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(54) **MIXER MEASUREMENT SYSTEM AND METHOD USING A CHAOTIC SIGNAL**

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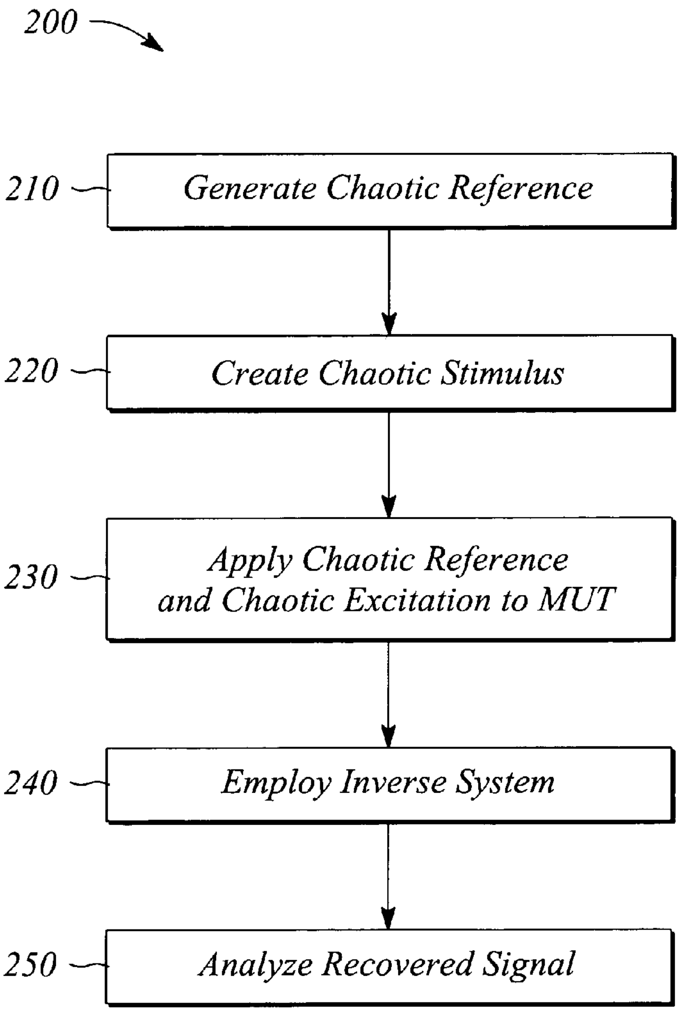
(57) **ABSTRACT**

A mixer measurement system and method use a chaotic signal to characterize a mixer under test. The mixer measurement system includes a chaotic reference source, an excitation source at an input end of the mixer under test and an inverse system at an output end of the mixer under test. The inverse system removes a chaotic component from a response signal from the stimulated mixer under test to produce a recovered signal having an included distortion that is characteristic of the mixer under test. The method of characterizing a mixer includes applying the chaotic stimulation to the mixer under test to obtain a response signal and employing the inverse system to remove the chaotic component from the response signal.



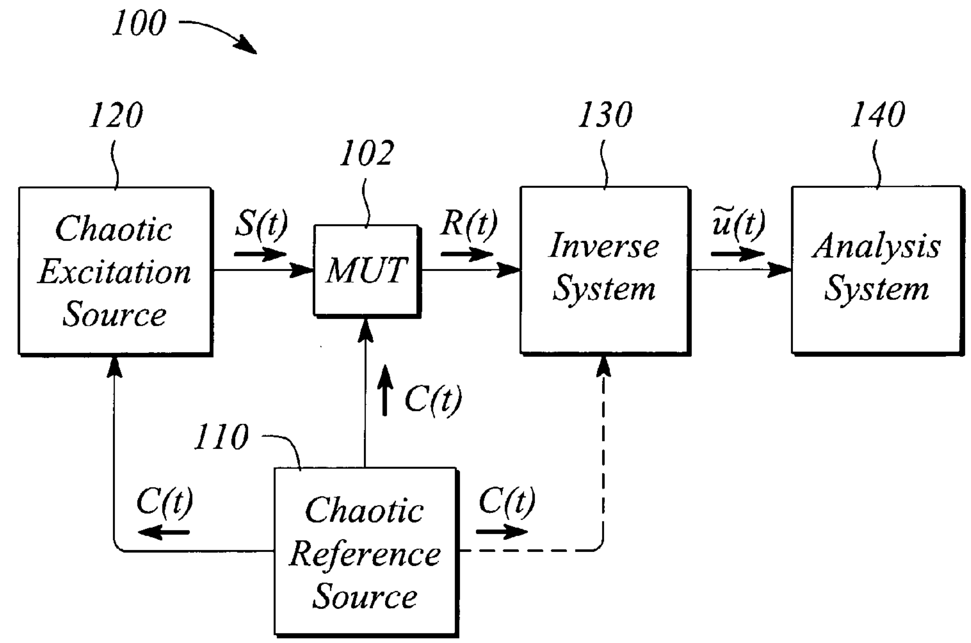

100
120
102
130
140
Chaotic Excitation Source
S(t)
MUT
R(t)
Inverse System
$\tilde{u}(t)$
Analysis System
C(t)
110
C(t)
Chaotic Reference Source
C(t)

FIG. 1

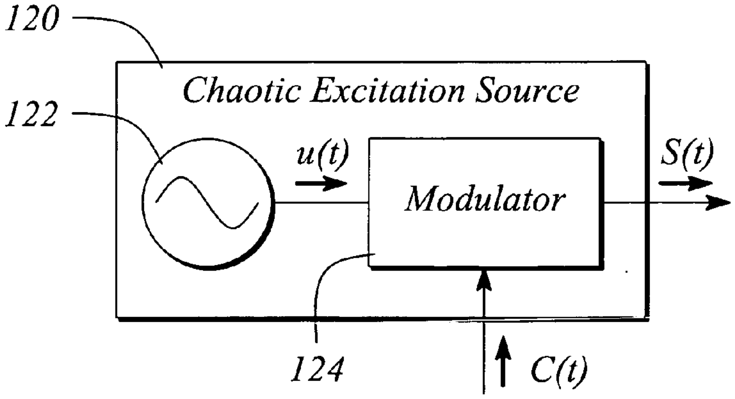

120
Chaotic Excitation Source
122
u(t)
Modulator
S(t)
124
C(t)

FIG. 2

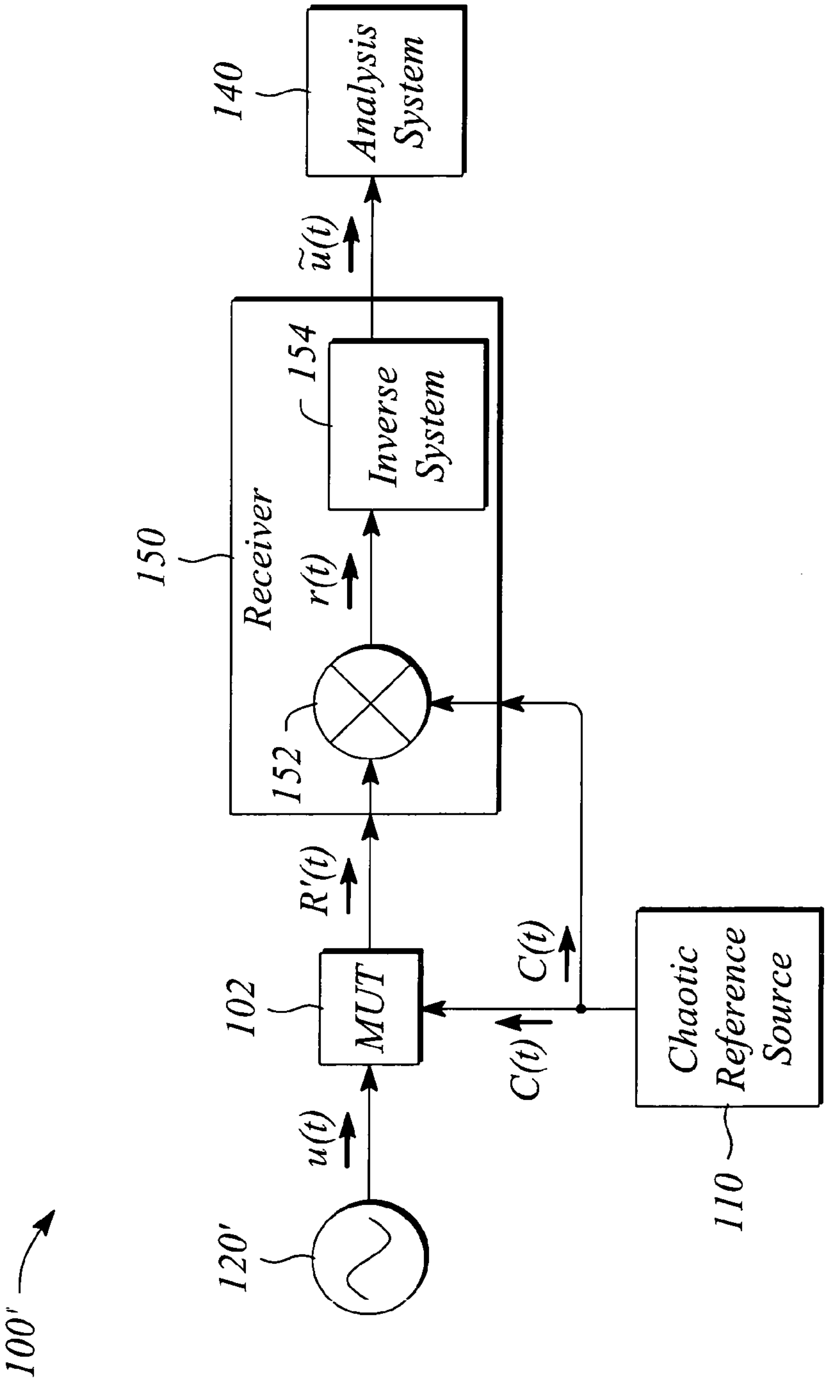

100'
120'
u(t)
102
MUT
C(t)
C(t)
Chaotic Reference Source
110
R'(t)
150
Receiver
152
r(t)
154
Inverse System
ũ(t)
140
Analysis System

FIG. 3

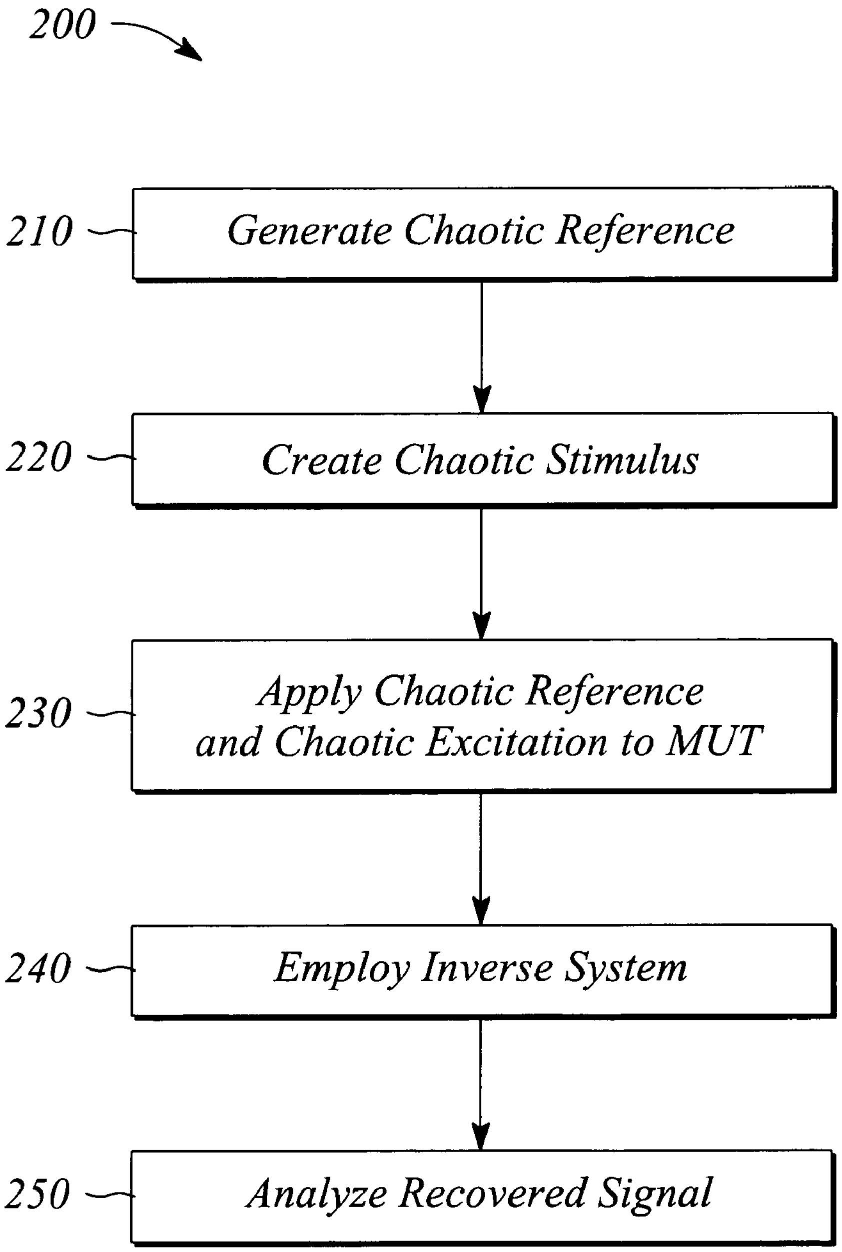

200
210
Generate Chaotic Reference
220
Create Chaotic Stimulus
230
Apply Chaotic Reference and Chaotic Excitation to MUT
240
Employ Inverse System
250
Analyze Recovered Signal

FIG. 4

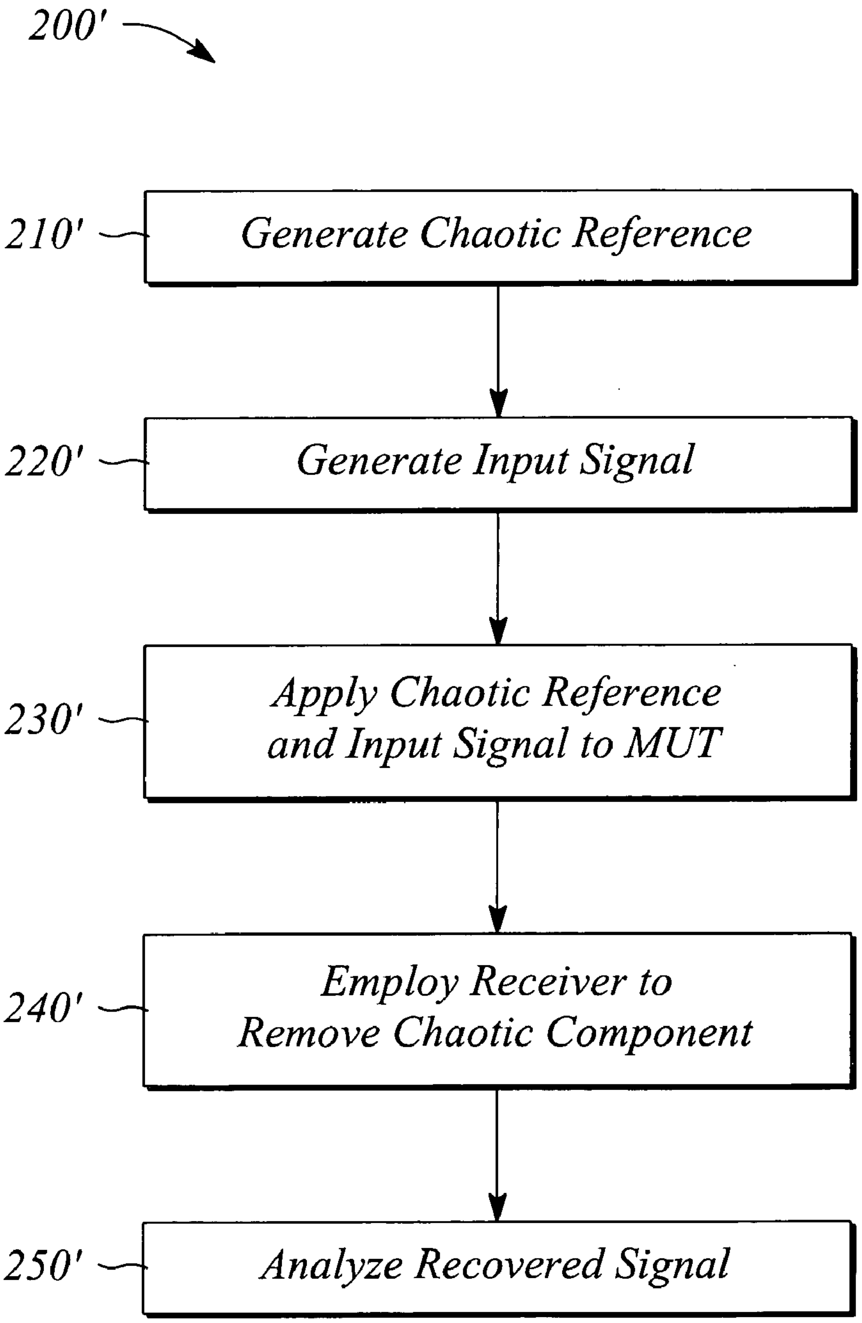

200'
210'
Generate Chaotic Reference
220'
Generate Input Signal
230'
Apply Chaotic Reference and Input Signal to MUT
240'
Employ Receiver to Remove Chaotic Component
250'
Analyze Recovered Signal

FIG. 5

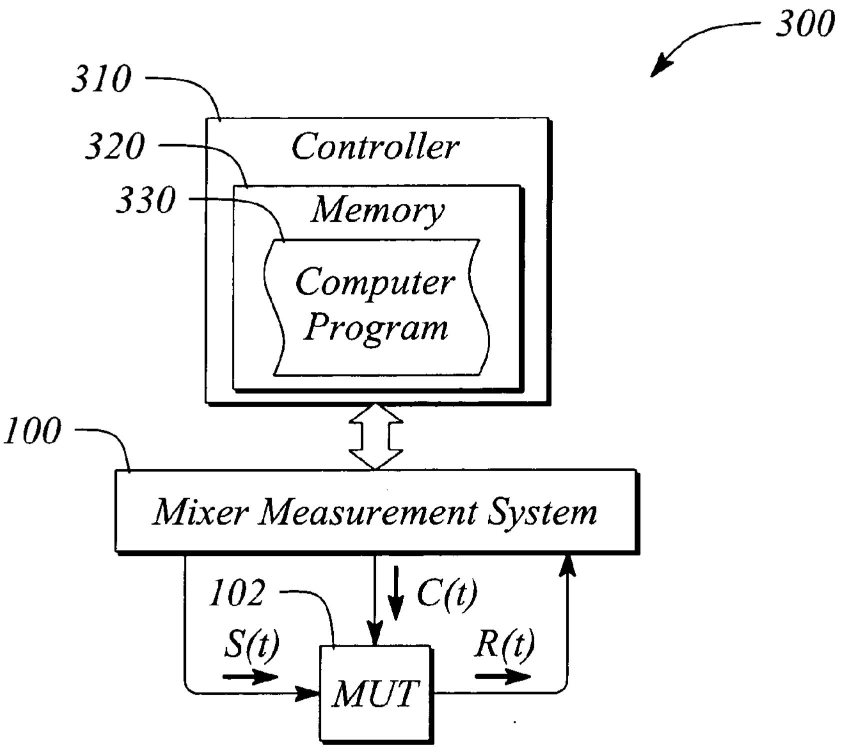

300
310
320
330
Controller
Memory
Computer Program
100
Mixer Measurement System
102
C(t)
S(t)
R(t)
MUT

FIG. 6

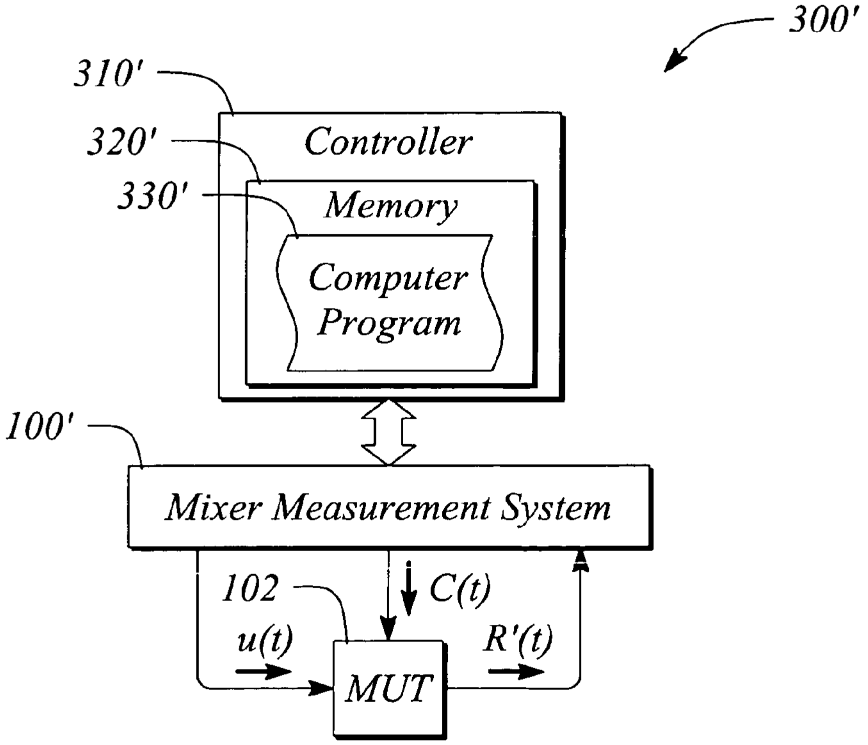

300'
310'
320'
330'
Controller
Memory
Computer Program
100'
Mixer Measurement System
102
C(t)
u(t)
R'(t)
MUT

FIG. 7

MIXER MEASUREMENT SYSTEM AND METHOD USING A CHAOTIC SIGNAL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] N/A

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] N/A

BACKGROUND

[0003] A mixer is a three-port device that has a pair of input ports and an output port. Mixers are often used as signal multipliers. As a signal multiplier, the mixer may be used to produce an output or product signal by multiplying together a pair of input signals. A typical use of a mixer is for effecting frequency translations in upconversion and downconversion stages of transmitters and receivers. For example, a mixer may be used to multiply together a radio frequency (RF) signal applied to a first input port (e.g., RF port) and a local oscillator (LO) signal at a second input port (e.g., LO port) to generate an intermediate frequency (IF) signal at the output port (e.g., IF port). As such, analog mixers and their digital counterparts find use in a wide variety of radar, communication and signal processing systems and related applications.

[0004] While the function of a mixer is to multiply input signals to produce an output signal representing a product of the input signals, mixers are real devices that exhibit non-ideal, 'nonlinear' or spurious outputs in addition to the desired product of signals. As such, characterization of the non-ideal or 'non-linear' performance of a mixer is typically an important component in the manufacturing and testing of both mixers and the systems that employ mixers.

[0005] There are many possible metrics that can be and often are used to characterize mixer nonlinearities including, but not limited to, total harmonic distortion (THD), second order distortion, third order distortion, and multiple signal intermodulation distortion. In the time domain, an analogous metric to THD is root mean square (RMS) error between an actual output signal produced by a mixer and an ideal signal from an ideal model of the mixer. To characterize mixer nonlinearities, conventional mixer test systems typically apply one or more single-frequency sinusoidal signals to each of the mixer input ports and measure the output signal at the output port. The results of such a test exemplify the mixer performance at essentially a single frequency or set of single frequencies. As such, to characterize a mixer across an operational band of frequencies of interest, many 'single-frequency' tests, each at a different frequency across the operational band, are typically employed. Only after completing many single-frequency tests can a complete broadband characterization of the mixer be constructed or synthesized from the various individual tests.

BRIEF SUMMARY

[0006] In some embodiments of the present invention, a mixer measurement system employing a chaotic signal is provided. The mixer measurement system comprises a chaotic reference source having an output that produces a chaotic reference signal on a first input of a mixer under test. The mixer measurement system further comprises an excitation source having an output that produces a stimulus signal on a second input of the mixer under test, the mixer under test generating a response signal that includes a distortion introduced by the mixer under test. The mixer measurement system further comprises an inverse system that removes a chaotic component from the response signal to measure a recovered signal that includes the distortion.

[0007] In other embodiments of the present invention, a method of characterizing a mixer using a chaotic signal is provided. The method of characterizing comprises applying a stimulus signal and a chaotic reference signal to inputs of a mixer under test to produce a response signal from an output of the mixer under test. The method of characterizing further comprises employing an inverse system on the response signal to remove a chaotic component from the response signal such that a recovered signal having an included distortion that is characteristic of the mixer under test is produced.

[0008] Certain embodiments of the present invention have other features that are one or both of in addition to and in lieu of the features described above. These and other features of the invention are detailed below with reference to the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The various features of embodiments of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, where like reference numerals designate like structural elements, and in which:

[0010] FIG. **1** illustrates a block diagram of a mixer measurement system according to an embodiment of the present invention.

[0011] FIG. **2** illustrates a block diagram of a chaotic excitation source according to an embodiment of the present invention.

[0012] FIG. **3** illustrates a block diagram of a mixer measurement system according to another embodiment of the present invention.

[0013] FIG. **4** illustrates a flow chart of a method of characterizing a mixer using chaotic stimulation according to an embodiment of the present invention.

[0014] FIG. **5** illustrates a flow chart of a method of characterizing a mixer using chaotic stimulation according to another embodiment of the present invention.

[0015] FIG. **6** illustrates a block diagram of a mixer measurement system according to another embodiment of the present invention.

[0016] FIG. **7** illustrates a block diagram of a mixer measurement system according to another embodiment of the present invention.

DETAILED DESCRIPTION

[0017] The embodiments of the present invention facilitate characterizing a broadband performance of a mixer. In some embodiments, a nonlinear performance is characterized. The characterization is performed using a multi-frequency or broadband stimulation signal having a rich or extended spectral structure. As a result, some embodiments of the present invention may provide a broadband characterization of the mixer with a single test. Various embodiments of the present invention are applicable to characterizing a wide variety of analog mixers including, but not limited to, intermediate frequency (IF) mixers, radio frequency (RF) mixers, microwave mixers, and millimeter band mixers. Other embodiments characterize digital mixers and related multiplier circuits. Examples of broadband nonlinear characterizations that may be realized with various embodiments of the present invention include, but are not limited to, total harmonic distortion (THD), second order distortion characterization, and third order distortion and intermodulation characterization.

[0018] According to some embodiments of the invention, a chaotic signal is employed as a reference signal in conjunction with a chaotic excitation source to essentially provide a baseband-to-baseband test of a mixer under test (MUT). In some embodiments, a chaotic excitation signal S(t) is produced by the chaotic excitation source using an arbitrary input signal u(t) and a chaotic reference signal C(t) from a chaotic reference source. The chaotic excitation signal S(t) is applied to a first input of the MUT. The chaotic reference signal C(t) is applied to a second input port of the MUT. The MUT produces an output or response signal R(t). The response signal R(t) is applied to an inverse system that produces a recovered signal ũ(t) that essentially represents the input signal u(t) plus distortions introduced by the MUT. In some embodiments, the recovered signal ũ(t) is analyzed to quantify the distortions. For example, the recovered signal ũ(t) may be compared to the input signal u(t) using a multiple regression analysis to estimate one or more parameters associated with the distortions introduced by the MUT (e.g., THD, second order distortions, third order distortions, etc.)

[0019] As used herein, the term 'chaotic' used with a signal refers to a signal that exhibits chaotic motion or chaotic oscillation. For a signal to exhibit chaotic oscillation, a characteristic of the signal (e.g. one or both of magnitude and phase, as a function of time) generally follows or 'traces out' an essentially chaotic trajectory or orbit when plotted or viewed in a state space or as a phase diagram (i.e., the signal exhibits chaotic motion). Specifically, when plotted or represented in state space, a characteristic of the chaotic signal will exhibit or trace out a trajectory exemplified by a strange attractor as opposed to a so-called normal attractor. A chaotic signal may be an output of, or produced by, a chaotic system, for example. The chaotic system is defined as a system in which a characteristic or operational mode thereof is governed by, or is defined in terms of, chaos theory.

[0020] Chaos theory is a branch of both mathematics and physics that deals with certain nonlinear dynamical systems known to exhibit chaos. A principle characteristic of chaos is a high degree of sensitivity to initial conditions. In particular, a fundamental property of chaotic oscillation is an inherent, long-term unpredictability associated with small variations or perturbations in an initial condition of a deterministic system. For example, a deterministic system having an output which diverges rapidly (e.g., exponentially) in essentially differing directions in state space, as a result of small perturbations in the initial conditions of the system, exhibits chaos and is typically termed a 'chaotic system'. For example, a Lorenz system associated with a so-called Lorenz attractor is a well-known chaotic system that may be employed to generate a chaotic signal. A Lorenz system, defined in terms of coupled differential equations, is described in more detail below. Chaos theory and examples of other chaotic systems and signals are familiar to one skilled in the art as exemplified by N. B. Tufillaro et al., *An Experimental Approach to Nonlinear Dynamics and Chaos,* Addison-Wesley, 1992, incorporated herein by reference.

[0021] Chaos and chaotic outputs may arise in certain types of solutions to a differential equation or a set of differential equations. In particular, when a solution has two orbits or trajectories in state space, such that the two orbits begin close together for close initial conditions and diverge essentially exponentially from one another as time progresses, the solution is typically considered to exhibit chaos, i.e., a chaotic solution.

[0022] A classical example of a chaotic system described by such a chaotic solution type is that of a differential equation describing an inverted pendulum started or released at an apex of the pendulum's motion. Small perturbations in an initial condition (e.g., initial or release location) of the inverted pendulum result in a motion of the pendulum away from the apex that is in either a clockwise or a counterclockwise direction about a point of rotation of the pendulum. When plotted in state space, these small perturbations in the initial condition of the pendulum produce two distinctly different and rapidly diverging orbits, one for the clockwise rotation and a second for the counterclockwise rotation.

[0023] Another example of a chaotic system is a dynamical system governed or described by the Lorenz system comprising a system of three coupled ordinary differential equations (ODEs) given by equation (1)

$$\begin{aligned} x' &= \sigma(x-y) \\ y' &= rx-y-xz \\ z' &= xy-bz \end{aligned} \tag{1}$$

where variables x', y' and z' are first derivatives with respect to time of variables x, y and z, respectively, and parameters σ, b and r are arbitrary predetermined constants, for example and not by way of limitation, parameter σ may equal 10, parameter b may equal 8/3, and parameter r may equal 28.

[0024] FIG. **1** illustrates a block diagram of a mixer measurement system **100** according to an embodiment of the present invention. The mixer measurement system **100** stimulates a mixer under test (MUT) **102** with a chaotic signal. A response of the stimulated MUT **102** is detected and measured by the mixer measurement system **100** to characterize the MUT **102**. In particular, a chaotic signal component embedded in a stimulation signal applied to the MUT **102** is employed by the mixer measurement system **100** to perform a broadband characterization a nonlinear performance exhibited by the MUT **102**. The nonlinear performance results in distortion of a response signal produced by the MUT **102** when stimulated by the mixer measurement system **100**.

[0025] As illustrated in FIG. **1**, the measurement system **100** comprises a chaotic reference source **110**. The chaotic reference source **110** produces a chaotic reference signal C(t). Essentially any signal source capable of producing a chaotic signal C(t) may be employed as the chaotic reference source **110**. For example, an arbitrary waveform generator appropriately programmed to generate the chaotic reference signal C(t) may be employed as the chaotic reference source **110**. In another example, a computer simulation of a chaotic system (e.g., solution to a set of differential equations), an output of which is passed through a digital to analog converter (DAC), may be employed as the chaotic reference source **110**. In yet another example, an oscillator modulated by a chaotic system may be employed as the chaotic reference source **110**.

[0026] An output of the chaotic reference source **110** is connected to an input port of the MUT **102** such that the chaotic reference signal C(t) is applied to the MUT **102**. In general, the chaotic reference source **110** may be connected to either one of the input ports of the MUT **102**. For example, when the connection is to an local oscillator (LO) input port of the MUT **102**, the chaotic reference signal C(t) acts as an LO signal. When the chaotic reference source **110** output is connected to an RF input port of the MUT **102**, the chaotic reference signal C(t) acts as an RF signal, for example.

[0027] For discussion purposes and not by way of limitation, the MUT **102** will be described in terms of a down-converting RF MUT **102** having an LO input port, an RF input port and an IF output port unless otherwise noted. One skilled in the art may readily extend the discussion herein to operating other frequency bands (e.g., IF band, millimeter band) and to an upconverting MUT **102** without undue experimentation.

[0028] The mixer measurement system **100** further comprises a chaotic excitation source **120** that produces a chaotic stimulus signal S(t) at an output thereof. The chaotic stimulus signal S(t) is synchronized with the chaotic reference signal C(t). In particular, the chaotic excitation source **120** produces the chaotic stimulus signal S(t) comprising a component that is proportional to the chaotic reference signal C(t). As such, the chaotic stimulus signal S(t) and the chaotic reference signal C(t) are said to be ‘synchronized’ by virtue of the proportionality therebetween.

[0029] In some embodiments, the chaotic reference source **110** is connected to the chaotic excitation source **120** such that the chaotic excitation source **120** receives the chaotic reference signal C(t). Such a connection is illustrated in FIG. **1**. The chaotic reference signal C(t) received by the chaotic excitation source **120** through the connection may be employed to facilitate the above-mentioned synchronization.

[0030] In some embodiments, the chaotic stimulus signal S(t) may comprise an arbitrary input signal u(t) that is modulated by the chaotic reference signal C(t). For example, the input signal u(t) may be a sinusoidal signal with a center frequency at or near a center of a frequency band of interest for the characterization. In some embodiments, the input signal u(t) is multiplied by the chaotic reference signal C(t) to achieve the modulation and produce the chaotic stimulus signal S(t).

[0031] The output of the chaotic excitation source **120** is connected to another input of the MUT **102** other than the MUT **102** input to which the output of the chaotic reference source **110** is attached. For example, when the chaotic reference source **110** is connected to the LO port of the MUT **102**, the chaotic excitation source **120** is connected to the RF input port of the MUT **102**. As such, the chaotic stimulus signal S(t) is applied as a second input signal to the MUT **102**.

[0032] FIG. **2** illustrates a block diagram of a chaotic excitation source **120** according to an embodiment of the present invention. As illustrated in FIG. **2**, the chaotic excitation source **120** comprises a signal source **122** and a modulator **124**. The signal source **132** includes, but is not limited to, a continuous wave (CW) source, such as an oscillator, a digital to analog (DAC) converter driven by a computer having a computer program that implements a model of a signal, and an appropriately programmed arbitrary waveform generator, for example. In other embodiments, the signal source **122** is a digital signal source such as, but not limited to, a computer having a computer program or a dedicated circuit implementing a digital signal source (e.g., discrete logic circuit, ASIC, etc.). The signal source **122** produces the input signal u(t), which is applied to the modulator **124**.

[0033] The modulator **124** receives the input signal u(t) from the signal source **122** and further receives the chaotic reference signal C(t) from the chaotic reference source **110**. The modulator **124** imparts a modulation to the input signal u(t) that is proportional to the chaotic reference signal C(t). A modulated output signal produced by the modulator **124** is the chaotic stimulus signal S(t) of the chaotic excitation source **120** illustrated in FIGS. **1** and **2**, depending on the embodiment.

[0034] In general, the modulator **124** may be essentially any analog modulator, digital modulator, or combination thereof that can modulate the signal from the signal source **122** according to the chaotic reference signal C(t). In some embodiments, the modulator **124** is a mixer **124**. The mixer **124** is essentially a signal multiplier that multiplies together a pair of signals to produce a product thereof. The mixer **124** employs the chaotic reference signal C(t) as a chaotic carrier. The input signal u(t) from the signal source **132** is essentially ‘added’ by the action of the mixer **124** to the chaotic carrier as a sideband to produce the chaotic excitation signal S(t). In other embodiments, the modulator **124** is a digital modulator that receives a digital input or inputs and generates an analog output signal compatible with the MUT **102** input. In such embodiments, the modulator **124** may be a digital multiplier followed by a DAC, for example. Also, in such embodiments, the chaotic reference source **110** may provide a digital representation of the chaotic reference signal C(t) to the digital modulator **124**.

[0035] For example, the modulator **124** may comprise an analog voltage multiplier such as, but not limited to, a microwave or millimeter wave mixer and an analog multiplier (i.e., either real or complex). In another example, the modulator **124** comprises a digital multiplier. In yet other exemplary embodiment, the modulator **124** is implemented as a computer program in either a general purpose computer or a specialized processor. Examples of a specialized processor include, but are not limited to, a discrete logic circuit, a signal processor and an application specific integrated circuit (ASIC).

[0036] In some embodiments (not illustrated), the chaotic excitation source **120** may further comprise an output (e.g., an output port) that is connected to an input (e.g., an input port) of the chaotic reference source **110**. A signal produced by the chaotic excitation source **120** at the output may be the input signal u(t) from the signal source **122**, for example. In such embodiments, the chaotic reference source **110** may employ the input signal u(t) in generating the chaotic reference signal C(t). For example, the chaotic reference source **110** may employ the input signal u(t), as described by the modulator equations (2) discussed below.

[**0037**] The MUT **102** produces a response signal R(t) from the applied chaotic reference signal C(t) and chaotic stimulus signal S(t) of the mixer measurement system **100**. For an ideal mixer, the response signal R(t) is simply a product of the applied signals. However, the MUT **102** has nonlinearities that manifest as distortions. As such, the response signal R(t) is a distorted product of the applied chaotic reference signal C(t) and chaotic stimulus signal S(t).

[**0038**] The mixer measurement system **100** further comprises an inverse system that acts as a receiver that receives the response signal R(t) and generates a recovered signal ũ(t). FIG. **1** illustrates an embodiment of the mixer measurement system **100** having an inverse system **130**, wherein an output of the MUT **102** is connected to an input of the inverse system **130**. FIG. **3** illustrates an embodiment of a mixer measurement system **100'** having an inverse system **154** included in a receiver **150**. An output of the MUT **102** is connected to an input of the receiver **150** and indirectly connected to the inverse system **154**. The embodiment of the mixer measurement system **100'** is described in more detail later. In both embodiments, the inverse system **130**, **154** generates the above-mentioned recovered signal ũ(t).

[**0039**] As discussed above, the recovered signal ũ(t) essentially represents the input signal u(t) plus distortions introduced by the MUT **102**. As used herein, the 'inverse system' is defined as any system that essentially implements a mathematical inverse of a chaotic modulation present in the response signal R(t). In other words, the inverse system essentially inverts non-transient behavior of a nonlinear dynamical system represented by the chaotic modulation. In particular, the inverse system may be implemented as, or described by, a set or system of inverse demodulator equations that essentially undo or implement an inverse of a set or system of modulator equations. Examples of using inverse functions in chaotic communications system is described by Abel et al., in "Chaos Communications—Principles, Schemes, and System Analysis,"*Proc. IEEE,* Vol. 90, No. 5, May 2002, pp. 691-710, incorporated herein by reference. In some embodiments of the inverse system, specific knowledge of how the chaotic modulation is created is employed in order to undo or remove it from the chaotic response signal R(t).

[**0040**] In some embodiments of the chaotic reference source that employ the inverse system, the chaotic reference signal C(t) may essentially transmit or carry an explicit copy of an input signal u(t). In addition, when a difference system is used to generate the chaotic reference signal C(t), the difference system may have a fixed point at an origin to assist in self-synchronization between a signal used to stimulate the MUT **102** and a response signal from the MUT **102**. Further, in order to provide relatively robust synchronizations in view of small perturbations, the fixed point may be hyperbolic, in some embodiments. Moreover, in some embodiments, eigenvalues of the fixed point are essentially negative such that transients will decay relatively quickly. Such a chaotic reference signal C(t) may be readily implemented as a simple analog circuit, for example. Examples of circuits that may be employed to generate the chaotic reference signal C(t) for use with the inverse system is presented by J. C. Sprott, "Simple chaotic systems and circuits,"*Am. J. Phys.,* Vol. 68, No. 8, August 2000, pp. 758-763, and by K. Kiers et al., "Precision measurement of a simple chaotic circuit,"*Am. J. Phys.,* Vol. 72, No. 4, April 2004, pp. 503-509, both of which are incorporated by reference herein.

[**0041**] For example and not by way of limitation, a nonautonomous, three-dimensional oscillator system described in terms of a 3-dimensional state vector x=(x_1(t), x_2(t), x_3(t)) may be employed to generate a suitable chaotic reference signal C(t) by modulator equations (2) below. The modulator equations are given by

$$x'=Ax+bf(x,u)$$
$$y=c^Tx+f(x,u)$$
$$f(x,u)=(x_1+DC)^2\cdot u(t) \tag{2}$$

where the vector x' is a first time derivative of the state vector x, the variable y is an output of the modulator equations (2), the matrix A is a constant matrix that defines a linear dynamic differential equation given by x'=Ax, the vector b is a 3-dimensional column vector of predetermined, arbitrarily chosen coefficients (e.g., $b=[0,0,1]^T$), the vector c^T is a transpose of another 3-dimensional vector of predetermined, arbitrarily chosen coefficients (e.g., $c^T=[1,0,0]$), and the term DC is a predetermined, arbitrarily chosen, constant offset. A first variable x_1(t) of the vector x is referred to as a modulator. The modulator x_1(t) may be passed through a band-limiting filter so that the variable has a well-defined center frequency. In some embodiments, the well-defined center frequency is much higher than a center frequency of the input signal u(t). In some embodiments, the modulator x_1(t) is essentially equivalent to the chaotic reference signal C(t). The function $f(\cdot)$ may be essentially any function. Explicit reference to time t is suppressed in the modulator equations (2) for notational simplicity and not by way of limitation.

[**0042**] Inverse demodulator equations corresponding to the modulator equations (2) may be given by demodulator equations (3) as

$$z'=Az+b(y-c^Tz)$$
$$\tilde{u}=f^{-1}(z,y-c^Tz) \tag{3}$$

where the vector z' is a first time derivative of the state vector z, and $f^{-1}(\cdot)$ is an inverse of the function $f(\cdot)$ with respect to the input signal u. In equations (3), the term ũ is essentially the input signal u(t) plus any signal characteristics or distortion products introduced by the action of the MUT **102**. As such, ũ (i.e., ũ(t)) represents an output of the mixer measurement system **100** that may be analyzed for information (e.g., distortion) regarding performance of the MUT **102**.

[**0043**] In some embodiments, the inverse function $f^{-1}(\cdot)$ is essentially a function that produces a feedback (e.g., a simplest feedback) that will create chaotic motion for parameter regions that are experimentally realizable. For example, if the function $f(\cdot)$ is a quadratic function, the inverse dynamical system and associated inverse function $f^{-1}(\cdot)$ is readily determined using the quadratic formula and keeping track of which root of the quadratic is being employed. In general, the inverse function $f^{-1}(\cdot)$ may be determined either analytically or numerically (e.g., using a root finding algorithm). For example, see M. Sain et al., "Invertibility of Linear Time-Invariant Dynamical Systems, "*IEEE Trans. Automatic Control,* Vol. 14, No. 2, April 1969, pp. 141-149, incorporated herein by reference.

[0044] A difference system applicable to the above-described modulator equations (2) and demodulator equations (3) is described by equations (4) as

$$d'=A\surd d-b(c^{T}\cdot d)$$

$$d=x-z \tag{4}$$

where the vector d' is a state vector of the difference system. The difference system described by equations (4) essentially measures the difference between the input and output signals. Specifically, the difference system state vector d approaches zero as the systems represented by the modulator equations (2) and the demodulator equations (3), respectively, become synchronized.

[0045] In an example of employing equations (2)-(4), let the vector c=0, so that the scalar variable $y=f(x,u)$ and the inverse system simply comprises an inverse function $f^{1}(x,u)$ with respect to the input signal u(t). The exemplary chaotic stimulus signal S(t) created by the excitation source **120** and applied to an input of the MUT **102** may be given by a last equation of the modulator equations (2), namely $S(t)=(x_1(t)+DC)\cdot u(t)$. Similarly, the chaotic response signal R(t) equals $(x_1(t)+DC)^2\cdot u(t)$. For the example, the inverse system may comprise an inverse of a quadratic function where $f(\cdot)$ is a quadratic function and an inverse of a cubic function where $f(\cdot)$ is a cubic function. In either case, the inverse function is generally known analytically.

[0046] In some embodiments of the inverse system **130** illustrated in FIG. **1**, the inverse system **130** is implemented as a specialized computer processor or computer program executed by a general purpose computer. Examples of a specialized processor include, but are not limited to, a discrete logic circuit, a signal processor and an application specific integrated circuit (ASIC). In other embodiments, the inverse system **130** may comprise a filter that filters the product of the chaotic stimulus signal S(t) and the chaotic reference signal C(t). In such embodiments, the filter may comprise a lowpass transfer function and is termed a 'lowpass' filter. In various embodiments, the filter may be implemented as one or more of an analog filter and a digital filter, depending on a particular realization and application of the inverse system **130**.

[0047] In some embodiments, the mixer measurement system **100** illustrated in FIG. **1** further comprises an analysis system **140**. The analysis system **140** essentially extracts from the recovered signal ũ(t) the distortions introduced by the MUT **102**. The analysis system **140** further quantifies the distortions. In some embodiments, the analysis system **140** is implemented as one or more of a specialized computer processor (e.g., signal processor) or computer program executed by a general purpose computer. A specific implementation of the analysis system **140** depends on a specific distortion or distortions being characterized as well as the method used to extract the distortion(s).

[0048] In some embodiments, the analysis system **140** implements an optimization function for a particular metric or metrics of interest. The analysis system **140** further implements an optimization method or technique that employs the optimization function to estimate the metric(s) of interest. The metric of interest is essentially a measure of the distortion introduced by the MUT **102**. The optimization function provides a means for assessing a quality of the estimated metric relative to the recovered signal ũ(t).

[0049] For example, the metric may represent one or more of various measures of distortion such as, but not limited to, 2nd order harmonic distortion, 3rd order harmonic distortion, total harmonic distortion (THD), third order intercept (TOI), intermodulation distortion (IMD), and adjacent channel power ration (ACPR). Alternatively, the metric of interest may be a parameter a model of the MUT **102** wherein the parameter represents the introduced distortion. Once a value for the parameter is determined by the analysis system **140**, one or more other measures of distortion may be computed by the analysis system **140** from the determined parameter.

[0050] In an exemplary embodiment, the analysis system **140** implements an optimization function that includes a model of the MUT **102**. The model has parameters that represent specific expected distortions. The analysis system **140** further implements a multiple regression algorithm (i.e., optimization method) that estimates parameters of the model (i.e., the metrics of interest). The multiple regression algorithm essentially adjusts the model parameters until an output of the model matches or closely approximates that of the recovered signal ũ(t). Other optimization methods that may be implemented by the analysis system **140** include, but are not limited to, gradient descent, Newton's method, conjugate gradient, simulated annealing, stochastic aunealing, and genetic algorithms.

[0051] In some embodiments (not illustrated), the chaotic reference source **110** may further comprise a delay element. The delay element may be located in one or both output paths from of the chaotic reference source **110** to a respective one of the MUT **102** and the chaotic excitation source **120**, for example. The delay element introduces a time delay in the chaotic reference signal C(t) passing through the delay element. For example, the delay element may be employed to introduce a time delay δt in the chaotic reference signal C(t) that is applied to the LO port of the MUT **102**. By introducing the time delay δt, a time-delayed chaotic reference signal C(t-δt) is produced that better corresponds with the chaotic component of the chaotic stimulus signal S(t) as it is applied to the RF port of the MUT **102**.

[0052] FIG. **3** illustrates a block diagram of a mixer measurement system **100'** according to another embodiment of the present invention. The mixer measurement system **100'** comprises many of the same elements as, and operates in essentially the same manner as, the mixer measurement system **100** described above with reference to FIG. **1**. The mixer measurement system **100'** essentially differs from the above-described mixer measurement system **100** the use of a different signal source **120'** and an addition of a mixer **152** in the receiver **150**. Furthermore, the MUT **102** acts as an upconverter in the mixer measurement system **100'** such that a first input port of the MUT **102** is an LO input port, a second input port of the MUT **102** is an IF input port, and an output port of the MUT **102** is an RF port.

[0053] As illustrated in FIG. **3**, the mixer measurement system **100'** comprises the chaotic reference source **110** and in some embodiments, comprises the analysis system **140**, as described above with respect to FIG. **1**. The mixer measurement system **100'** further comprises an excitation source **120'**. The excitation source **120'** is essentially similar to the signal source **122** described above with respect to FIG. **2**. Specifically, the excitation source **120'** generates the input signal u(t). As illustrated in FIG. **3**, the excitation source **120'** is connected to and applies the input signal u(t) to the second input port (e.g., IF input port) of the MUT **102**. The chaotic reference source **110** is connected to and applies the chaotic references signal C(t) to the first input port (e.g., LO input port) of the MUT **102**. The MUT **102** generates a response signal R'(t) at the output port (e.g., RF port).

[0054] The mixer measurement system **100'** further comprises a receiver **150**. The receiver **150** receives the response signal R'(t) and using the inverse system **154**, generates the recovered signal ũ(t) as an output signal. In some embodiments, the receiver **150** is a chaotic lock-in amplifier (CLA) **150**. The CLA **150** is connected to the output port of the MUT **102** and receives the response signal R'(t) from the MUT **102**. The CLA **150** is further connected to the chaotic reference source **110** and receives the chaotic reference signal C(t) from the chaotic reference source **110**. An output of the CLA **150** is connected to the analysis system **140**, depending on the embodiment. Various implementations of the CLA **150** are described by Tufillaro et al., in co-pending U.S. patent application Ser. No. 11/314,791, filed Dec. 21, 2005, incorporated herein by reference.

[0055] As illustrated in FIG. **3**, the CLA **150** comprises a mixer **152** and an inverse system **154**. The inverse system **154** is essentially similar to the inverse system **130** described above. In some embodiments, the mixer **152** is an analog mixer that multiplies together a pair of input signals to produce a product of signals as an output.

[0056] The mixer **152** accepts at a first input port (e.g., LO port) the chaotic reference signal C(t). The mixer **152** further accepts at a second input port (e.g., RF input port) the response signal R'(t) from the MUT **102**. The mixer **152** multiplies together the chaotic reference signal C(t) and the response signal R'(t) to produce a downconverted response signal r(t) representing the product of the two signals C(t) times R'(t). The downconverted response signal r(t) is applied to the inverse system **154**. The inverse system **154** converts the downconverted response signal r(t) into the recovered signal ũ(t) in a manner analogous to that employed with the mixer measurement system **100**.

[0057] Consider, for example and not by way of limitation, the mixer measurement system **100** illustrated in FIG. **1**, wherein a third order distortion product of the MUT **102** is to be characterized. In the exemplary mixer characterization, a response of the MUT **102** may be modeled by

$$w(t)=s_1(t)(s_2(t)+\epsilon s_2(t)^3) \tag{5}$$

where w(t) is an output signal and $s_1(t)$ and $s_2(t)$ are input signals. A coefficient ϵ represents or models a relative level of a third order distortion product produced by the MUT **102**. For example, in terms of the discussion above, w(t) may be the response signal R(t), $s_1(t)$ may be the chaotic stimulus signal S(t), and $s_2(t)$ may be the chaotic reference signal C(t). In the example, a value for the coefficient ϵ in equation (5) is determined using the mixer measurement system **100** to characterize the third order distortion product of the MUT **102**.

[0058] For the example, the chaotic reference source **110** employs a 3-dimensional chaotic system defined in terms of a state vector q and its time derivative q' and are described by

$$\begin{bmatrix} q_1' \\ q_2' \\ q_3' \end{bmatrix} = \begin{bmatrix} q_2 - 0.001q_1 \\ q_3 \\ q_1 - q_2 - 0.7q_3 - q_1^3 + (q_1 + d)^2 u(t) \end{bmatrix} \tag{6}$$

where

$$q \equiv \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} \text{ and } q' \equiv \begin{bmatrix} q_1' \\ q_2' \\ q_3' \end{bmatrix} \tag{7}$$

where the variable d is an offset and where the input signal u(t) is an arbitrary signal. For example, the input signal u(t) may be given by

$$u(t)=a+b\cos(\omega t) \tag{8}$$

where variables a and b are arbitrary scalar constants and ω is a frequency of the input signal u(t). The exemplary chaotic reference source **110** generates a chaotic reference signal C(t) equal to a first state variable q_1. Note that a time-dependence of the state variables $\{q_1, q_2, q_3\}$ and their respective derivatives is suppressed herein for clarity of description. Also note that the 3-dimensional chaotic system of equation (6) explicitly employs the input signal u(t) which may be provided to the chaotic reference source **110** by way of a connection (not illustrated) between the signal source **122** of the chaotic excitation source **120** and the chaotic reference source **110** (referring to FIGS. **1** and **2**).

[0059] The chaotic excitation source **120** in the example generates an excitation signal S(t) that is a product of the input signal u(t) and the chaotic reference signal C(t) described by

$$S(t)=u(t)q_1 \tag{9}$$

For purposes of discussion, and not by way of limitation, the exemplary excitation signal S(t) is assumed to be an ideal or undistorted signal. Specifically, as defined by equation (9), the exemplary excitation signal S(t) includes no distortion products from the multiplication in the modulator **124**. In practice, an ideal modulator **124** is not readily realizable. However, in many cases, a distortion introduced by the modulator **124** is significantly smaller than that expected from the MUT **102** such that the modulator-introduced distortion may be ignored. For example, the modulator **124** may comprise a "golden" mixer or an instrumentation mixer that is specially designed and carefully tuned to provide a low or very low THD compared to an expected THD of the MUT **102**. Alternatively, a more general form of equation (9) may be readily constructed that explicitly accounts for the modulator-introduced distortion without departing from the scope of the present invention.

[0060] A response signal R(t) of the MUT **102**, in turn, is described by

$$R(t)=S(t)\cdot g(C(t))=u(t)q_1\cdot(q_1+\epsilon q_1^3) \tag{10}$$

where a distortion function g(·) describes a distortion introduced by the MUT **102**. For the example, the distortion is assumed to be the third order distortion described above in equation (5). However, essentially any distortion function $g(\cdot)$ may be employed in modeling the response signal R(t) without departing from the scope of the present invention. Moreover, other distortions not described by equation (10) may be included in a model of, or an equation that describes, the response signal R(t) without exceeding the scope of the present invention. For example, such other distortions may include, but are not limited to, a distortion of the excitation signal S(t) introduced by the MUT **102** (e.g., $g_a(S(t))$ where $g_a(\cdot)$ is another arbitrary distortion function) and various intermodulation distortions by the MUT **102** involving both the chaotic reference signal C(t) and the chaotic excitation signal S(t) (e.g., $g_{IM}(S(t),C(t))$ where $g_{IM}(\cdot)$ is an arbitrary intermodulation distortion function).

[0061] Continuing with the example, the inverse system **130** of FIG. **1** may employ a 3-dimensional inverse chaotic system defined in terms of a state vector z and its time derivative z' and are described by

$$\begin{bmatrix} z_1' \\ z_2' \\ z_3' \end{bmatrix} = \begin{bmatrix} z_2 - 0.001 z_1 \\ z_3 \\ z_1 - z_2 - 0.7 z_3 - z_1^3 + (y - c \cdot z) \end{bmatrix} \tag{11}$$

where

$$z \equiv \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} \text{ and } z' \equiv \begin{bmatrix} z_1' \\ z_2' \\ z_3' \end{bmatrix} \tag{12}$$

and where a response variable y is given by

$$y = c \cdot q + R(t). \tag{13}$$

The recovered signal $\tilde{u}(t)$ is given by

$$\tilde{u}(t) = \frac{(y - c \cdot z)}{z_1^2}. \tag{14}$$

A vector c in equations (11), (13) and (14) is a selection vector. The selection vector c is a row vector that essentially 'selects' from each of the state vectors q and z one of the respective state variables. For example, c=[1,0,0] is used in equation (13) to select a first state variable q_1 from the state vector q, and similarly in equations (11) and (14) to select a first state variable z_1 from the state vector z (i.e., $[1,0,0] \cdot q = q_1$ and $[1,0,0] z \cdot = z_1$).

[0062] When employing a non-zero selection vector c, a connection between the chaotic reference source **110** and the inverse system **130** may be used to supply to the inverse system **130** with the appropriate the state variable $\{q_1, q_2, q_3\}$ for processing according to equation (13). When no connection between the chaotic reference source **110** and the inverse system **130**, **154** is illustrated, the selection vector c is identically zero (i.e., c=[0, 0, 0]).

[0063] In order to determine the coefficient ϵ in the example, the recovered signal $\tilde{u}(t)$ is processed by the analysis system **140**. In some embodiments, a multiple linear regression method is employed to estimate the coefficient ϵ such that a difference between the input signal u(t) and the recovered signal $\tilde{u}(t)$ is minimized. Multiple linear regression methods are familiar to the skilled artisan. While a multiple regression is employed in the example herein, any other method of estimating a value for the coefficient ϵ such that the difference is minimized may be used instead of or in addition to the multiple regression.

[0064] When employing the multiple linear regression, a comparison between the recovered signal $\tilde{u}(t)$ and the input signal u(t) is performed using a parametric dependence defined by

$$\tilde{u}(t) = h(u(t), q_1, \epsilon) \tag{15}$$

wherein $h(\cdot)$ is a bivariate polynomial in terms of u(t) and q_1. Multiple linear regression is used to find coefficients of the polynomial $h(\cdot)$. By expanding the term '$y-c \cdot z$' in equation (11), a formula may be obtained that provides an estimate of the coefficient ϵ denoted by ϵ^*. Specifically, by examining the coefficient of an $u^1 q^0_1$ term of the polynomial $h(\cdot)$, denoted as a term r herein, a relationship between the term r and the estimate ϵ^* can be determined. The determined relationship is given by

$$\varepsilon^* = \frac{r}{2d^4} \tag{16}$$

In particular, for $1e^{-6} < \epsilon < 1e^{-1}$, there is a linear relationship between the actual nonlinearity represented by the coefficient ϵ and the estimate ϵ^*. Thus, the estimate ϵ^* provides a good characterization of the nonlinearity of the exemplary MUT **102** modeled in the example. The above discussion and ranges are presented for discussion purposes only and are not intended to limit the scope of the present invention.

[0065] FIGS. **4** and **5** illustrate flow charts of methods of characterizing a mixer using chaotic stimulation according to embodiments of the present invention. The methods include applying a chaotic stimulus to a mixer under test to generate a response signal therefrom, and employing an inverse system to remove a chaotic component from the response signal such that a recovered signal is obtained. The recovered signal has an included distortion that is characteristic of the mixer under test. FIG. **4** illustrates a flow chart of a method **200** of characterizing a mixer using chaotic stimulation according to an embodiment of the present invention. In various embodiments, the method **200** of characterizing a mixer comprises generating **210** a chaotic reference signal C(t). The chaotic reference signal C(t) is essentially any signal having or exhibiting chaotic oscillation, as described above. For example, the chaotic reference signal C(t) may be generated **210** by a chaotic system such as, but not limited to, a Lorenz system.

[0066] The method **200** of characterizing a mixer further comprises generating **220** a chaotic stimulus signal S(t). When generated **220**, the chaotic stimulus signal S(t) comprises at least one signal component that is proportional to the chaotic reference signal C(t). The chaotic stimulus signal S(t) is a stimulus signal of a form that is compatible with stimulating a response from the mixer being characterized or under test (MUT). In some embodiments, the chaotic stimulus signal S(t) is created by modulating an input signal u(t) with the chaotic referenced signal C(t). For example, generating a chaotic stimulus signal S(t) **220** may comprise multiplying together the chaotic reference signal C(t) and the input signal u(t) to produce a product of the two signals.

[0067] The method **200** of characterizing a mixer further comprises applying **230** the chaotic reference signal C(t) and the chaotic stimulation signal S(t) to the MUT. In some embodiments, the chaotic reference signal C(t) is applied to a first input of the MUT (e.g., an LO input). In some embodiments, the chaotic stimulation signal S(t) is applied to a second input of the MUT (e.g., an RF input). Applying **230** the signals causes the MUT to produce a chaotic response signal R(t).

[0068] In general, the chaotic response signal R(t) includes a distortion introduced by the MUT. The introduced distortion is that which is characterized by the method **200**. For example, the distortion may include a third order distortion. However, essentially any distortion or combination of distortions may be characterized by the method **200** and thus, are within the scope of the various embodiments of the present invention.

[0069] The method **200** of characterizing a mixer further comprises employing **240** an inverse system to remove a chaotic component from the chaotic response signal R(t) generated by the MUT. The inverse system essentially implements a mathematical inverse of, and is synchronized to, a chaotic dynamical system used to generate the chaotic reference signal C(t). As such, employing **240** the inverse system essentially removes the chaotic signal component(s) of the chaotic response signal R(t) to generate a recovered signal ũ(t). The recovered signal ũ(t) is essentially the input signal u(t) plus the distortions introduced by the MUT.

[0070] In some embodiments, the method **200** of characterizing a mixer further comprises analyzing **250** the recovered signal ũ(t) to extract an estimate of the distortions. In some embodiments, analyzing **250** comprises comparing the input signal u(t) to the recovered signal ũ(t). For example, a model of the distortions may be constructed wherein the model incorporates coefficients that represent distortion terms of interest. A difference between the recovered signal ũ(t) and the input signal u(t) may be minimized using the model to assign values to the model coefficients. The coefficient values then represent an estimate of the distortions. A multiple linear regression using a bivariate polynomial is an example of an optimization or minimization method that may be employed, as described above by way of example.

[0071] FIG. **5** illustrates a flow chart of a method **200'** of characterizing a mixer using chaotic stimulation according to another embodiment of the present invention. The method **200'** of characterizing a mixer is similar to the method **200** described hereinabove except for differences in the stimulation of the MUT and the removal of the chaotic component. The method **200'** of characterizing a mixer essentially differs from the above-described method **200** of characterizing a mixer in the signals that are applied to the MUT **102** and how the chaotic component is removed, because the MUT **102** acts as an upconverter in the method **200'** and acts as a downconverter in method **200**.

[0072] In various embodiments, the method **200'** of characterizing a mixer comprises generating **210'** a chaotic reference signal C(t). Generating **210'** a chaotic reference signal C(t) is essentially similar to generating **210** a chaotic reference signal C(t) that is described above with respect to the method **200**.

[0073] The method **200'** of characterizing a mixer further comprises generating **220'** an arbitrary input signal u(t). The arbitrary input signal u(t) may be essentially any signal compatible with, or in a frequency range of, an input port of the MUT. For example, the input signal u(t) may be a sinusoidal signal with a center frequency at or near a center of a frequency band of interest for the characterization. In some embodiments, the arbitrary input signal u(t) is essentially similar to the input signal u(t) described above with respect to the mixer measurements system **100**, **100'** and the method **200** of characterizing a mixer.

[0074] The method **200'** of characterizing a mixer further comprises applying **230'** to the MUT the chaotic reference signal C(t) and the arbitrary input signal u(t). In some embodiments, the chaotic reference signal C(t) is applied to a first input of the MUT (e.g., an LO input). In some embodiments, the arbitrary input signal u(t) is applied to a second input of the MUT (e.g., an RF input). Applying **230'** the signals causes the MUT to produce a response signal R'(t).

[0075] As described above for the method **200**, the response signal R'(t) includes a distortion introduced by the MUT. The introduced distortion in the response signal R'(t) is characterized by the method **200'** not unlike the introduced distortion in the response signal R(t) being characterized by the method **200**. For example, the distortion may include a third order distortion. However, essentially any distortion or combination of distortions may be characterized by and thus, are within the scope of the various embodiments of the present invention.

[0076] The method **200'** of characterizing a mixer further comprises employing **240'** a receiver to remove a chaotic component from the response signal R'(t) generated by the MUT to produce a recovered signal ũ(t). In some embodiments, employing **240'** a receiver comprises multiplying the response signal R'(t) with the chaotic reference signal C(t) to produce a downconverted response signal r(t). Employing **240'** further comprises applying the downconverted response signal r(t) to an inverse system. The inverse system essentially implements a mathematical inverse of and is synchronized to a chaotic dynamical system used to generate the chaotic reference C(t). As such, the inverse system essentially removes the chaotic signal component(s) of the chaotic downconverted response signal r(t) to generate the recovered signal ũ(t). The recovered signal ũ(t) is essentially the input signal u(t) plus the distortions introduced by the MUT.

[0077] The method **200'** of characterizing a mixer further comprises analyzing **250'** the recovered signal ũ(t) to extract an estimate of the distortions. In some embodiments, analyzing **250'** the recovered signal ũ(t) comprises comparing the input signal u(t) to the recovered signal ũ(t). In some embodiments, analyzing **250'** is essentially similar to analyzing **250** described above with respect to the method **200**.

[0078] FIG. **6** illustrates a mixer measurement system **300** according to another embodiment of the present invention. In this embodiment, the mixer measurement system **300** comprises the mixer measurement system **100** described above. The mixer measurement system **300** further comprises a controller **310** that controls an operation of elements of the mixer measurement system **100**. In various embodiments, the controller **310** is implemented as one or more of a general purpose computer, a special purpose processor or microprocessor, a portion of an application specific integrated circuit (ASIC), and a discrete logic circuit. The measurement system **300** further comprises a memory **320** and a computer program **330** stored in the memory **320**. In some embodiments, the controller **310** may comprise the memory **320**, as illustrated in FIG. **6**. In other embodiments, the memory **320** may be separate from the controller **310** (not illustrated).

[0079] Instructions of the computer program **330**, when executed by controller **310**, implement a method of characterizing a mixer. For example, the instructions of the computer program **330** implement stimulating the mixer with chaotic signals at different input ports of the mixer to obtain a chaotic response signal from the mixer. The chaotic response signal comprises distortions of the mixer to be characterized. The instructions of the computer program **330** further implement removing the chaotic component of the response signal to produce a recovered signal that may be analyzed for the distortions. In some embodiments, the instructions of the computer program **330** implement one or more embodiments of the method **200** described above. In some embodiments, all or a portion of the inverse system **130** of the mixer measurement system **100** may be implemented by a combination of the controller **310** and executable instructions of the computer program **330**. In some embodiments, all or a portion of the analysis system **140** of the mixer measurement system **100** is implemented by a combination of the controller **310** and executable instructions of the computer program **330**.

[0080] FIG. **7** illustrates a mixer measurement system **300'** according to another embodiment of the present invention. In this embodiment, the mixer measurement system **300'** comprises the mixer measurement system **100'** described above. The mixer measurement system **300'** further comprises a controller **310'** that controls an operation of elements of the mixer measurement system **100'**. In various embodiments, the controller **310'** is implemented as one or more of a general purpose computer, a special purpose processor or microprocessor, a portion of an application specific integrated circuit (ASIC), and a discrete logic circuit. The measurement system **300'** further comprises a memory **320'** and a computer program **330'** stored in the memory. In some embodiments, the controller **310'** may comprise the memory **320'** as illustrated in FIG. **7**. In other embodiments, the memory **320'** may be separate from the controller **310'** (not illustrated).

[0081] Instructions of the computer program **330'**, when executed by controller **310'**, implement a method of characterizing a mixer. For example, the instructions of the computer program **330'** implement stimulating the mixer with a chaotic reference signal and an input signal at different input ports of the mixer to obtain a chaotic response signal from the mixer. The chaotic response signal comprises distortions of the mixer to be characterized. The instructions of the computer program **330'** further implement removing the chaotic component of the response signal to produce a recovered signal that may be analyzed for the distortions. In some embodiments, the instructions of the computer program **330'** implement one or more embodiments of the method **200'** described above. In some embodiments, all or a portion of the input signal source **120'** of the mixer measurement system **100'** is implemented by a combination of the controller **310'** and executable instructions of the computer program **330'**. In some embodiments, all or a portion of the receiver **150** of the mixer measurement system **100'** is implemented by a combination of the controller **310'** and executable instructions of the computer program **330'**. In some embodiments, all or a portion of the analysis system **140** of the mixer measurement system **100'** is implemented by a combination of the controller **310'** and executable instructions of the computer program **330'**.

[0082] Thus, there have been described embodiments of a mixer measurement system and respective methods of characterizing a mixer that both employ chaotic stimulation. It should be understood that the above-described embodiments are merely illustrative of some of the many specific embodiments that represent the principles of the present invention. Clearly, those skilled in the art can readily devise numerous other arrangements without departing from the scope of the present invention as defined by the following claims.

1. A mixer measurement system comprising:

a chaotic reference source having an output that produces a chaotic reference signal on a first input of a mixer under test;

an excitation source having an output that produces a stimulus signal on a second input of the mixer under test, the mixer under test generating a response signal that includes a distortion introduced by the mixer under test;

an inverse system that removes a chaotic component from the response signal to measure a recovered signal that includes the distortion; and

an analysis system connected to an output of the inverse system that analyzes the included distortion in the recovered signal.

2. The mixer measurement system of claim 1, wherein the output of the chaotic reference source is further connected to an input of the excitation source.

3. The mixer measurement system of claim 1, wherein the excitation source is a chaotic excitation source that comprises a signal source and a modulator, an output of the signal source being connected to a first input of the modulator, the modulator having a second input that is connected to an input of the chaotic excitation source, the output of the chaotic reference source being connected to the second input of the modulator by way of the chaotic excitation source input, an output of the modulator being connected to the output of the chaotic excitation source.

4. The mixer measurement system of claim 3, wherein the modulator produces a chaotic signal as the stimulus signal at the output of the chaotic excitation source, the chaotic stimulus signal being a modulation of a signal from the signal source that is proportional to the chaotic reference signal.

5. The mixer measurement system of claim 1, wherein the output of the chaotic reference source is further connected to an input of the inverse system.

6. The mixer measurement system of claim 1, further comprising a receiver having a first input connected to an output of the mixer under test, the receiver comprising a mixer and the inverse system, the mixer having a first input connected to the first input of the receiver, a second input connected to a second input of the receiver, and an output connected to an input of the inverse system, the inverse system having an output connected to an output of the receiver,

wherein the response signal and the chaotic reference signal are applied to the inputs of the receiver such that the signals are mixed by the mixer, a mixed response signal from the mixer being applied to the inverse system, and

wherein the excitation source applies a nonchaotic signal as the produced stimulus signal to the second input of the mixer under test.

7. (canceled)

8. The mixer measurement system of claim 1, wherein the analysis system estimates a coefficient representing a relative level of the included distortion.

9. The mixer measurement system of claim 1, further comprising:

a controller that controls the chaotic reference source, the excitation source and the inverse system;

a memory that is accessible by the controller; and

a computer program stored in the memory, the computer program having instructions that are executed by the controller, wherein the executed instructions implement measuring the recovered signal from the mixer under test.

10. The mixer measurement system of claim 9,

wherein the controller further controls the analysis system, the instructions of the computer program further implementing analyzing the included distortion in the recovered signal, such that a coefficient representing a relative level of the included distortion is estimated.

11. A mixer measurement system comprising:

a controller;

a memory that is accessible by the controller; and

a computer program stored in the memory, the computer program having instructions that are executed by the controller, wherein the executed instructions implement applying a chaotic reference signal and a stimulus signal on inputs of a mixer under test, employing an inverse system to remove a chaotic component in a response signal from an output of the mixer under test such that a recovered signal is measured, the recovered signal including a distortion that is characteristic of the mixer under test, and analyzing the recovered signal for an estimate of the included distortion.

12. The mixer measurement system of claim 11, wherein the stimulus signal is a chaotic stimulus signal that is proportional to the chaotic reference signal.

13. The mixer measurement system of claim 11, wherein the stimulus signal is a nonchaotic stimulus signal, the chaotic reference signal being further applied to the response signal before the instructions that implement employing the inverse system are executed.

14. (canceled)

15. A mixer measurement system comprising:

a chaotic reference source that produces a chaotic reference signal;

a chaotic excitation source that produces a chaotic stimulus signal from the chaotic reference signal; and

an inverse system,

wherein the chaotic reference signal and the chaotic stimulus signal are applied to respective inputs of a mixer under test to produce a response signal that includes a distortion introduced by the mixer and wherein the inverse system removes from the response signal a chaotic component to produce a recovered signal that includes the distortion.

16. The mixer measurement system of claim 15, wherein the chaotic excitation source comprises a signal source and a modulator, the modulator receiving the chaotic reference signal and producing a modulation of a signal from the signal source that is proportional to the chaotic reference signal.

17. A method of characterizing a mixer, the method comprising:

applying a stimulus signal and a chaotic reference signal to inputs of a mixer under test to produce a response signal from an output of the mixer under test;

employing an inverse system on the response signal to remove a chaotic component from the response signal such that a recovered signal having an included distortion that is characteristic of the mixer under test is produced;

analyzing the included distortion in the recovered signal; and

providing a result of analyzing as an output product that characterizes the mixer under test.

18. The method of characterizing of claim 17, further comprising:

generating the chaotic reference signal; and

generating the stimulus signal having at least one signal component that is proportional to the chaotic reference signal, both of the chaotic reference signal and the stimulus signal being generated before applying the respective signals to the mixer under test.

19. The method of characterizing of claim 17, further comprising:

generating the chaotic reference signal;

generating a nonchaotic signal as the stimulus signal, both of the chaotic reference signal and the nonchaotic stimulus signal being generated before applying the respective signals to the mixer under test, and further comprising:

applying the chaotic reference signal to the response signal before employing the inverse system.

20. (canceled)

21. The method of characterizing of claim 17, wherein employing an inverse system comprises employing a chaotic lock-in amplifier to remove the chaotic component.

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