consecutive points (e.g., four consecutive points) are grouped on a rotating basis. For example, the first four points are used for generating the first spline series, the 2nd to 5th points for the second spline series, and so on. All but the first and last spline series use only intermediate points (e.g., the equation from points 2 to 3) as valid fitting equations. Using intermediate points for the equations leaves the first and last two points without respective equations. Different spline methods vary first and last spline construction. One method, an extrapolated cubic spline, uses the first two splines of the first series (e.g., points 1 to 2), the last two splines of the last series (e.g. points 3 to 4). Other suitable spline fit methods may also be used, as will be appreciated by those skilled in the art.

[0070] Referring to FIG. 16, two sine wave curves produced from respective series of splines are shown. Each curve is a spline fitting of a sine wave. Each line is one spline series within the spline fitting. The series are offset by -0.5 dB per spline series to show the overlapping spline series. Without the offset, the consecutive spline series would

2007200714 19 Feb 2007

overlap. Data was taken from every 10th point. The upper figure is constructed of four point splines. The lower figure shows the upper spline with only the used data transposed, as mentioned above. The respective sine curves are offset by 4 dB for clarity purposes. Bold and dotted lines show the intermediate line transposition of the upper figure to the lower.

[0071] As noted above, path loss curve fitting reduces the measurement time of non-measured channels. Time is improved in systems with consecutive channel path loss difference exceeding the interpolation error. Linear interpolation will advantageously result in typical accuracy of under ±0.1 dB. The path loss method described above with reference to FIG. 6 may be used for radiated and conducted path loss measurements, as will be appreciated by those skilled in the art.

[0072] Another factor that may need to be accounted for in certain path loss/receiver sensitivity test measurements is the hysteresis of the particular handheld device under test. More particularly, receiver path loss is measured by comparing base station emulator TCH level output against the signal received by the handheld device and relayed to the emulator as RSSI. Consecutive 0.1 dB adjustments of the emulator's amplification will detect a region at which the change in amplification yields a change in RSSI. At this "edge" point the radio could oscillate between two RSSI readings with no amplification change. This edge point may be caused by system error, changing position or changing signal intensity, for example. As the RSSI readings oscillate, the handheld device could respond by changing its transmitter power in a similar oscillatory pattern, affecting the handheld power management. As such, many handheld devices manufacturers implement software within each mobile handheld device to change the edge to account for this problem.

2007200714 19 Feb 2007

[0073] More particularly, the problematic single RSSI edge point is divided into two different values. These two points straddle the actual edge point by an amount typically less than 0.5 dB, which is set within the handheld. As the received TCH level changes, the RSSI edge point will be reported prematurely, as shown in FIG. 17. This dual-edge system, known as hysteresis, decreases the likelihood of any oscillations within the RSSI and TX power control. As the device RSSI decreases, the reported RSSI to the base station emulator will change in such a way as to remove any oscillations if the device RSSI increases by only a small amount.

[0074] While the hysteresis prevents oscillations, it also creates an offset from the true RSSI edge. For a known device with known hysteresis, the value can be applied as an offset to each channel. For an unknown device, the hysteresis may need to be determined using a stepping algorithm, and then factored in to each path loss channel. The hysteresis is removed to obtain the true edge point. The hysteresis typically applies to all channels the same within a given band.

[0075] One exemplary method for determining path loss including a hysteresis search is now described with reference to FIG. 7. It should be noted that this approach may be used either for conducted path loss or radiated path loss, as will be appreciated by those skilled in the art. Beginning at Block **70**, a pair of hysteresis edges is determined about a given RSSI value transition at the RF receiver by sweeping RF power values transmitted from the RF source in increasing and decreasing directions, at Block **71**. A relationship is determined between the relatively fine granularity RF power values and the relative coarse granularity RSSI values using the hysteresis transition edges, at Block **72**. More particularly, since the RSSI transition point for the receiver **32** or **32'** is located half-way between the hysteresis

2007200714 19 Feb 2007

transition edges, the location of the actual RSSI transition relative to the TCH power level may be determined once the TCH power levels corresponding to the hysteresis transition edges are known. RF path loss for a given channel may then be determined based upon a given RSSI at a given RF power value and the determined relationship between the relatively fine granularity RF power values and the relative coarse granularity RSSI values, at Block **73**, thus concluding the illustrated method (Block **74**).

[0076] The scan finds the edge point as the TCH level is increased and decreased. By way of example, the coarse granularity RSSI values may be in 1.0 dB increments (i.e., the reported accuracy of the handheld receiver), while the relatively fine granularity increments may be 0.1 dB (i.e., the accuracy of the internal receiver amplifier(s)). To find the first edge, the internal amplification of the receiver may be increased in +0.1 dB increments until the edge is found. Then, a +1.0 dB step may be taken, followed by a series of -0.1 dB steps until the second edge is found. The actual RSSI value will be located half-way between the two edges. It should be noted that the direction first measured has no bearing on the results, as either edge can be found first. That is, the first hysteresis edge could be found with -0.1 dB steps, followed by a -1.0 dB step and +0.1 dB steps to find the second hysteresis edge, as will be appreciated by those skilled in the art.

[0077] Further aspects of the test method are now described with reference to FIG. 8. The RF source **31** or **31'** transmits RF power values at a relatively fine granularity, and the RF receiver **32** or **32'** generates RSSI values at a relatively coarse granularity and have an unknown hysteresis about each transition between adjacent RSSI values, as noted above. A signal is transmitted from the RF source **31** or **31'** at an initial RF power level, and a corresponding initial RSSI value

2007200714 19 Feb 2007

of the RF receiver **32** or **32'** is measured, at Block **80'**. An initial internal amplification of the RF source **31** or **31'** is set based upon a difference between the initial RF power level and the corresponding initial RSSI value, at Block **75'**, to thereby calibrate the RF receiver **32** or **32'** with the RF source.

[0078] In addition, the method may also include repeating the three determining steps for at least one other given RF channel in the given RF frequency band to determine a plurality of RF path losses, at Blocks **76'** and **77'**, and determining an RF path loss function based upon the plurality of RF path losses at Block **78'**, using a least squares algorithm, a plurality of splines, etc., as discussed further above. An RF path loss for at least one other channel within the given RF frequency band may then be determined based upon the RF path loss function, at Block **79'**.

[0079] Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

2007200714 19 Feb 2007

THAT WHICH IS CLAIMED IS:

1. A test method for determining conducted radio frequency (RF) receiver sensitivity defined based upon a traffic channel (TCH) power level at a desired bit error rate (BER) for a plurality of channels extending over at least one frequency band using an RF source coupled to an RF receiver by an RF cable, the test method comprising:

determining a BER versus TCH power level function for an initial channel;

determining an estimated TCH power level for a subsequent channel based upon the BER versus TCH power level function and the desired BER;

measuring a BER of the subsequent channel based upon the estimated TCH power level;

comparing the measured BER to the desired BER and using a difference therebetween along with the BER versus TCH power level function to determine a next estimated TCH power level; and

repeating measuring and comparing if the difference is greater than a threshold to thereby determine a TCH power level in the subsequent channel corresponding to the desired BER.

2. The test method of Claim 1 wherein determining the BER versus TCH power level function for the initial channel comprises:

measuring respective TCH power levels for a plurality of BERs within a target BER range; and

determining the BER versus TCH power level function based upon the measured BERs in the target BER range.

3. The test method of Claim 2 wherein the target BER range is from about one to three percent.

2007200714 19 Feb 2007

4. The test method of Claim 1 further comprising using a linear approximation to determine the TCH power level in the subsequent channel corresponding to the desired BER when the difference between the measured BER and the desired BER is less than or equal to the threshold.

5. The test method of Claim 1 wherein the BER versus TCH power level function comprises an exponential function.

6. The test method of Claim 1 wherein determining the BER versus TCH power level function comprises determining the BER versus TCH power level function based upon a least squares algorithm.

7. The test method of Claim 1 wherein the RF receiver comprises a Global System for Mobile Communications (GSM) receiver.

8. The test method of Claim 1 wherein the RF receiver comprises a General Packet Radio Service (GPRS) receiver.

9. The test method of Claim 1 wherein the RF receiver comprises an Enhanced Data Rates for Global System for Mobile Communications (GSM) Evolution (EDGE) receiver.

10. The test method of Claim 1 wherein the RF source comprises a base station emulator.

11. A test system for determining conducted radio frequency (RF) receiver sensitivity defined based upon a traffic channel (TCH) power level at a desired bit error rate (BER) for a plurality of channels extending over at least one frequency band, the system comprising:

2007200714 19 Feb 2007

an RF source;

an RF receiver;

an RF cable coupling said RF source to said RF receiver; and

a test controller coupled to said RF receiver for

determining a BER versus TCH power level function for an initial channel,

determining an estimated TCH power level for a subsequent channel based upon the BER versus TCH power level function and the desired BER,

measuring a BER of the subsequent channel based upon the estimated TCH power level,

comparing the measured BER to the desired BER and using a difference therebetween along with the BER versus TCH power level function to determine a next estimated TCH power level, and

repeating measuring and comparing if the difference is greater than a threshold to thereby determine a TCH power level in the subsequent channel corresponding to the desired BER.

12. The test system of Claim 11 wherein said test controller determines the BER versus TCH power level function for the initial channel by:

measuring respective TCH power levels for a plurality of BERs within a target BER range; and

determining the BER versus TCH power level function based upon the measured BERs in the target BER range.

13. The test system of Claim 12 wherein the target BER range is from about one to three percent.

14. The test system of Claim 11 wherein said test controller uses a linear approximation to determine the TCH

2007200714 19 Feb 2007

power level in the subsequent channel corresponding to the desired BER when the difference between the measured BER and the desired BER is less than or equal to the threshold.

15. The test system of Claim 11 wherein the BER versus TCH power level function comprises an exponential function.

16. The test system of Claim 11 wherein said test controller determines the BER versus TCH power level function by determining the BER versus TCH power level function based upon a least squares algorithm.

17. The test system of Claim 11 wherein said RF receiver comprises a Global System for Mobile Communications (GSM) receiver.

18. The test system of Claim 11 wherein said RF receiver comprises a General Packet Radio Service (GPRS) receiver.

19. The test system of Claim 11 wherein said RF receiver comprises an Enhanced Data Rates for Global System for Mobile Communications (GSM) Evolution (EDGE) receiver.

20. The test system of Claim 11 wherein said RF source comprises a base station emulator.

21. A test method for determining conducted radio frequency (RF) receiver sensitivity substantially as hereinbefore described with reference to the accompanying drawings.

2007200714 19 Feb 2007

22. A test system for determining conducted radio frequency (RF) receiver sensitivity substantially as hereinbefore described with reference to the accompanying drawings.

2007200714 19 Feb 2007

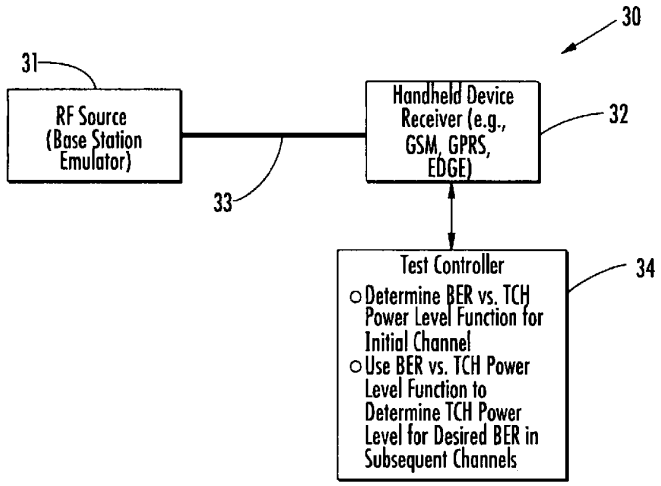


FIG. 1

2007200714 19 Feb 2007

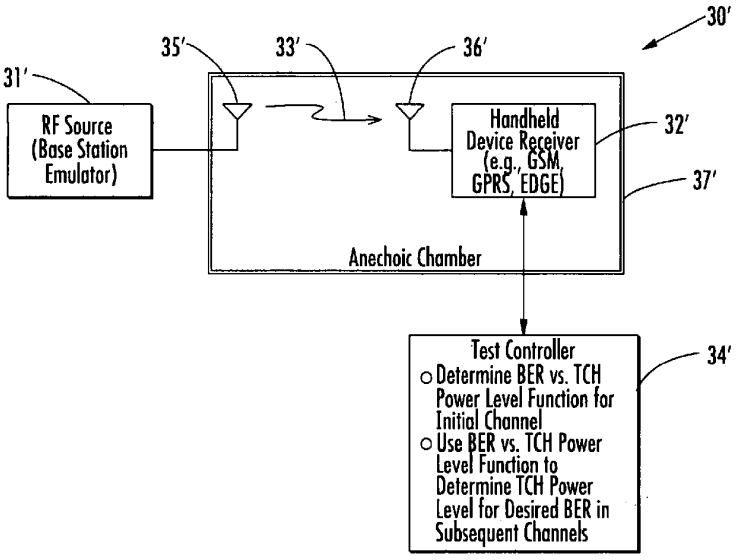


FIG. 2

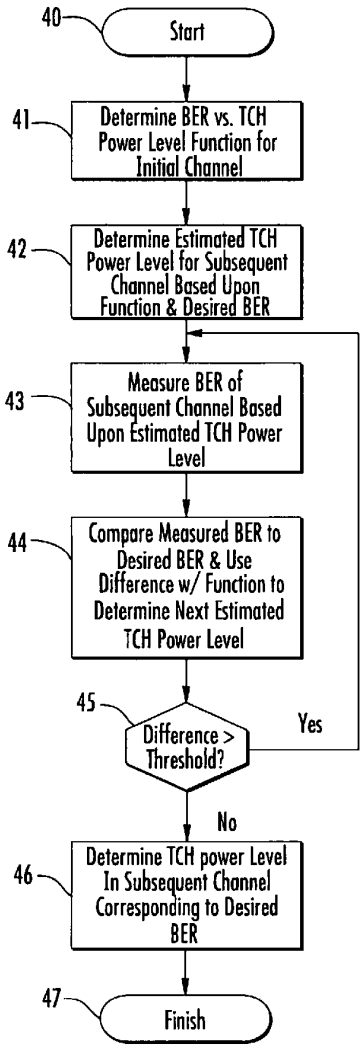

40
Start
41
Determine BER vs. TCH Power Level Function for Initial Channel
42
Determine Estimated TCH Power Level for Subsequent Channel Based Upon Function & Desired BER
43
Measure BER of Subsequent Channel Based Upon Estimated TCH Power Level
44
Compare Measured BER to Desired BER & Use Difference w/ Function to Determine Next Estimated TCH Power Level
45
Difference > Threshold?
Yes
No
46
Determine TCH power Level In Subsequent Channel Corresponding to Desired BER
47
Finish

FIG. 3

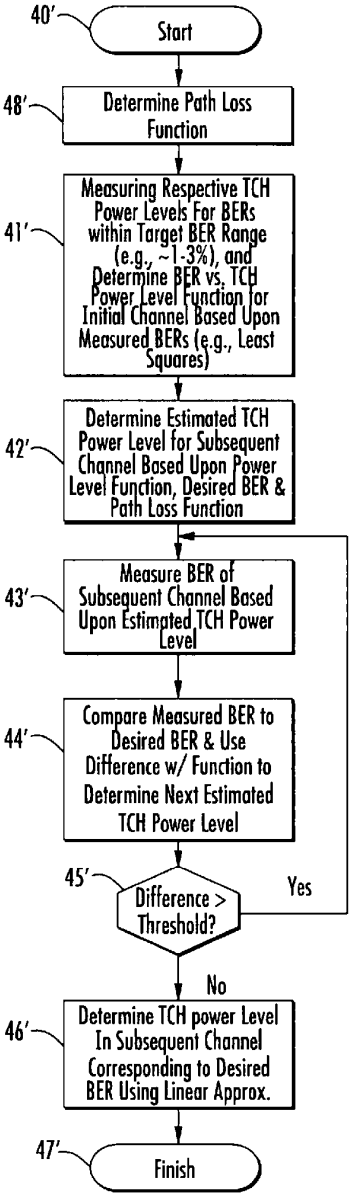

40'
Start
48'
Determine Path Loss Function
41'
Measuring Respective TCH Power Levels For BERs within Target BER Range (e.g., ~1-3%), and Determine BER vs. TCH Power Level Function for Initial Channel Based Upon Measured BERs (e.g., Least Squares)
42'
Determine Estimated TCH Power Level for Subsequent Channel Based Upon Power Level Function, Desired BER & Path Loss Function
43'
Measure BER of Subsequent Channel Based Upon Estimated TCH Power Level
44'
Compare Measured BER to Desired BER & Use Difference w/ Function to Determine Next Estimated TCH Power Level
45'
Difference > Threshold?
Yes
No
46'
Determine TCH power Level In Subsequent Channel Corresponding to Desired BER Using Linear Approx.
47'
Finish

FIG. 4

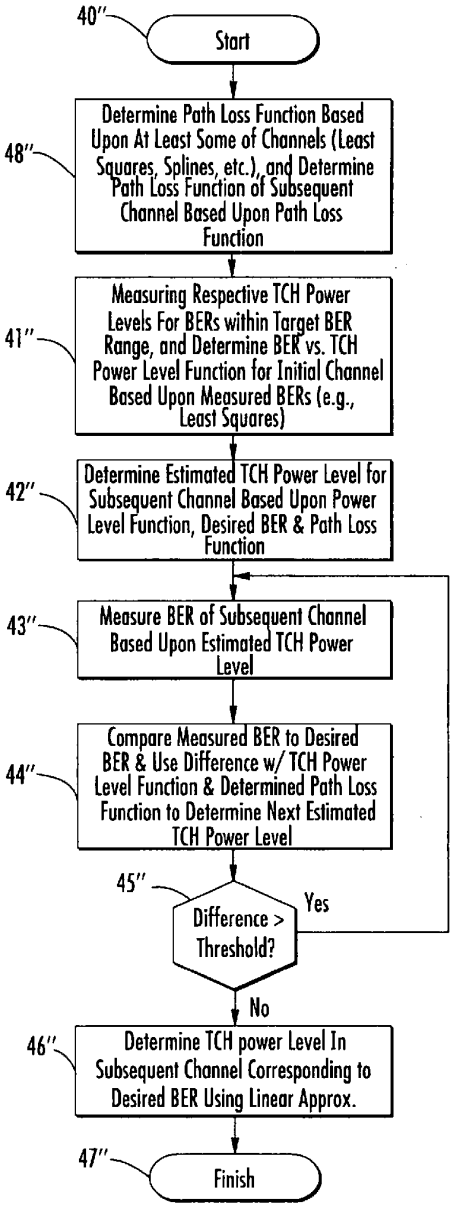

40″
Start
48″
Determine Path Loss Function Based Upon At Least Some of Channels (Least Squares, Splines, etc.), and Determine Path Loss Function of Subsequent Channel Based Upon Path Loss Function
41″
Measuring Respective TCH Power Levels For BERs within Target BER Range, and Determine BER vs. TCH Power Level Function for Initial Channel Based Upon Measured BERs (e.g., Least Squares)
42″
Determine Estimated TCH Power Level for Subsequent Channel Based Upon Power Level Function, Desired BER & Path Loss Function
43″
Measure BER of Subsequent Channel Based Upon Estimated TCH Power Level
44″
Compare Measured BER to Desired BER & Use Difference w/ TCH Power Level Function & Determined Path Loss Function to Determine Next Estimated TCH Power Level
45″
Difference > Threshold?
Yes
No
46″
Determine TCH power Level In Subsequent Channel Corresponding to Desired BER Using Linear Approx.
47″
Finish

FIG. 5

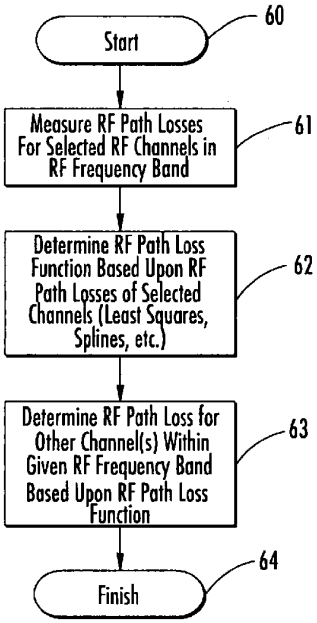

Start
60
Measure RF Path Losses For Selected RF Channels in RF Frequency Band
61
Determine RF Path Loss Function Based Upon RF Path Losses of Selected Channels (Least Squares, Splines, etc.)
62
Determine RF Path Loss for Other Channel(s) Within Given RF Frequency Band Based Upon RF Path Loss Function
63
Finish
64

FIG. 6

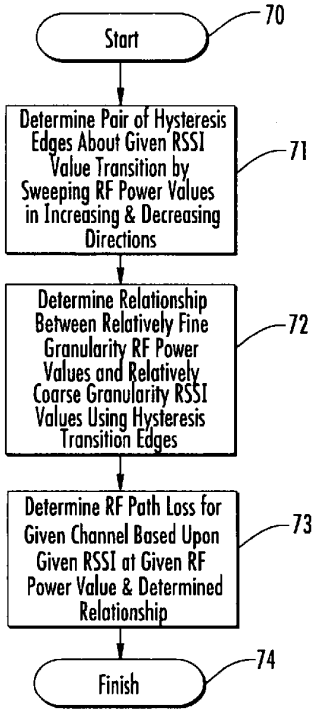

Start
70
Determine Pair of Hysteresis Edges About Given RSSI Value Transition by Sweeping RF Power Values in Increasing & Decreasing Directions
71
Determine Relationship Between Relatively Fine Granularity RF Power Values and Relatively Coarse Granularity RSSI Values Using Hysteresis Transition Edges
72
Determine RF Path Loss for Given Channel Based Upon Given RSSI at Given RF Power Value & Determined Relationship
73
Finish
74

FIG. 7

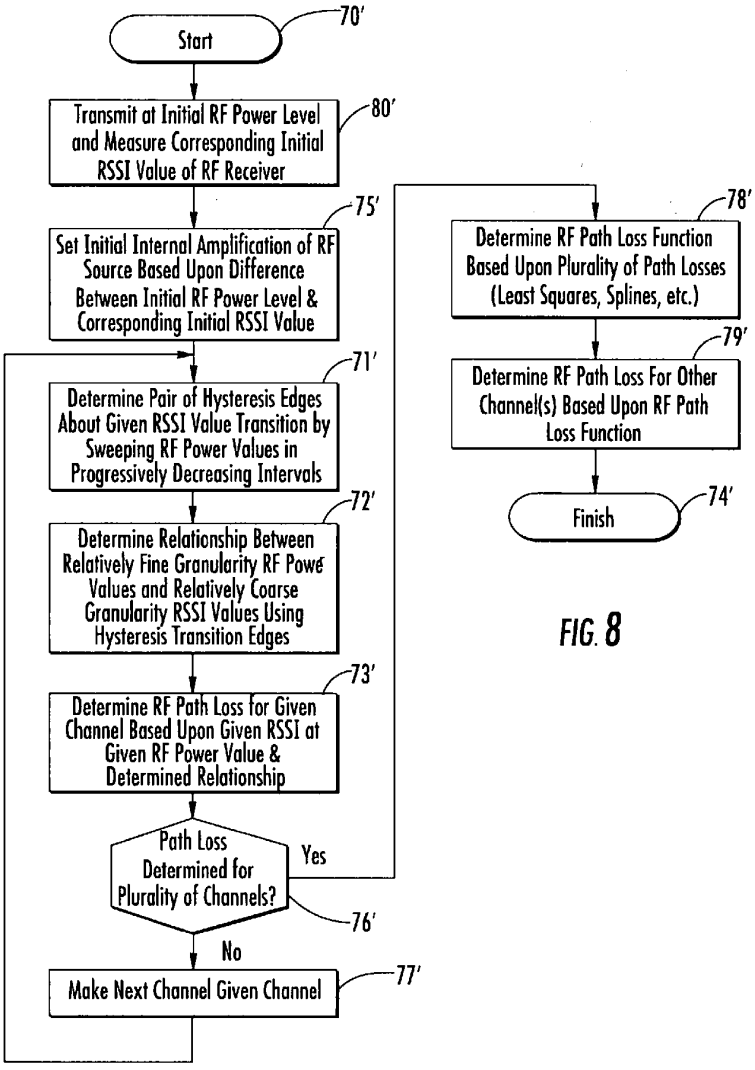

Start
70'
Transmit at Initial RF Power Level and Measure Corresponding Initial RSSI Value of RF Receiver
80'
Set Initial Internal Amplification of RF Source Based Upon Difference Between Initial RF Power Level & Corresponding Initial RSSI Value
75'
Determine Pair of Hysteresis Edges About Given RSSI Value Transition by Sweeping RF Power Values in Progressively Decreasing Intervals
71'
Determine Relationship Between Relatively Fine Granularity RF Powe Values and Relatively Coarse Granularity RSSI Values Using Hysteresis Transition Edges
72'
Determine RF Path Loss for Given Channel Based Upon Given RSSI at Given RF Power Value & Determined Relationship
73'
Path Loss Determined for Plurality of Channels?
Yes
76'
No
Make Next Channel Given Channel
77'
Determine RF Path Loss Function Based Upon Plurality of Path Losses (Least Squares, Splines, etc.)
78'
Determine RF Path Loss For Other Channel(s) Based Upon RF Path Loss Function
79'
Finish
74'

FIG. 8

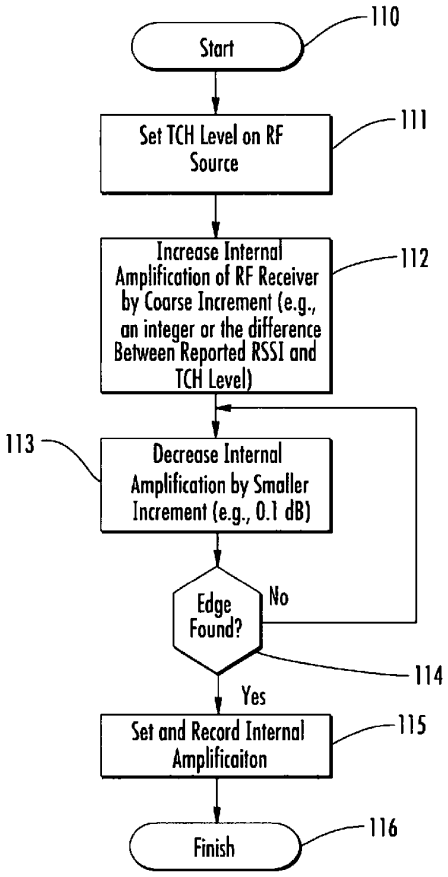

Start
110
Set TCH Level on RF Source
111
Increase Internal Amplification of RF Receiver by Coarse Increment (e.g., an integer or the difference Between Reported RSSI and TCH Level)
112
113
Decrease Internal Amplification by Smaller Increment (e.g., 0.1 dB)
Edge Found?
No
114
Yes
Set and Record Internal Amplificaiton
115
Finish
116

FIG. 9

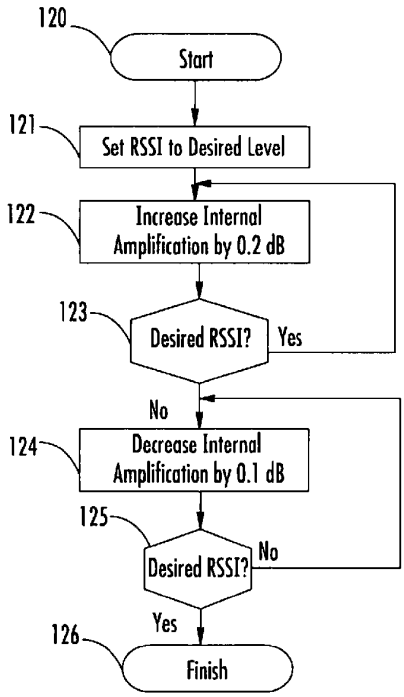

120
Start
121
Set RSSI to Desired Level
122
Increase Internal Amplification by 0.2 dB
123
Desired RSSI?
Yes
No
124
Decrease Internal Amplification by 0.1 dB
125
Desired RSSI?
No
Yes
126
Finish

FIG. 10

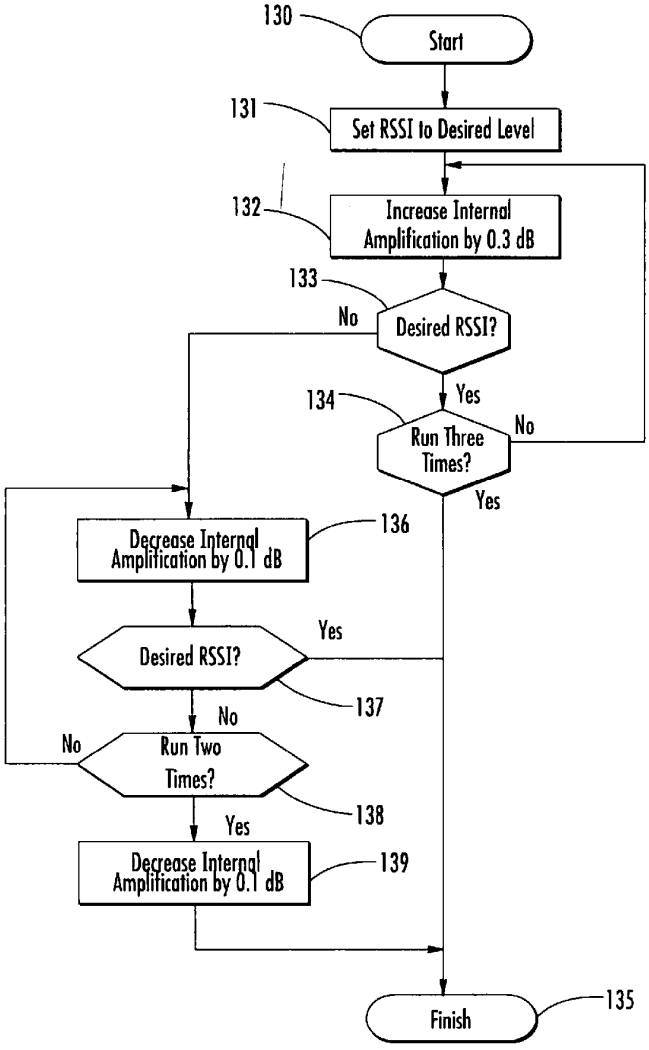

130
Start
131
Set RSSI to Desired Level
132
Increase Internal Amplification by 0.3 dB
133
Desired RSSI?
No
Yes
134
Run Three Times?
No
Yes
136
Decrease Internal Amplification by 0.1 dB
Desired RSSI?
Yes
137
No
No
Run Two Times?
138
Yes
139
Decrease Internal Amplification by 0.1 dB
Finish
135

FIG. 11

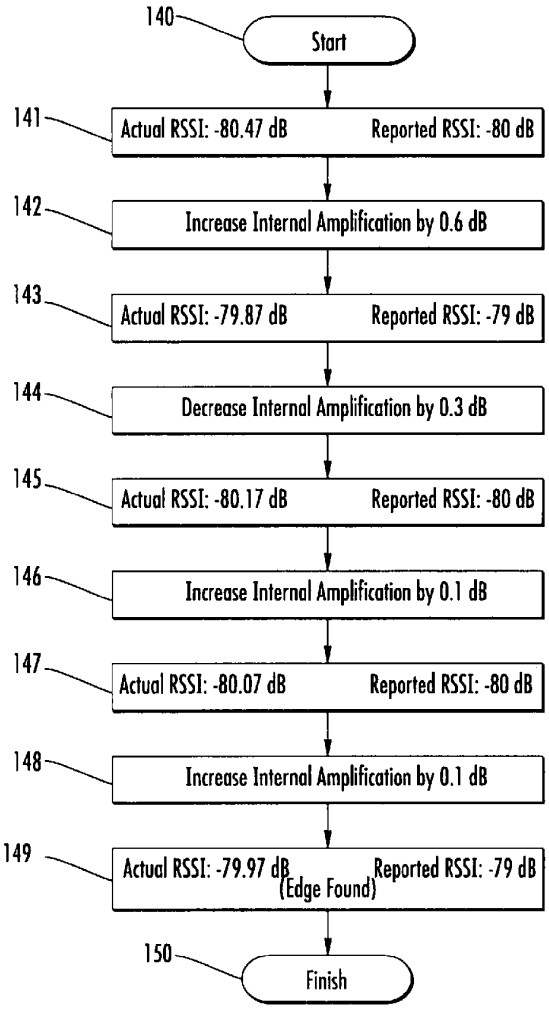

140
Start
141
Actual RSSI: -80.47 dB
Reported RSSI: -80 dB
142
Increase Internal Amplification by 0.6 dB
143
Actual RSSI: -79.87 dB
Reported RSSI: -79 dB
144
Decrease Internal Amplification by 0.3 dB
145
Actual RSSI: -80.17 dB
Reported RSSI: -80 dB
146
Increase Internal Amplification by 0.1 dB
147
Actual RSSI: -80.07 dB
Reported RSSI: -80 dB
148
Increase Internal Amplification by 0.1 dB
149
Actual RSSI: -79.97 dB
Reported RSSI: -79 dB
(Edge Found)
150
Finish

FIG. 12

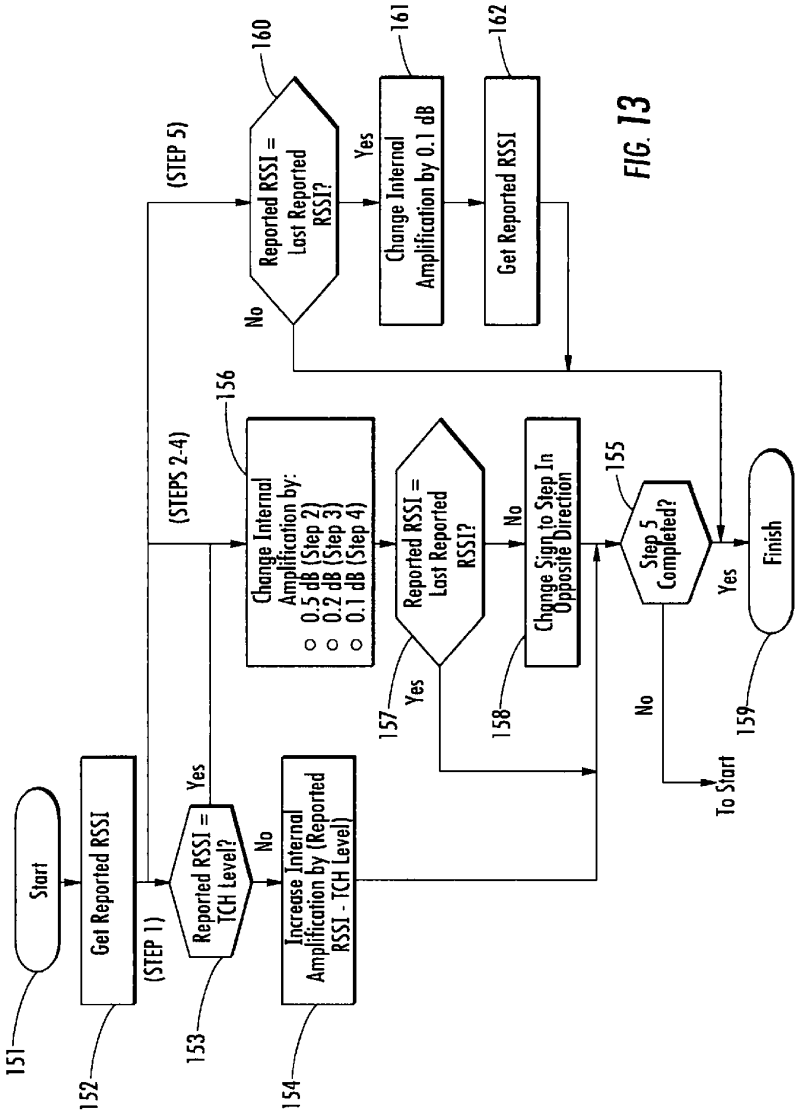

Start
151
Get Reported RSSI
152
(STEP 1)
Reported RSSI = TCH Level?
153
Yes
No
Increase Internal Amplification by (Reported RSSI - TCH Level)
154
(STEPS 2-4)
Change Internal Amplification by:
o 0.5 dB (Step 2)
o 0.2 dB (Step 3)
o 0.1 dB (Step 4)
156
Reported RSSI = Last Reported RSSI?
157
Yes
No
Change Sign to Step In Opposite Direction
158
Step 5 Completed?
155
No
To Start
Yes
Finish
159
(STEP 5)
Reported RSSI = Last Reported RSSI?
160
No
Yes
Change Internal Amplification by 0.1 dB
161
Get Reported RSSI
162

FIG. 13

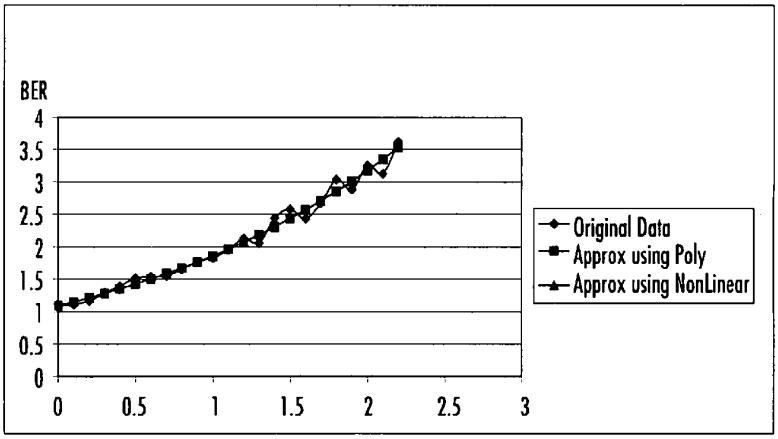

BER
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
Original Data
Approx using Poly
Approx using NonLinear
TCH Level Change

FIG. 14

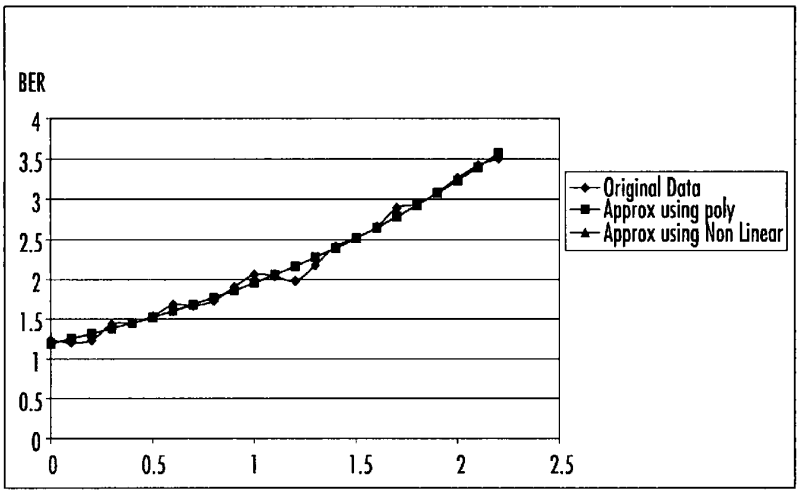

BER
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
Original Data
Approx using poly
Approx using Non Linear
TCH Level Change

FIG. 15

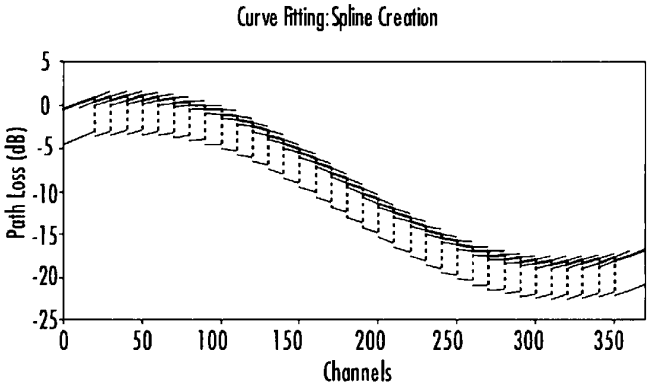

Curve Fitting: Spline Creation
Path Loss (dB)
5
0
-5
-10
-15
-20
-25
0
50
100
150
200
250
300
350
Channels

FIG. 16

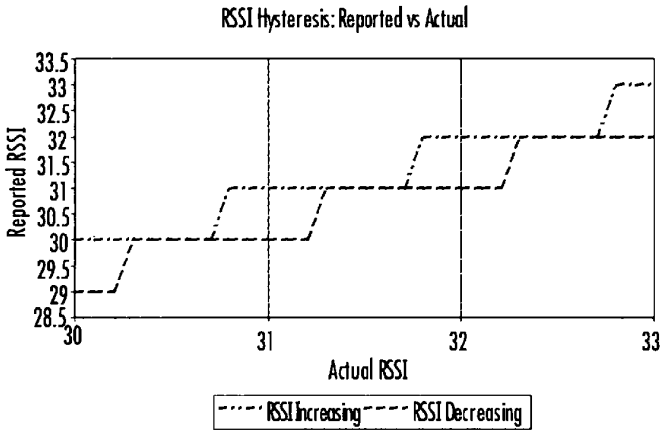

RSSI Hysteresis: Reported vs Actual
Reported RSSI
33.5
33
32.5
32
31.5
31
30.5
30
29.5
29
28.5
30
31
32
33
Actual RSSI
RSSI Increasing
RSSI Decreasing

FIG. 17

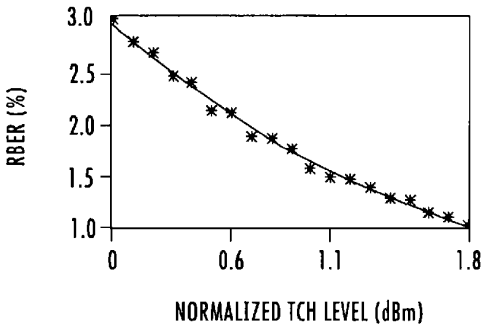


FIG. 18