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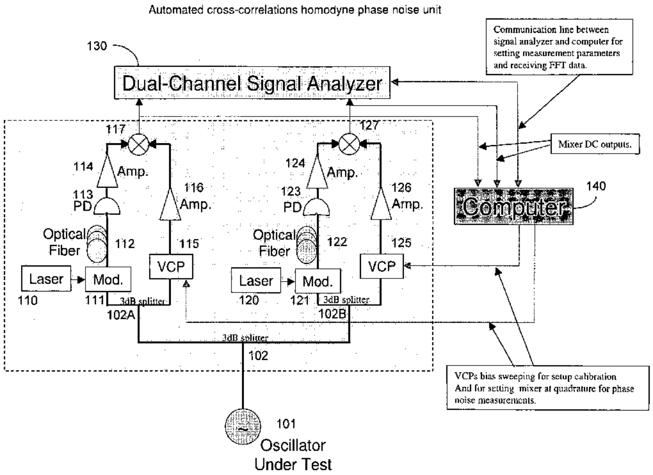
(54) **Title:** PHOTONIC BASED CROSS-CORRELATION HOMODYNE DETECTION WITH LOW PHASE NOISE

FIG. 1

Automated cross-correlations homodyne phase noise unit



(57) **Abstract:** In one aspect, this document provides an implementation of a system for characterizing an oscillator. This system includes an input port that receives an oscillation signal from an oscillator under test; an input port signal splitter that splits the received oscillation signal into a first oscillation signal and a second oscillation signal; a first photonic signal processing branch circuit that processes the first oscillation signal to produce a first branch output signal; a second photonic signal processing branch circuit that processes the second oscillation signal to produce a second branch output signal; a dual channel signal analyzer that receives the first and second branch output signals to measure noise in the received oscillation signal; and a computer controller that controls the first and second photonic signal processing branch circuits and the dual channel signal analyzer to control measurements of the noise in the received oscillation signal.

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PHOTONIC-BASED CROSS-CORRELATION HOMODYNE DETECTION WITH LOW PHASE NOISE

Priority Claim and Related Application

[0001] This document claims the benefits of U.S. Provisional Application No. 61/002,918 entitled "PHOTONIC-BASED CROSS-CORRELATION HOMODYNE DETECTION WITH LOW PHASE NOISE" and filed November 13, 2007, the disclosure of which is incorporated by reference as part of the specification of this document.

Background

[0002] This application relates to oscillators and characterization of oscillators, including oscillators in RF, microwave, or millimeter spectral range.

[0003] An oscillator is a device that produces an oscillation signal at a desired oscillation frequency. The output of the oscillator may be used as a frequency reference for various applications and thus it is desirable that the noise of the oscillator be low and can be properly measured. A measurement apparatus for characterizing an oscillator should have low noise.

Summary

[0004] In one aspect, this document provides an implementation of a system for characterizing an oscillator. This system includes an input port that receives an oscillation signal from an oscillator under test; an input port signal splitter that splits the received oscillation signal into a first oscillation signal and a second oscillation signal; a first photonic signal processing branch circuit that processes the first oscillation signal to produce a first branch output signal; a second photonic signal processing branch circuit that processes the second oscillation signal to produce a second branch output signal; a dual channel signal analyzer that receives the first and second branch output signals to measure noise in the received oscillation signal; and a computer controller that controls the first and second photonic signal processing branch circuits and the dual channel signal analyzer to control measurements of the noise in the received oscillation signal.

[0005] In one implementation of the above system, the first photonic signal processing branch circuit includes a first signal splitter to splits the first oscillation signal into a first branch signal and a second branch signal; a photonic branch that receives the first branch signal and comprises a laser that produces a laser beam, an optical modulator that modulates the laser beam in response to the first branch signal to produce a modulated laser beam that carries the first branch signal, an optical delay unit that transmits the modulated laser beam to produce a delay in the modulated laser beam, and an optical detector that converts the modulated laser beam into a detector signal; an electrical branch that receives the second branch signal and comprises a voltage controlled phase shifter that receives the second branch signal and to changes a phase of the second branch signal to produce an output signal; and a signal mixer that mixes the detector signal and the output signal to produce the first branch output signal.

[0006] These and other features are described in greater detail in the drawings, the description and the claims.

Brief Description of Drawings

[0007] FIG. 1 shows an example for an automated opto-electronics cross-correlation homodyne phase noise setup to illustrate various technical features.

Detailed Description

[0008] This application describes techniques, apparatus and systems for characterizing oscillators in RF, microwave, or millimeter spectral range based on photonic components.

[0009] FIG. 1 shows an example for an automated opto-electronics cross-correlation homodyne phase noise setup to illustrate various technical features. This exemplary setup is implemented via optical fiber serving as a long delay line. The dual homodyne setup is then cross correlated at the signal analyzer to reduce the noise of each of the homodyne branches by averaging out noise that is not correlated with the oscillator under test.

[0010] Phase noise measurements of microwave/RF oscillators generating high purity electro-magnetic signals requires low phase noise measurement setup. The present technique can be used to reduce the noise floor of a single homodyne measurement setup by cross correlating the signals of two measurement setups. In this way, the uncorrelated noise from each of the setups is averaged out at the signal analyzer. The phase noise floor of the cross-correlated dual systems can be improved by 20log(N) (in dB units), where N is the number of averages.

[0011] Each of the two measurement setups is an electro-optic homodyne setup with two signal branches. A signal splitter splits a received microwave/RF signal into the two branches. The oscillator 101 under test is coupled to the input port of the system which includes an input port splitter 102. The two signal branches include two branch signal splitters 102A and 102B, respectively. Each of the splitters 102A and 102B splits the received signal into two signals for two branches.

[0012] The first signal branch is a photonic signal branch which includes a high-speed optical modulator (MOD) 111 or 121 to modulate a CW laser beam from a laser 110 or 121 in response to the microwave/RF signal to produce a modulated optical signal that carries the microwave/RF signal. The modulated optical signal is directed along an optical fiber which serves as a signal delay line 112 or 122, allowing for efficient discrimination of the noise. The increase of the length of the fiber 112 or 122 leads to an increased delay of the signal and reduces the close-in phase noise of the setup. The photodetector (PD) 113 or 123 converts the modulated light back into a microwave signal which is then amplified by an amplifier 114 or 124. The second signal branch includes a voltage controlled phase shifter (VCP) 115 or 125 and a signal amplifier 116 or 126. A signal mixer 117 or 127 is used to combine the two branches together to mix the signals from the two branches to produce a beat signal.

[0013] A dual channel signal analyzer 130 is provided to receive the beat signals from the two measurement setups.

[0014] Such a system can be automated by using a voltage controlled phase shifters (VCPs) and a computer controller 140. The VCPs 115 and 125 are used for the calibration (voltage to phase) of the setup and for tuning the phase of the signal at the mixer (bring to quadrature) so it would be sensitive to phase noise. The computer or microprocessor is used to carry out the measurement automatically. The computer measures the calibration factor and put the mixer in quadrature. The computer also controls the signal analyzer parameters, such as frequencies, the number of averages, the resolution, the bandwidth etc. In addition, the computer plots the phase noise at the monitor and allows for saving the data.

[0015] Following is a tuning and calibration procedure for the cross-correlation homodyne phase noise set-up in FIG. 1. The computer can be operated to perform this procedure automatically.

[0016] 1. Calibration:

[0017] a. The computer sweeps the bias voltage over the voltage controlled phase shifters (VCPs), and at the same time records the mixers output voltage response through an A/D card.

[0018] b. Stored calibrated formulas for the voltage controlled phase shifters as a function of the VCP's bias voltage, ϕ(VVCP), allow the computer to calculate the calibration responses between phases to the mixer voltage ($\Delta\phi/\Delta$Vmixer at Vmixer=0), for each of the two identical setups.

[0019] 2. Quadrature setting:

[0020] a. The computer tunes the VCPs bias voltage so that the mixers are at zero DC output. This sets the mixers at quadrature, which makes them phase noise sensitive (low sensitivity to amplitude noise at saturation).

[0021] 3. Phase noise measurements:

[0022] a. The computer controls the signal analyzer in terms of range of measurement frequencies, resolution bandwidth, number of averages (the user has control over these parameters through the user interface software) and other parameters.

[0023] b. The computer retrieves the mixer's voltage fluctuations FFT data from the signal analyzer.

[0024] c. At the same time, the computer monitors the mixers voltage. If the voltage drifts over the allowable range due to oscillator frequency drift and/or the delay thermal drift, then the computer sets the signal analyzer on a pause mode, brings the system to quadrature again, and continues with the FFT measurements.

[0025] d. The data is then converted to phase noise spectral density using the calibration value measured in section 1 and the fiber delay length factor.

[0026] e. The data is then plotted on the screen, and optionally could be stored into a file.

[0027] The noise floor of the system could be improved by increasing the number of FFT averages N. The noise floor drops as $5 \cdot \log(N)$ (in dB units).

[0028] The above procedure describes only one of the software modes of operation. Other modes allow to use only one of the two homodyne setups, or measure the mixer voltage spectral density directly (for active/passive device phase noise measurements). The user also has control over the delay length.

[0029] This setup has the advantage of direct phase noise measurements (no need for second oscillator and phase locking). The RF carrier frequency range is wide and usually limited by the RF amplifiers and VCPs. In our current setup it is between 6 to 12GHz.

[0030] In a recent build of a new cross correlation homodyne setup, the setup noise floor was improved and is currently better than:

a. -110dBc/Hz at 100Hz offset

b. -140dBc/Hz at 1kHz offset

c. -170dBc/Hz for >10kHz offsets

[0031] While this specification contains many specifics, these should not be construed as limitations on the scope of an invention or of what may be claimed, but rather as descriptions of features specific to particular embodiments of the invention. Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or a variation of a subcombination.

[0032] Only a few implementations are disclosed. However, it is understood that variations and enhancements may be made.

Claims

What is claimed is:

1. A system for characterizing an oscillator, comprising:

an input port that receives an oscillation signal from an oscillator under test;

an input port signal splitter that splits the received oscillation signal into a first oscillation signal and a second oscillation signal;

a first photonic signal processing branch circuit that processes the first oscillation signal to produce a first branch output signal;

a second photonic signal processing branch circuit that processes the second oscillation signal to produce a second branch output signal;

a dual channel signal analyzer that receives the first and second branch output signals to measure noise in the received oscillation signal; and

a computer controller that controls the first and second photonic signal processing branch circuits and the dual channel signal analyzer to control measurements of the noise in the received oscillation signal.

2. The system as in claim 1, wherein:

the first photonic signal processing branch circuit comprises:

a first signal splitter to splits the first oscillation signal into a first branch signal and a second branch signal;

a photonic branch that receives the first branch signal and comprises a laser that produces a laser beam, an optical modulator that modulates the laser beam in response to the first branch signal to produce a modulated laser beam that carries the first branch signal, an optical delay unit that transmits the modulated laser beam to produce a delay in the modulated laser beam, and an optical detector that converts the modulated laser beam into a detector signal;

an electrical branch that receives the second branch signal and comprises a voltage controlled phase shifter that receives the second branch signal and to changes a phase of the second branch signal to produce an output signal; and

a signal mixer that mixes the detector signal and the output signal to produce the first branch output signal.

3. The system as in claim 2, wherein:

the optical delay unit comprises a fiber delay line.

4. The system as in claim 2, wherein:

the voltage controlled phase shifter is under a control of the computer controller.

5. The system as in claim 4, wherein:

the computer controller controls the voltage controlled phase shifter to set a phase of the signal mixer at a quadrature condition.

FIG. 1

Automated cross-correlations homodyne phase noise unit