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Inventor: <u>HAL L. LEVITT</u>

NOTICE

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WASHINGTON DC 20375

PATENT APPLICATION/TECHNICAL DIGEST PUBLICATION RELEASE REQUEST

FROM: Associate Counsel (Patents) (1008.2)
TO: Associate Counsel (Patents) (1008.2)

Via: (1) Hal Levitt (Code 5721)
      (2) Division Superintendent (Code 5700)
      (3) Head, Classification Management & Control (Code 1221)

SUBJ: Patent Application/Technical Digest entitled: **"MULTIPLE SIMULTANEOUS OPTICAL FREQUENCY MEASUREMENT"** Request for release for publication.

REF: (a) NRL Instruction 5510.40C
      (b) Chapter 6, ONRINST 5870.1C

ENCL: (1) Copy of Patent Application/Technical Digest

1. In accordance with the provision of references (a) and (b), it is hereby requested that the subject Patent Application/Technical Digest be released for publication.

2. It is intended to offer this Patent Application/Technical Digest to the National Technical Information Service, for publication.

3. This request is in connection with Navy Case No. 79,276

_____
(date)

_____
JOHN J. KARASEK
Associate Counsel (Patents)

FIRST ENDORSEMENT   Date:

FROM: Hal Levitt (Code 5721)
TO: Division Superintendent (Code 5700)

1. It is the opinion of the Inventor(s) that the subject Patent Application/Technical Digest (is) (is not) classified and there is no objection to public release.

_____ 18 Jan 2001
Inventor's Signature

NDW-NRL 551/3001 (Rev. 6-89) (Page 1 of 2)

SECOND ENDORSEMENT   Date:

FROM: Division Superintendent (Code 5700)
TO: Classification Management & Control (Code 1221)

1. Release of Patent Application/Technical Digest (is) (is not) approved.

2. To the best knowledge of this Division, the subject matter of this Patent Application/Technical Digest (has) (has not) been classified.

3. This recommendation takes into account military security, sponsor requirements and other administration considerations and there in no objection to public release.

_____
                Division Superintendent

THIRD ENDORSEMENT   Date:

FROM: Head, Classification & Control (Code 1221)
TO: Associate Counsel (Patents) (1008.2)

1. This Patent Application/Technical Digest is authorized for public release.

_____
Head, Classification, Management & Control

MULTIPLE SIMULTANEOUS OPTICAL
FREQUENCY MEASUREMENT

BACKGROUND OF THE INVENTION

5   Field of the Invention

The present invention is directed to electrical frequency measurement, and particularly to a signal processing apparatus for providing accurate temporal frequency measurement of multiple time-coincident radio frequency ("RF") signals over a wide instantaneous bandwidth and dynamic

10   range.

Description of the Related Art

Electrical frequency measurement is a requirement for numerous signal processing, communication, and signal measurement systems in use today and in the foreseeable future. A wide instantaneous

15   operating bandwidth is essential in many systems. Frequency is a key measurement parameter for the purpose of RF signal tracking, characterization, and identification. Commercial and military applications operating in congested RF environments must process multiple signals simultaneously and provide measurement of selected signals while rejecting

20   other undesirable interfering signals within the operating bandwidth. Present day applications include satellite and terrestrial communications systems, radar receivers, air traffic control radar, and RF test equipment.

Existing equipment implement one or more frequency measurement devices including instantaneous frequency measurement

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("IFM") receivers, frequency discriminators, and channelized receivers. Each alternative has drawbacks. For example, most frequency discriminators and IFMs operate within a limited internal input signal dynamic range, typically within the saturation region, and, hence, require additional circuits to

5   constrain input signals to this region. Because these devices are not frequency channelized, they are unable to correctly resolve time-coincident pulse-on-pulse or pulse-on-continuous wave ("CW") signals. These devices are constrained to handle a single signal at a time. If a second signal occurs in the same time window, an IFM cannot measure the second signal. RF

10   channelizer technology alone cannot provide sufficient frequency resolution without incurring a high cost for the required large number of equivalent RF filter bank elements and video circuitry, and suffer from false "rabbit ears" triggering with such narrow filter widths. In addition, RF channelizers provide only relatively coarse frequency measurements.

15   Furthermore, because the IFM can measure only one signal at a time, a CW wave (i.e., a signal that is very long in pulse width) can hinder the ability of an IFM to measure the remaining environment. Thus, by driving an IFM with a strong signal that is turned on continuously, the IFM becomes unable to operate and collect other threats in the environment.

20   A U.S. patent of interest includes U.S. Pat. No. 5,682,238 to Levitt et al. (the subject matter of which is incorporated herein by reference), which discloses a signal processing apparatus with an optical phase measurement processor that provides phase difference measurements of multiple signal inputs.

SUMMARY OF THE INVENTION

The present invention measures frequency of multiple, time-coincident (i.e., two or more signals in which a portion of one signal duration coincides in time with a portion of one or more other signal durations) RF

5   signals within a wide instantaneous input bandwidth and dynamic range. In one embodiment of the present invention, RF delay line 104 circuits are combined with a single optical processor 200, a spatial-domain phase measurement technique, and associated algorithms to provide simultaneous fine frequency measurement resolution that is maintained over the entire

10   dynamic range. RF delay line 104 and power splitter 102 components provide two wideband RF inputs for the optical processor 200, one time-delayed relative to the other. Channelizer processing circuitry utilizes optical processor photodetector outputs to perform signal detection, coarse frequency estimation, fine frequency estimation, frequency and phase calibration, and

15   combination of coarse and fine frequency for final output.

Multiple signal inputs of interest are simultaneously detected and measured in frequency, and optionally, other time-domain parameters. Basic frequency measurement occurs through two concurrent processes – detection of signal presence with (1) coarse frequency measurement, and (2)

20   fine frequency measurement. Both functions are performed in a single measurement cycle.

Detection and coarse frequency measurement are achieved through modulator induced optical beam deflection onto a photodetector array 212, wherein active detector positions directly correspond to incident

25   RF signal spectral components. Within a corresponding photodetector element bandwidth, fine frequency is obtained by measurement of relative phase difference between the original RF0 and a delayed version RF1 of the

incident RF signal, effectively through frequency to phase translation. This is accomplished by RF modulation of two optical input beams 205 followed by projection of the modulated beams to produce an optical interference pattern upon the photodetector elements. The resulting spatial intensity pattern phase

5   variation is decoded by an efficient spatial sampling technique and associated algorithms, such as those employed in the '238 patent.

The delay time is selected to achieve a specified fine frequency resolution and provide unambiguous phase measurement within one coarse frequency resolution width. The number of photodetector

10   elements along the frequency deflection axis of the photodetector array 212, instantaneous operating bandwidth, in conjunction with other opto-electronic design parameters determine the effective coarse frequency resolution.

The photodetector outputs are applied to a frequency encoder 400 circuit to correct the raw phase and amplitude (or magnitude) data

15   offsets, detect and locate active signals within the array 212, convert phase to fine frequency, and finally, concatenate coarse to fine frequency for readout. The encoded combination of coarse frequency with fine frequency discriminator output permits precision frequency measurement over the entire system bandwidth. Additionally, multiple time-coincident RF input sources,

20   which are resolvable in frequency, can be processed in parallel using the present invention.

Unlike commercial electronic frequency discriminator and IFM devices, the present invention permits frequency measurement of multiple, time-coincident, and continuous wave signals, which is a shortfall

25   of these single channel devices. The present invention has a separation at the frequency subchannels, and each subchannel performs the frequency discriminator type operation simultaneously. Most frequency discriminators and IFMs function similar to only one subchannel of the present invention,

thereby processing the composite input bandwidth without first separating

individual RF signals. This often leads to gross frequency measurement

errors under time-coincident signal conditions.

      Compared to other multi-channel techniques, such as RF filter

5   banks and channelized receivers, the present invention provides increased

frequency measurement resolution using intrachannel phase-based

techniques, with sustainable accuracy across the entire operating bandwidth

and temperature range through continuous phase offset correction. Current

frequency discriminator and IFM devices must operate with a saturated input

10   and therefore function (internally) over a limited amplitude dynamic range to

attain accurate measurements. In contrast, the present invention functions

correctly over a much wider dynamic range, limited principally by noise and

photodetector saturation. This extends the achievable system dynamic range

and eliminates RF limiting circuitry, resulting in reduced system cost and

15   improved performance.

      Additionally, coherent (IF output) or incoherent (video output)

signal detection can be utilized in the present invention. Incoherent or power

detection simplifies subsequent signal processing hardware requirements,

operating at relatively narrow video bandwidth. In contrast, coherent or

20   heterodyne detection requires more complex processing hardware operating

at intermediate frequencies ("IF"), but, in principle, can achieve a larger

dynamic range. A typical coherent approach requires optical carrier mixing

and filtering operations to convert the RF modulated optical photodetector

output to a corresponding electrical IF signal, which must then be time-

25   domain processed to measure frequency. The preferred embodiment

discussed herein utilizes incoherent signal detection methods to illustrate a

relatively simple and low cost approach to frequency measurement.

These, together with other advantages that will be
subsequently apparent, reside in the details of construction and operation as
more fully hereinafter described and claimed, reference being had to the
accompanying drawings forming a part hereof, wherein like numerals refer to

5   like parts throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic block diagram of a preferred
embodiment of the multiple simultaneous optical frequency measurement
apparatus of the present invention;

10   FIG. 2 is a schematic block diagram of the channelized optical
phase measurement (COPM) module of FIG. 1 of the present invention;

FIG. 3 is a flow diagram of photodetector video processing
within the COPM of FIG. 2;

FIG. 4 is a flow diagram of processing within the frequency

15   encoder module of FIG. 1 of the present invention;

FIG. 5 is a schematic block diagram of the multiple
simultaneous optical frequency measurement apparatus of the present
invention in an exemplary radio frequency measurement application; and

FIG. 6 is a graph of frequency measurement performance of

20   the apparatus of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a schematic block diagram of a preferred
embodiment of the present invention, which is a multiple simultaneous
optical frequency measurement ("MSOFM") apparatus 100. In FIG. 1, an RF

input signal is split into two separate paths by an RF power splitter 102. One path incurs an additional fixed time delay relative to the other as a consequence of a delay line 104. The delayed RF1 and direct RF0 (non-delayed) signals then serve as inputs to a module providing multiple

5   concurrent measurement and readout of coarse frequency, phase, and optionally magnitude, on a (coarse) frequency channelized basis. Preferably, the channelized optical phase measurement ("COPM") module 200 of the '238 patent is used, which extracts phase and amplitude of N parallel frequency channels simultaneously.

10   A frequency encoder 400 corrects phase and amplitude (or magnitude) data offsets, detects and locates active signals within a photodetector array 212 of the COPM 200 (described below), converts phase to fine frequency, and, finally, concatenates or otherwise combines coarse to fine frequency for readout, along with a signal indicating the data is valid and

15   ready to be output. Periodic calibration interlaced or overlaid with normal operation (by employing an internal signal source) sustains system accuracy over time and temperature, and significantly reduces RF and optical component phase match requirements.

Other types of input signals may alternatively be used, such as

20   sound, heat, light, electrical voltage, or any other measurable quantity capable of modulating or otherwise altering a carrier signal to impose frequency, phase, and optionally amplitude information.

Also, the delay line 104 lengths may vary, such that for the single MSOFM 100 system implementation, phase ambiguities can be

25   avoided within a single coarse channel bandwidth. In addition, other technologies for the delay line 104 (e.g., a bulk acoustic wave delay line) and the power splitter 102 may be used. Although these components are depicted

7

within the RF signal input path of the preferred embodiment, they may alternatively be implemented in the optical path.

FIG. 2 illustrates a schematic block diagram of the COPM module 200 of the present invention. The COPM module 200 provides phase

5   and frequency measurements for each frequency bin or channel, corresponding to a sub-band of the composite RF operating bandwidth. A beam splitter 204 divides an optical beam from a laser 202 into two mutually coherent optical beams 205. The two optical beams 205 propagate through two separate channelizer circuits, preferably two acousto-optic Bragg cell

10   modulators 206, that separate the input RF bandwidth into separate coarse frequency channels. Alternatively, a single Bragg cell 206 fabricated with dual RF transducers may be used. The Bragg cell 206 optical aperture spacing is independent of RF frequency or delay line 104 time.

Input signals RF0 and RF1, corresponding to direct and

15   delayed RF environment, respectively, are injected into the Bragg cells 206. Within the Bragg cells 206, each light beam 205 is modulated by the frequency and phase of its associated RF input, imposing incident RF signal amplitude and frequency (and inherently phase) onto each optical carrier. Thus, a relative phase difference at the IF input is replicated in the Bragg cell

20   206 optical outputs 207.

In addition to optical carriers, the carrier may also be represented in other forms (e.g., radio waves) or other frequency spectral ranges as well. Thus, for example, RF applications may use microwave, millimeter-wave bands, or optical carriers at infrared or ultraviolet

25   wavelengths.

Upon exiting the Bragg cells 206, the two optical beams 207 interfere spatially to develop an interference pattern. This optical interference pattern is Fourier-transformed by a Fourier Transform lens 210 and imaged

onto an area detector or photodetector array 212, providing a spectral decomposition of the incident RF spectrum.

One axis (Y-axis) of the photodetector array 212 corresponds to frequency channel number ("Frequency Chan#"), while the orthogonal axis (X-axis) corresponds to relative signal phase (and amplitude) information in spatial form as a sinusoidal intensity pattern. The two optical beams are deflected along the Frequency Chan# axis at an angle approximately proportional to the incident RF signal frequency. Because both RF inputs, RF0 and RF1, are identical with the exception of a time delay, their spectral intensity decomposition patterns are also identical along the Frequency Chan# axis. Thus, the resulting photodetector image intensity modulation pattern is two-dimensional, with phase interference occurring along the phase or X-axis and the RF signal Fourier transform occurring along the Frequency Chan# axis.

At a Frequency Chan# axis position associated with the RF frequency of the signal to be measured, a differential phase corresponding to the time delay between RF inputs, and thereby proportional to frequency, is imposed onto the optical beams 205. This results in an interference pattern spatial phase proportional to input RF frequency, which is subsequently converted to a fine frequency estimate by algorithms implemented within the frequency encoder 400.

Each coarse channel bin unambiguously resolves frequency to within one phase rotation. This is accomplished by using either or both of the following exemplary techniques: (1) reducing coarse channel width to less than one equivalent fine frequency phase rotation, and (2) utilizing adjacent coarse channel response magnitudes to interpolate within one channel. Other alternative methods may be employed to satisfy this objective.

In a preferred implementation, the COPM 200 uses an
efficient three-point spatial sampling scheme. The photodetector array 212
phase axis contains three detector elements that sample the interference
pattern at fixed spatial locations chosen to most efficiently transform the three

5   photodetector voltage outputs representing optical intensities to RF phase
difference using a simple phase extraction algorithm 306 (FIG. 3).

The embodiment shown in FIG. 2 depicts three outputs from
each photodetector array 212 row (corresponding to Frequency Chan# i, for i
from 1 to N) being applied to one of a multitude of phase extraction

10   processors 300, each applying the aforementioned algorithm 306 to calculate
a phase difference between the two RF inputs. An advantage of using three
(or more) detector outputs for phase measurement is the added capability of
measuring RF signal magnitude (or absolute amplitude), which is necessary
for subsequent threshold detection and centroid operations performed within

15   the frequency encoder 400 (described below).

Use of the three-detection element spatial sampling format and
algorithm provides high measurement accuracy and built-in correction for
detector amplitude offsets, which vary as a function of input and reference
carrier signal strength. User of fewer (e.g., three) spatial sampling-detection

20   elements also results in higher speed and less complex implementation of the
apparatus.

The detectors of the photodetector array 212 may be a single
integrated device, or the detectors may be multiple separate detectors
adjacently positioned at the Fourier transform plane or remotely located, such

25   that Fourier transform plane information is transferred to appropriate detector
elements. One example is to position an array of optical fibers at the Fourier
plane, the fibers effectively transporting the light intensity pattern to a
remotely located array of individual photodetectors.

The spatial intensity pattern phase variation is preferably

decoded by the COPM 200 optical processor of the '238 patent to provide

coarse frequency, phase, and amplitude measurement functionality. The

COPM 200 performs coarse RF channelization by, for example, a dual

5   transducer acousto-optic Bragg cell modulator within the optical processor,

which is an operation analogous to an RF filter bank, with filter output

detection accomplished by the array 212 of photodetector elements.

Video and A/D conversion circuits (not shown) then encode

individual photodetector element outputs into a binary-encoded digital format

10   for subsequent digital processing. After digitization of photodetector video

output, detection circuitry recognizes signal presence based on photodetector

output level, or signal magnitude computation, and provides a coarse

frequency estimate. Electrical phase measurements are then performed on the

photodetected two-beam optical interference pattern using an optical spatial

15   sampling technique.

FIG. 3 is a flow diagram of photodetector video processing

within the phase extraction processors 300 of the COPM 200. In FIG. 3, "N"

denotes the number of photodector elements along the Frequency Chan# axis.

In this embodiment, three photodetector elements are used for phase

20   measurement along the phase axis. A gain correction module 302 and an

offset correction module 304 perform gain correction and offset correction,

respectively, on the photodetector outputs (video) before processing by the

extraction algorithm 306 for phase and amplitude. Not shown, but implicit, is

A/D conversion of the video prior to processing for phase and amplitude.

25   The operations of the phase extraction processors 300 may be implemented in

either software, hardware, or a hybrid of both.

The configuration of RF delay line 104 and power splitter 102

circuits driving COPM 200 inputs corresponds to a classical delay-line

frequency discriminator at each photodetector (coarse) frequency channel output. Discriminator operation is characterized by production of a variable relative phase difference between delayed and non-delayed signal paths linearly proportional to input frequency. COPM 200 optical processing

5   translates incident electrical (time-domain) phase difference to a spatial image pattern retaining phase information sampling by three or more photodetectors at each frequency channel position.

FIG. 4 is a flow diagram of processing within the frequency encoder 400 of FIG. 1. A phase offset correction module 402 receives phase

10   outputs from the COPM 200 and performs phase offset correction and coarse frequency offset corrections on a bin-to-bin basis. The corrected phase values are converted to fine frequency by a phase to fine frequency module 410.

The phase to fine frequency module 410 provides high resolution interpolation within a coarse channel bandwidth, representing the

15   primary contributor to overall system frequency measurement performance. Within the phase to fine frequency module 410, measured phase difference is transformed to fine frequency shift (in Hertz) from an arbitrary reference, as given by the following equation:

20
$$\Delta F \cong \frac{\Delta \theta}{T \cdot 360} \qquad (1)$$

where,

$$\Delta \theta \equiv measured \ phase \ difference \ (degrees),$$
$$T \equiv time \ delay \ (secs),$$
$$360 \equiv conversion \ constant \ (degrees/Hertz).$$

To avoid fine frequency measurement ambiguity, the delay line 104 (FIG. 1) time is chosen to constrain phase shift to within +/- 180

degrees corresponding to +/- 0.5 coarse bin frequency width about the bin center frequency.

An amplitude offset correction module 404 receives amplitude outputs from the COPM 200 and performs amplitude offset correction. Phase offset correction and amplitude offset correction are achieved as necessary by subtraction of calibration offsets stored in memory associated with a particular coarse frequency channel.

A detection logic module 406 receives the corrected amplitude values and compares coarse channel amplitude to a predetermined threshold for detection of signal presence. After detection of signal presence, centroid logic operations within a frequency channel centroid logic module 408 determine the coarse frequency as the primary active channel within consecutive active channels.

A frequency formatter module 412 receives the fine frequency measurement from the phase to fine frequency module 410 and the coarse frequency measurement channel number (or index) from the frequency channel centroid logic module 408. The coarse frequency channel index is converted to a coarse frequency value (e.g., in MHz) within the frequency formatter 412. Alternatively, the coarse frequency channel index may be converted within the frequency channel centroid logic module 408. The calculated fine frequency is summed within the frequency formatter 412 to the coarse initial frequency associated with the active centroided coarse frequency channel number. The delay line 104 time is chosen to limit phase excursions to less than 360 degrees within a coarse channel bandwidth, removing the requirement for phase ambiguity resolution circuitry.

Finally, the frequency formatter 412 optionally uses the RF band number obtained from an RF downconverter 504 (FIG. 5) to correct coarse frequency offset, thereby selecting a starting frequency offset from, for

example, circuits (such as calibration tables) embedded within the frequency formatter 412. The RF band number is used to sum a fixed global RF frequency offset to the current IF frequency estimate, thereby extending operational receiver measurement range to the entire input RF bandwidth. The frequency formatter module 412 outputs a "valid" signal indicating the data is valid and ready to be output, along with the summed frequency.

The frequency encoder 400 may be implemented in either software, hardware, or a hybrid of both. For example, look-up tables and sums may be used, such as a look-up table for phase to fine frequency determination. Also, phase offset correction and amplitude offset correction (i.e., calibration values) may be implemented as tables in memory to convert from relative numbers to actual values. For example, for amplitude, the correction is for flatness. The amplitude measured is a relative number, and the actual amplitude is the measured amplitude plus an offset.

The frequency formatter module 412 generates the final frequency for readout by, for example, concatenation of coarse and fine frequency, or summation of absolute starting frequency band number, coarse frequency offset to the band starting frequency, and fine frequency offset relative to coarse frequency. The band number may be determined from a look-up table (e.g., band #1 may correspond to 2,000 MHz). For speed, the frequency formatter module 412 is preferably implemented in hardware using, for example, a digital adder or digital tables.

FIG. 5 is a schematic block diagram of the multiple simultaneous optical frequency measurement apparatus 100 of the present invention in an exemplary RF receiver application. An RF bandwidth containing multiple input signals of interest propagating in free-space is acquired by a reception antenna 502. An RF downconverter 504 then frequency translates the RF bandwidth to an appropriate IF band for injection

into the present invention (i.e., the MSOFM) 100. The MSOFM 100 detects

signal presence and measures signal parameters, primarily that of electrical

frequency, for each signal in the active instantaneous IF bandwidth.

     The MSOFM 100 outputs the measured signal parameters to a

5   conventional parameter extractor 506. The parameter extractor 506 formats

these (conceptually) parallel data patterns of signal parameters into pulse

descriptor words (PDWs). Each PDW corresponds to a single measurement

event. For each detected incident signal (e.g., radar) pulse, parameters for

passive radar signal detection (e.g., coarse frequency, fine frequency, time of

10   arrival (TOA), amplitude, and pulse repetition interval (PRI)) are measured,

then formatted into a digital description of the single RF pulse event as a

PDW, emphasizing composite fine frequency. The PDWs are processed by

algorithms within a conventional signal sorter 508 to coalesce multiple

isolated PDWs into a consolidated parametric description of the signal system

15   type. A conventional recognizer 510 then database-associates the

consolidated parametric description to a specific signal identification (ID)

code for readout on a display 512. Parameter extractors, sorters, and

recognizers are typical subsystem components of electronic support systems

receivers and radar warning receivers (RWR), such as the AN/ALR-67 RWR.

20   The present invention has been experimentally demonstrated

for the preferred embodiment. FIG. 6 is a graph of cumulative phase and

frequency accuracy measurements. Deviation from a linear fit is

representative of calibrated frequency error. Using a 29.04 nanosecond delay

line, measured frequency error was less than 0.25 MHz over a 34 MHz

25   unambiguous range. Frequency measurement linearity with input frequency

was verified over a 50 MHz range (one coarse channel) in 1 MHz steps.

These results indicate the present invention is useful in numerous practical

applications.

The present invention provides many advantages over the prior art. IFM technology lacks multiple signal handling capabilities, while RF channelizers provide relatively coarse frequency measurements. Unlike commercial electronic frequency discriminator and IFM devices, the present

5 invention permits frequency measurement of multiple, time-coincident, and CW signals. Compared to multi-channel techniques such as RF filter banks and channelized receivers, the present invention provides increased frequency measurement resolution using intrachannel phase-based techniques, and sustainable accuracy across the entire operating bandwidth and temperature

10 range through continuous phase offset correction.

Additionally, current frequency discriminator and IFM devices must function (internally) over a limited amplitude dynamic range to achieve acceptable measurement accuracy. In contrast, the present invention functions correctly over a much wider dynamic range, limited primarily by

15 noise and photodetector saturation. This extends the achievable system-level dynamic range and simplifies the system design by eliminating RF limiting circuitry requirements. The resulting compact size, low power consumption, and reduced complexity increases system mean time before failure (MTBF) to reduce operational cost.

20 In the preferred embodiment, several optimizations may be identified as characteristic of the present invention in general. First, a single apparatus performs signal detection and coarse/fine frequency measurement, avoiding additional delay lines and associated cueing circuitry typically required to coordinate separate coarse and fine frequency measurement

25 assets. Also, a preferred delay time value may be chosen to provide enhanced frequency accuracy, yet avoid phase ambiguities throughout a wide instantaneous bandwidth, which is a feature exploited from channelized

optical phase measurement. In addition, a continuous calibration scheme provides phase offset correction over bandwidth and temperature to significantly reduce component phase matching requirements of the RF and optical system elements. Further, low system complexity, as previously

5 described, is expected to result in reduced size, weight, power consumption, and cost over alternative approaches.

Incoherent or coherent detection is possible using the present invention. Incoherent (power) detection, depicted in the preferred embodiment, simplifies subsequent signal processing hardware requirements

10 by performing parameter measurements at a relatively narrow video bandwidth. In contrast, typical coherent signal detection requires more complex processing hardware for operation at intermediate frequencies, but potentially has a larger dynamic range.

Alternative embodiments of the present invention address

15 varying application requirements, such as increased fine frequency resolution, increased bandwidth, or alternate photodetector array 212 readout/frequency encoder 400 configurations, among others.

To achieve increased system bandwidth, multiple instances of the present invention may be configured in end-to-end fashion, each

20 frequency offset from its neighbor to obtain a composite bandwidth equivalent to the sum of individual bandwidths of the present invention.

Improved fine frequency resolution can be achieved using multiple parallel-configured instances of the present invention, each operating over an identical instantaneous bandwidth, but differing in delay line 104

25 time. In this configuration, individual MSOFM 100 units have carefully chosen delay times that may independently provide ambiguous frequency measurements. Subsequent composite processing of the multiple independent

frequency measurements then resolves the ambiguities, using techniques borrowed from the field of RF interferometry. Maximum achievable frequency measurement resolution using this technique typically corresponds to an (ambiguous) frequency measurement resolution of the MSOFM 100

5   instance having the longest time delay.

Also, the number of coarse frequency channels and overall instantaneous bandwidth is arbitrary. In the preferred embodiment, coarse frequency channels are assumed to be equally spaced and sequentially ordered, but this is not a requirement.

10   The many features and advantages of the invention are apparent from the detailed specification and, thus, it is intended by the appended claims to cover all such features and advantages of the invention which fall within the true spirit and scope of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the

15   art, it is not desired to limit the invention to the exact construction and operation illustrated and described, and accordingly all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.

MULTIPLE SIMULTANEOUS OPTICAL
FREQUENCY MEASUREMENT

ABSTRACT OF THE DISCLOSURE

A signal processing apparatus for providing concurrent electrical frequency measurements of multiple, time-coincident signal inputs. In one embodiment of the present invention, an input signal is received that contains a plurality of individual signals independent of each other in frequency, phase, and electrical amplitude. A power splitter splits the input signal into two separate input signals. A delay line introduces a time delay to one of the two separate input signals. Two Bragg cells within a channelized optical phase measurement (COPM) device modulates two optical carrier signals with the delayed and non-delayed input signals, respectively, separating the modulated delayed and non-delayed input signals into multiple time-concurrent frequency channel signals. Upon exiting the Bragg cells, the two optical beams interfere spatially to develop an interference pattern along the phase and frequency channel number axes of a photodetector array. The resulting spatial intensity pattern phase variation is decoded to provide coarse frequency, phase, and amplitude measurements. A frequency encoder receives the photodetector outputs, corrects phase and amplitude data offsets, and converts phase to fine frequency. Finally, the frequency formatter concatenates coarse to fine frequency for readout.
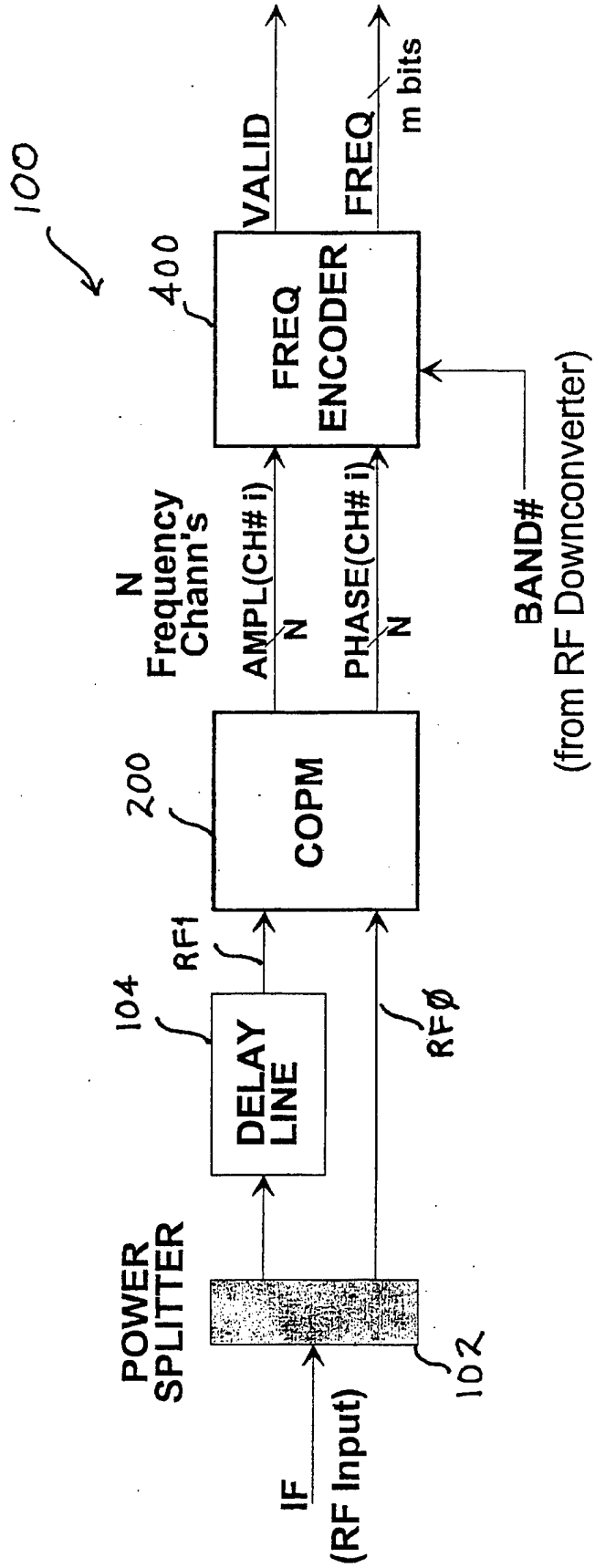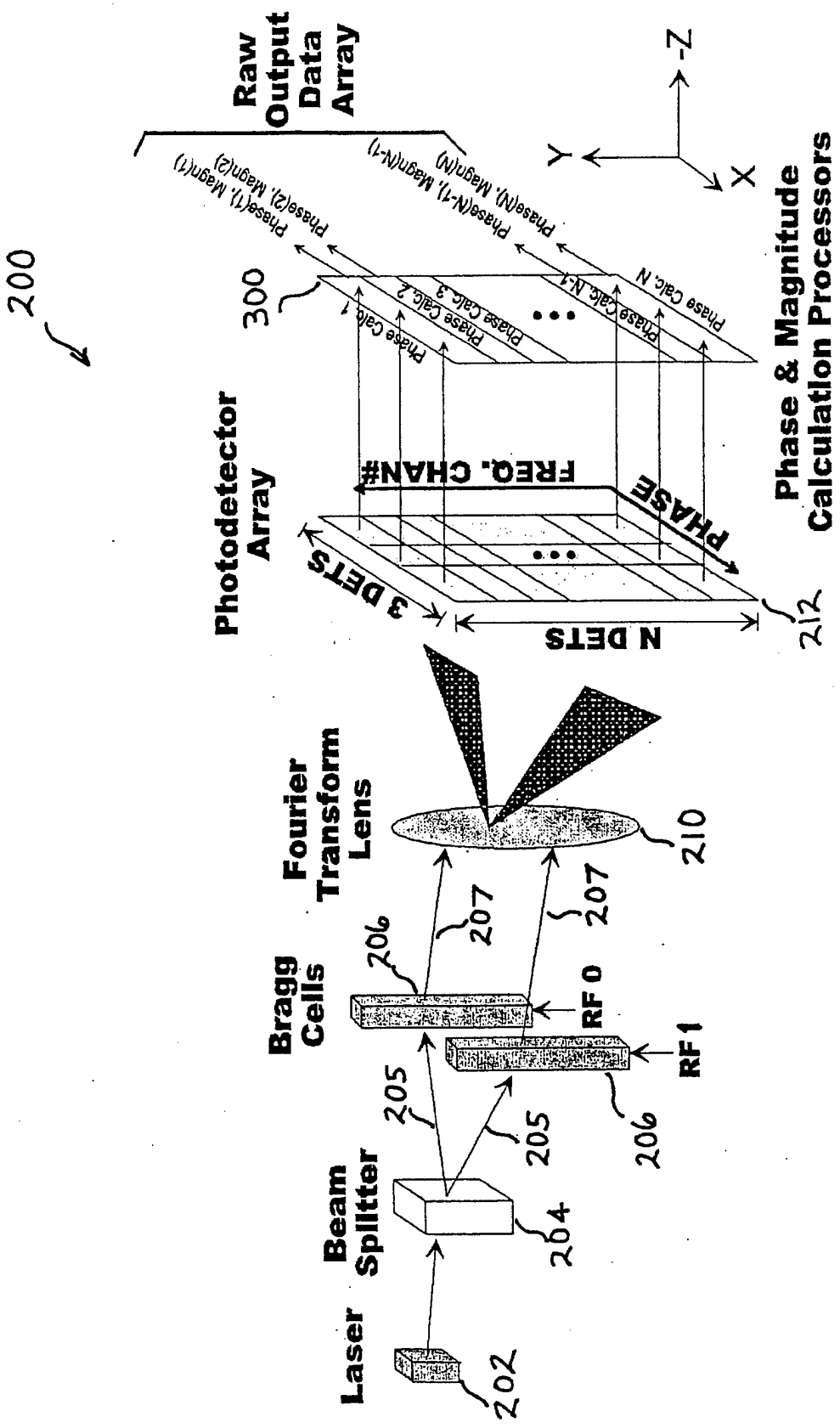
FIG. 1

FIG. 2

Photodetector
Video

$\xrightarrow{\quad}$
Nx3

| Gain
Correction | $\xrightarrow{\quad}$
Nx3 | Offset
Correction | $\xrightarrow{\quad}$
Nx3 | Phase & Amplitude
Extraction Algorithm |

302   304   306

300

$\xrightarrow{\quad}$ Phase.
N

$\xrightarrow{\quad}$ Amplitude.
N

FIG. 3

FIG. 4

ANTENNA

502

RF → 504

IF → MSOFM 100

RF DOWNCONV.

PARAMETER EXTRACTOR 506

PDW's → SORTER 508

RECOGNIZER 510

DISPLAY 512
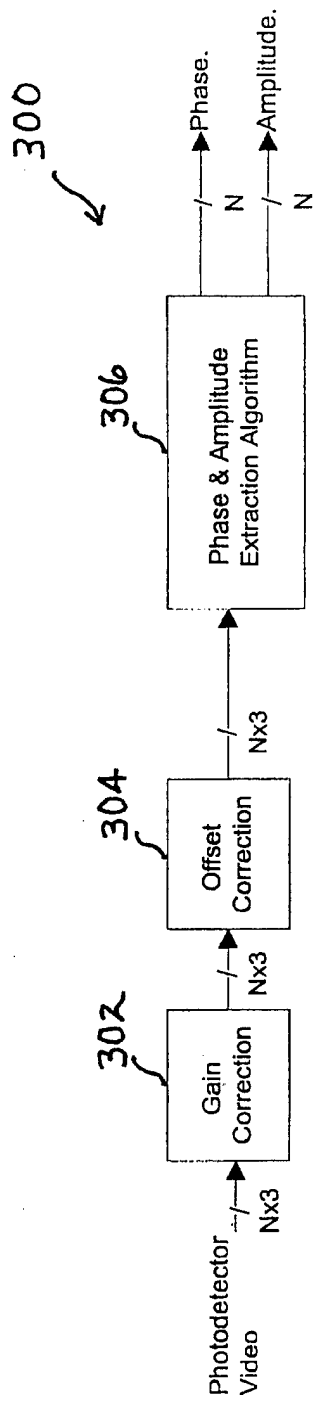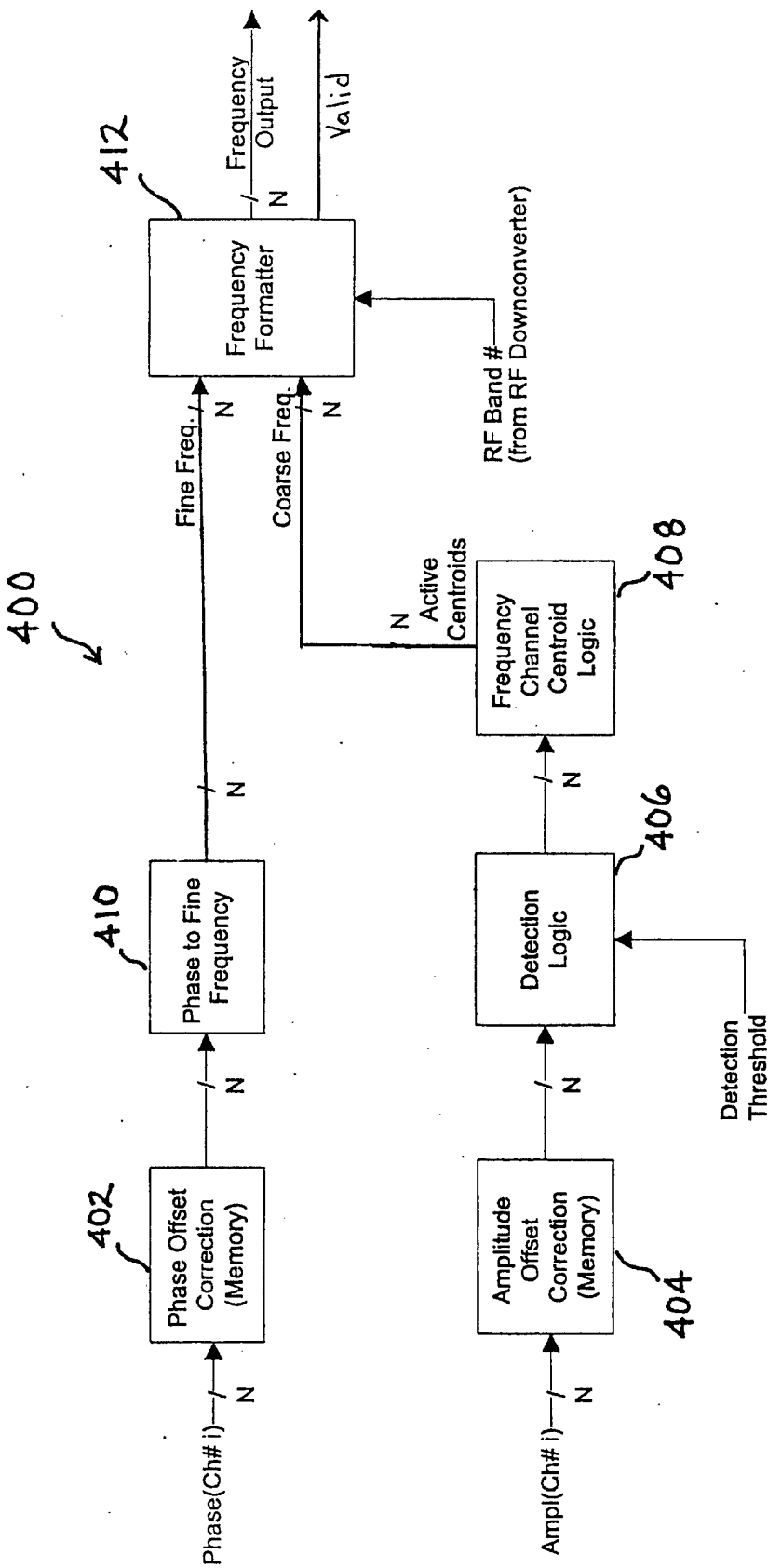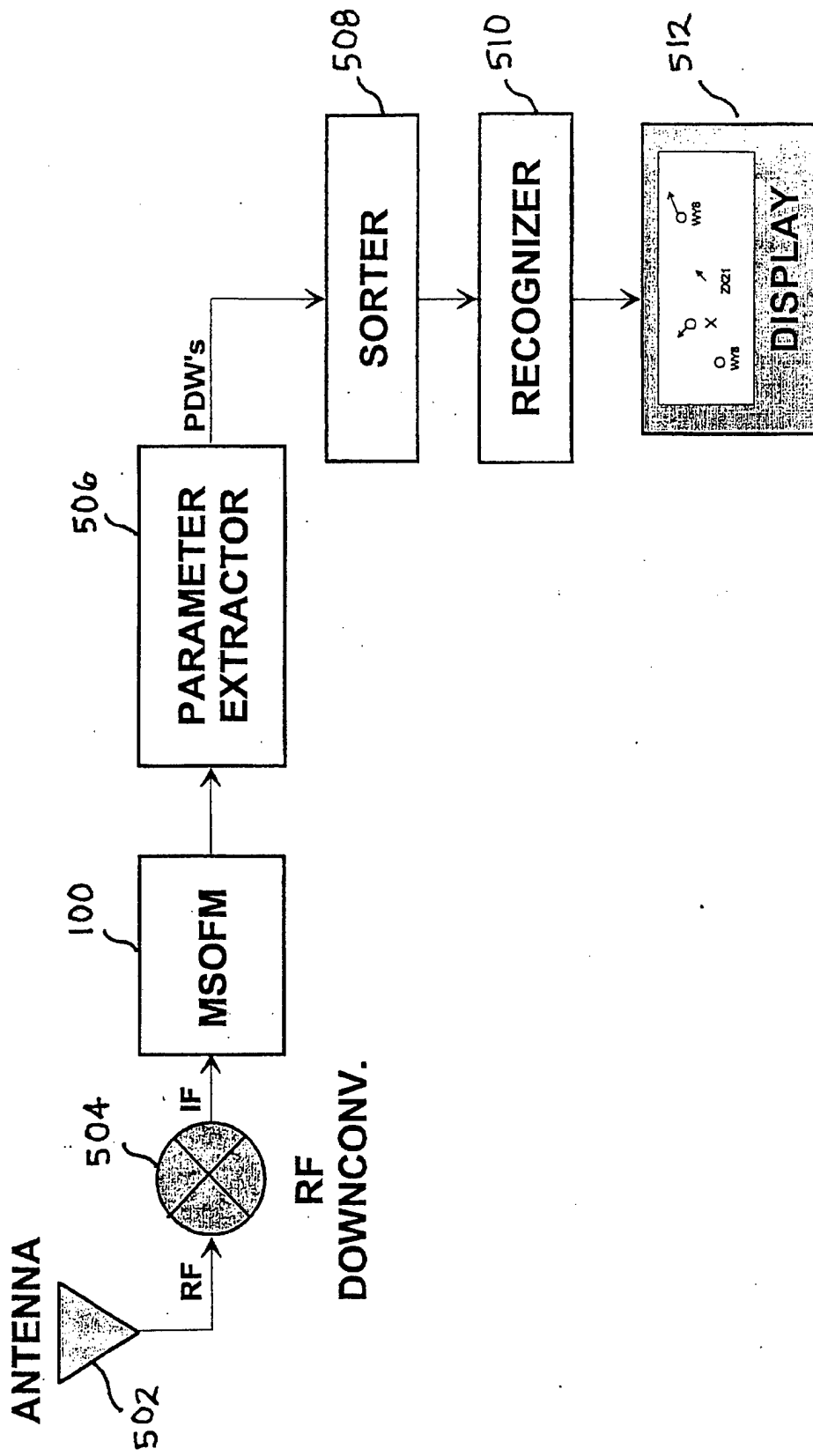
FIG. 5

Peak Frequency Error <250 KHz (representative 50 MHz Bandwidth)

CUMULATIVE PHASE

(Pulse Width=CW, Delay Line=~26ns, File: 1211_02D5)

DATA
LS-FIT

Chann N+1

Chann N

LS-Fit=10.46 degs/Mhz
Calc Delay=29.04 ns

Cumulative Phase (degs)

600
500
400
300
200
100
0

RF Frequency (GHz)

2.2
2.203
2.206
2.209
2.212
2.215
2.218
2.221
2.224
2.227
2.23
2.233
2.236
2.239
2.242
2.245
2.248
2.251

Frequency Accuracy

(Pulse Width=CW, Delay=29.04ns, File: 1211_02D5)

Error (MHz)

0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25

Input Frequency (MHz)

2.2
2.2
2.2
2.21
2.21
2.21
2.21
2.22
2.22
2.22
2.22
2.23
2.23
2.23
2.24
2.24
2.24
2.24
2.25
2.25
2.25

Phase Slope =10.49 degs/Mhz

FIG. 6