

WIDEBAND SIGNAL ANALYZER

FIELD OF THE DISCLOSED TECHNIQUE

The disclosed technique relates to signal analyzers, in general,
5 and to methods and systems for analyzing a plurality of signals simultaneously over a wide frequency band, in particular.

BACKGROUND OF THE DISCLOSED TECHNIQUE

Signal analyzers are devices which can analyze a signal and
10 determine various characteristics of the signal, such as its frequency, time of arrival and bandwidth. Other components of the signal can also be characterized. The signal may be provided to the signal analyzer or the signal may be received by the signal analyzer. The signal may be electrical, electromagnetic (herein abbreviated EM), acoustic or optical.
15 Reference is now made to Figure 1A, generally referenced 10, which is a schematic illustration of a prior art signal analyzer. Signal analyzer 10 can receive signals to be analyzed and can characterize the frequency or frequencies of the received signal or signals. Signal analyzer 10 includes an antenna 12, an amplifier 14 and a filter 16. Amplifier 14 is coupled with
20 antenna 12 and filter 16. Incoming signals 18, shown by a set of arrows 20, impinge on antenna 12 which receives incoming signals 18. Incoming signals 18 may be EM signals. Antenna 12 converts the received incoming signals to electrical signals and provides the electrical signals to amplifier 14. Amplifier 14 amplifies the electrical signals and provides the
25 amplified electrical signals to filter 16. Filter 16 may include a plurality of filters (not shown), such as low pass filters, high pass filters and bandpass filters. Filter 16 substantially filters the electrical signals, thereby determining the frequency, or frequency band of the electrical signals and thus the frequency, or frequency band of incoming signals 18. For
30 example, if filter 16 includes a plurality of bandpass filters, then the

frequency of incoming signals 18 can be determined according to which one of the plurality of bandpass filters passes incoming signals 18. The narrower the bandpass, the more precisely signal analyzer 10 can determine the frequency of incoming signals 18.

5 Reference is now made to Figure 1B, generally referenced 50, which is another schematic illustration of a prior art signal analyzer. Signal analyzer 50 can receive signals to be analyzed and can determine various characteristics of the received signals. Signal analyzer 50 includes an antenna 52, an analog processor 54 and a digital processor 56. Analog
10 processor 54 is coupled with antenna 52 and digital processor 56. Incoming signals 58, shown by a set of arrows 60, impinge on antenna 52 which receives incoming signals 58. Incoming signals 58 may be EM signals. Antenna 52 converts the received incoming signals into electrical signals and provides the electrical signals to analog processor 54. Analog
15 processor 54 analyzes and processes the electrical signals as analog signals. Analog processor 54 may include an amplifier (not shown) and a filter (not shown), as shown above in Figure 1A. Analog processor 54 may also include an analog-to-digital converter (herein abbreviated ADC), which converts the analog electrical signals into representative digital
20 signals. Analog processor 54 then provides the representative digital signals to digital processor 56. Digital processor 56 analyzes the representative digital signals and characterizes various components of incoming signals 58.

In general, signal analyzers which include a digital processor for
25 characterizing the various components of a received signal are required to sample the received signal at a sampling rate in accordance with the Nyquist-Shannon sampling theorem in order to perfectly reconstruct the received signal and thereby determine characteristics of the received signal. The received signal is substantially an analog signal having a
30 continuous set of values representing the received signal. In order to convert the analog signal into a digital signal for digital processing by the

digital processor, the analog signal must be sampled. Sampling substantially refers to the process by which discrete measurements of the analog signal are taken. The rate at which the discrete measurements, also known as samples, are taken is referred to as the sampling rate.

5 According to the Nyquist-Shannon sampling theorem, to perfectly reconstruct the analog signal and its characteristics from the digital signal, the sampling rate must be at least double the highest frequency of the received analog signal, which includes the signal bandwidth. The signal bandwidth substantially refers to the difference between the highest and
10 lowest frequencies present in the analog signal and can also be referred to as a frequency band. The frequency of such a sampling rate is known as the Nyquist frequency. For many frequency bands, signal samplers exist which can sample the analog signal at or above the Nyquist frequency. In the case of very wide frequency bands, for example on the order of tens of
15 gigahertz (herein abbreviated GHz), signal samplers which can sample the analog signal at the Nyquist frequency may not be available or may not exist. In such cases, devices known as down-converters can be used in the signal analyzers which convert the analog signal to an analog signal having a lower frequency band, i.e., to a lower highest frequency in the
20 analog signal. At the lower frequency band, known signal samplers can be used to sample the lower frequency analog signal at or above its Nyquist frequency. It is noted that in signal analyzers including down-converters, a plurality of signal analyzers may be required in order to simultaneously cover a wide frequency band.

25 Signal analyzers which include down-converters for analyzing very high frequency signals and very wide frequency bands are known in the art. U.S. Patent Application Publication No. 2007/0086544 A1 issued to Fudge et al., entitled "Nyquist folded bandpass sampling receivers and related methods," is directed to a Nyquist folded bandpass sampling
30 receiver that uses wideband filters and modulated sampling clocks to identify received signals. The Nyquist folded bandpass sampling receiver

includes receive path circuitry which includes a wideband filter circuitry. The wideband filter circuitry has a center frequency within a frequency range of interest and a bandwidth less than or equal to the frequency range of interest yet wide enough to cover multiple Nyquist zones
5 associated with a modulated sampling clock. The sampling receiver also includes sampling circuitry configured to receive a filtered signal from the wideband filter circuitry and to receive the modulated sampling clock signal as an input. The modulated sampling clock signal is configured to provide non-uniform sampling for signals within the multiple Nyquist zones to
10 induce frequency modulation on signals dependent on a Nyquist zone of origin. The modulated sampling clock signal can be a frequency modulated clock signal.

During operation of the Nyquist folded bandpass sampling receiver, multiple Nyquist zones are allowed to fold on top of each other
15 during sampling. An RF sampling clock in the sampling receiver is modulated, thereby inducing separate frequency modulations within each Nyquist zone. The signals that are folded together from different Nyquist zones can then be identified and distinguished. When the Nyquist zones fold on top of each other, the different signals from different Nyquist zones
20 can be separated and identified based on the fact that the added modulation is different for each Nyquist zone. By using one or more clock modulations to induce frequency modulations that are Nyquist zone dependent, multiple Nyquist zones can be aliased together while still allowing for signals from different Nyquist zones to be separated and
25 identified. A similar Nyquist folded bandpass sampling receiver is disclosed in U.S. Patent Application Publication No. 2007/0081578 A1 issued to Fudge et al. and entitled "Nyquist folded bandpass sampling receivers with narrow band filters for UWB pulses and related methods."

U.S. Patent Application Publication No. 2008/0013653 A1 issued
30 to Fudge et al., entitled "Direct bandpass sampling receivers with analog interpolation filters and related methods," is directed to a reconfigurable

direct radio frequency (RF) bandpass sampling receiver that uses analog interpolation filters to improve performance. The bandpass sampling receiver includes a receive path circuitry having decoupled quantization. The receive path circuitry includes a bandpass filter circuitry having a center frequency within a frequency range of interest and having a bandwidth less than the frequency range of interest. The bandpass sampling receiver also includes a non-quantizing sampling circuitry which is configured to receive a filtered signal from the bandpass filter circuitry and to receive a bandpass sampling clock signal as an input. The bandpass sampling clock signal meets Nyquist sampling criteria of the bandpass filter but does not meet Nyquist sampling criteria of the total frequency range of interest. The bandpass sampling receiver further includes an analog interpolation filter which receives the output of the non-quantizing sampling circuitry where the analog interpolation filter has a center frequency within a Nyquist zone of operation for the non-quantizing sampling circuitry. Analog to digital converter (ADC) circuitry is also included in the sampling receiver to receive a quantization sampling clock signal and to quantize an analog signal received from the analog interpolation filter. The analog interpolation filter may be a tunable analog interpolation filter having a center frequency that is tunable within a Nyquist zone of operation for the non-quantizing sampling circuitry. The bandpass filter circuitry can be a tunable bandpass filter circuitry having a tunable center frequency dependent upon a filter control signal where the center frequency is tunable across the frequency range of interest. In addition, the quantization sampling clock signal can be tunable to determine a Nyquist zone of operation for the ADC. The addition of an analog interpolation filter to the bandpass sampling receiver allows the quantization clock to be de-coupled from the RF sampling clock. As such, the quantization can be performed at a much slower rate than the initial RF sampling, allowing the final analog bandwidth to be much narrower than the bandwidth of the first stage filter located before the high-speed

sampler. A similar reconfigurable direct RF bandpass sampling receiver is disclosed in U.S. Patent No. 7,489,745 issued to Fudge and entitled "Reconfigurable direct RF bandpass sampling receiver and related methods."

5 U.S. Patent No. 7,269,354 issued to Silverman et al., entitled "Superheterodyne photonic receiver using non-serial frequency translation," is directed to an optoelectronic RF signal receiver. The receiver includes a first RF-to-photonic modulator for receiving an optical carrier signal and an electrical signal from a local oscillator. The first
10 modulator produces an optical carrier signal with first optical sidebands offset from the carrier signal by the local oscillator frequency. The receiver also includes a second RF-to-photonic modulator for receiving an electrical RF signal and the signals from the first modulator. The second modulator produces second sidebands to each of the first optical
15 sidebands from the first modulator with each of the second sidebands being offset from the first sidebands by the RF signal frequency. The receiver further includes a detector for receiving signals produced by the second modulator. The detector produces an electrical intermediate frequency (IF) signal for further processing. The receiver does not use a
20 frequency translation device in the RF signal path and thereby eliminates RF loss, noise and limited dynamic range. The two modulators can be biased for optimum linearity and for optimum rejection of in-band spurious signal products.

An article entitled "Photonic subsampling analog-to-digital
25 conversion of microwave signals at 40-GHz with higher than 7-ENOB resolution," written by Kim et al., published in Optics Express, Vol. 16, No. 21 (October 2008) is directed to a photonic subsampling analog-to-digital converter (ADC) that down-converts and digitizes narrowband high frequency microwave signals. The ADC includes a passively mode-locked
30 erbium fiber laser which generates an ultralow-jitter optical pulse train. The optical pulse train is used to subsample down-convert a narrowband

high frequency microwave signal. The ADC also includes an intensity modulator which convolves the optical pulse train used for subsampling with the microwave signal. Due to subsampling of the microwave signal, the spectrum of the microwave signal is aliased at every harmonic of the repetition rate of the optical pulse train, including at the baseband frequency. The baseband frequency copy is provided to a low pass filter in the ADC for down-converting the high frequency microwave signal to the baseband frequency in the optical domain. The down-converted baseband signal is converted from the optical domain to the electronic domain by applying the modulated pulse train to photodiodes that are reverse-biased by an on-chip current source, thereby generating a photocurrent. The resulting signal-dependent photocurrent is charged onto a capacitor and is also provided as input to a continuous-time (CT) Delta-Sigma modulator, included in the ADC. The CT Delta-Sigma modulator inherently filters out aliased copies of the narrowband microwave signal while the baseband signal is retained and quantized by a 1-bit resolution ADC, included in the ADC, operating at a high sampling rate. The oversampled 1-bit serial stream is provided to a digital filter in the ADC. The digital filter includes a decimator which digitally re-samples the oversampled 1-bit serial stream and generates a 1-bit digitized output code.

An article entitled "Multi-rate asynchronous sampling of sparse multi-band signals," written by Rosenthal et al., published online at [arXiv:0807.1222v1](https://arxiv.org/abs/0807.1222v1) [physics.optics] is directed to a scheme for reconstructing multi-band signals. The scheme entails gathering samples of a multi-band signal at several different rates whose sum is substantially lower than the Nyquist sampling rate. The scheme enables the spectrum amplitude and the spectrum phase to be reconstructed. An article entitled "Optical under-sampling and reconstruction of several bandwidth-limited signals," written by Feldster et al., is directed to a system for under-sampling a bandwidth-limited signal with a carrier frequency not

known a priori. The system undersamples asynchronously at three different sampling rates and uses a wavelength division multiplexing technique. The system enables the reconstruction of the amplitude and the phase of the signal.

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SUMMARY OF THE PRESENT DISCLOSED TECHNIQUE

It is an object of the disclosed technique to provide a novel method and system for instantaneously and continuously analyzing a wide frequency spectrum which may include a plurality of signals which
10 overcomes the disadvantages of the prior art. In accordance with the disclosed technique, there is thus provided a system for collecting at least one signal simultaneously including an analog sampler, at least two digital frequency analyzers (DFAs) and a processor. The DFAs are each respectively coupled with the analog sampler and the processor is coupled
15 with each one of the DFAs. The analog sampler is for receiving the signal as at least one analog electrical signal and for folding the analog electrical signal using at least two different comb frequencies simultaneously into at least one sampled analog electrical signal. The analog sampler is also for demultiplexing the sampled analog electrical signal into at least two
20 respective intermediate frequency (IF) signals respectively according to the different comb frequencies. Each one of the DFAs is for digitally sampling a respective one of the respective IF signals into at least one respective digital signal and for spectrally analyzing the respective digital signal. The processor is for determining a plurality of linear combinations
25 of the respective IF signals with respect to the different comb frequencies used in the analog sampler. The processor is also for determining at least one frequency of the signal by evaluating the plurality of linear combinations of the respective IF signals.

According to another aspect of the disclosed technique there is
30 thus provided a system for collecting at least one signal simultaneously, with a frequency of the signal being within a defined intermediate

frequency (IF) band, the system including an analog sampler, at least one digital frequency analyzer (DFA) and a processor. The DFA is coupled with the analog sampler and the processor is coupled with the DFA. The analog sampler is for receiving the signal as at least one analog electrical signal and for folding the analog electrical signal using at least one comb frequency into at least one sampled analog electrical signal. The analog sampler is also for converting the sampled analog electrical signal into at least one respective IF signal according to the comb frequency. The DFA is for digitally sampling the respective IF signal into at least one respective digital signal and for spectrally analyzing the respective digital signal. The processor is for determining a plurality of linear combinations of the respective IF signal with respect to the comb frequency used in the analog sampler. The processor is also for determining at least one frequency of the signal by evaluating the plurality of linear combinations of the respective IF signal. The respective IF signal has a frequency within the IF band.

According to a further aspect of the disclosed technique there is thus provided a method for collecting at least one signal simultaneously including the procedures of collecting at least one signal and folding the collected signal using at least two different comb frequencies simultaneously, thereby generating at least two respective intermediate frequency (IF) signals. The method also includes the procedures of digitally sampling each one of the respective IF signals, thereby generating at least two respective sampled IF signals and spectrally analyzing the respective sampled IF signals. The method further includes the procedure of processing each one of the respective sampled IF signals, thereby determining at least one characteristic of the collected signal.

According to another aspect of the disclosed technique there is thus provided a method for collecting at least one signal simultaneously including the procedures of collecting at least one signal and folding the collected signal using at least two different comb frequencies

simultaneously, thereby generating at least two respective intermediate frequency (IF) signals. The method also includes the procedures of digitally sampling each one of the respective IF signals, thereby generating at least two respective sampled IF signals and digitally processing the
5 respective sampled IF signals. The method further includes the procedure of processing each one of the respective sampled IF signals, thereby determining at least one characteristic of the collected signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed technique will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

5 Figure 1A is a schematic illustration of the prior art;

 Figure 1B is another schematic illustration of the prior art;

 Figure 2 is a schematic illustration of a signal analyzer, constructed and operative in accordance with an embodiment of the disclosed technique;

10 Figure 3A is a schematic illustration of the analog sampler of Figure 2 embodied as an analog optical sampler, constructed and operative in accordance with another embodiment of the disclosed technique;

 Figure 3B is a schematic illustration of one of the optical pulse generators of Figure 3A, constructed and operative in accordance with a further embodiment of the disclosed technique;

 Figure 3C is a schematic illustration of the digital frequency analyzers of Figure 2, constructed and operative in accordance with another embodiment of the disclosed technique;

20 Figure 3D is a schematic illustration of the processor of Figure 2, constructed and operative in accordance with a further embodiment of the disclosed technique;

 Figure 3E is another schematic illustration of the analog sampler of Figure 2 embodied as an analog RF sampler, constructed and operative in accordance with another embodiment of the disclosed technique;

 Figure 3F is a schematic illustration of one of the RF comb generators of Figure 3E, constructed and operative in accordance with a further embodiment of the disclosed technique;

30 Figure 4 is a schematic illustration showing a plurality of frequency diagrams of the signals generated by either one of the analog optical sampler of Figure 3A or the analog RF sampler of Figure 3E,

constructed and operative in accordance with another embodiment of the disclosed technique; and

Figure 5 is a schematic illustration of a method for analyzing a plurality of signals simultaneously, operative in accordance with a further
5 embodiment of the disclosed technique.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The disclosed technique overcomes the disadvantages of the prior art by providing a novel signal analyzer system and method for instantaneously and continuously analyzing a plurality of signals over a wide frequency spectrum. The signal may have a frequency ranging from the kilohertz (herein abbreviated KHz) range to the terahertz (herein abbreviated THz) range, for example between 5 KHz and 50 THz, including the entire megahertz (herein abbreviated MHz) and gigahertz (herein abbreviated GHz) ranges. The signal may be electrical, electromagnetic (herein abbreviated EM), optical and may include the entire frequency spectrum. The signal may also include a plurality of signals received, provided to or intercepted by the signal analyzer simultaneously. In addition, the signal may also be a noise signal. According to the disclosed technique, the signal analyzer includes an analog sampler which folds the received signal using a plurality of different sampling frequencies, either optically or using radio frequency (herein abbreviated RF) signals. The signal analyzer also includes a plurality of novel digital frequency analyzers which determine linear combinations of the sampling frequencies used to fold the received signal. According to the disclosed technique, the frequency of the received signal, or the frequencies of a plurality of signals received simultaneously, can be determined based on the determined linear combinations of the sampling frequencies used and the corresponding measured intermediate frequencies. In addition, the signal analyzer of the disclosed technique includes a novel processor which can determine other characteristics of the received signal, some of which are based on the determined linear combinations of the sampling frequencies used. For example, the novel processor can determine the amplitude of received signal as well as its frequency spread, both of which can be used to determine the time of arrival of the received signal, the time of end of the received signal, power level parameters relating to the received signal and amplitude level

parameters relating to the received signal. Also, amplitude and frequency variations within the received signal can be used to determine frequency, phase and amplitude modulations related to the received signals, within a pulse of the received signal and between pulses of the received signal.

5 The signal analyzer of the disclosed technique can be used in a plurality of applications where any spectrum (in particular a wideband spectrum) of frequencies is to be monitored simultaneously for incoming signals, providing a high signal-to-noise ratio (herein abbreviated SNR), when the frequency, or frequencies, of the incoming signals are not known a priori.

10 Examples of such applications include spectrum analysis, determining the location of a lost cellular telephone, detecting a plurality of beacons simultaneously for navigation purposes, such as for airplane pilots, mapping the amplitude and RF spectrum used by transmit antennas of cellular telephone companies for the safety of citizens living near such
15 transmit antennas, detecting pirate radio stations, detecting pirate TV stations, electromagnetic interference testing, radio frequency interference testing and the like. The signal analyzer of the disclosed technique can also be used in applications where the frequency, or frequencies, of the incoming signals are known a priori.

20 In general, prior art signal analyzers as described above in Figures 1A and 1B are designed while taking into account a signal-noise tradeoff. If such systems are designed to analyze signals having a narrow bandwidth, then a high SNR can be achieved in the analyzed signals. At the same time, such systems can only analyze a narrow bandwidth of
25 frequencies instantaneously, which may be appropriate in certain applications. For signals which fall within the narrow bandwidth, a high level of analysis and accurate characterization of the components of the signal can be achieved. Yet signals which fall outside the narrow bandwidth are substantially disregarded by such systems. Alternatively, if
30 such systems are designed to analyze signals in a wide bandwidth, then signals in a wide band of frequencies can be analyzed using a single

system. At the same time, the signals analyzed by such systems may exhibit a low SNR, substantially suffering from high noise levels and therefore having a low sensitivity for detecting signals. Also in some prior art signal analyzers an internal scanning filter is used to simultaneously
5 view signals in substantially small portions of a wide bandwidth. As the bandwidth of the internal scanning filter is increased, a greater portion of the wide bandwidth can be viewed at the same time yet the noise level of the viewed signals increases as the bandwidth of the internal scanning filter is increased. In applications where signals in a wide band of
10 frequencies need to be analyzed having a high SNR, multiple narrow band signal analyzers may be coupled together where each narrow band signal analyzer analyzes and processes signals in a different narrow band. Whereas such systems may be able to accurately analyze signals in a wide band of frequencies, such systems may not be cost effective due to
15 the number of multiple narrow band signal analyzers required to cover the desired wide frequency band to be analyzed. Multiple signal analyzers in a single system can also increase the volume, power consumption and weight of such systems. In addition, such systems, since they involve multiple narrow band signal analyzer subsystems may suffer from higher
20 maintenance costs and increased complexity in setting up. It is also noted that prior art signal analyzers can substantially analyze and determine the characteristics of a single received or provided signal for a given time period. If two or more signals are received by the signal analyzer within the given time period, then the additional signals received simultaneously
25 (i.e., the second signal received, the third signal received, and so on...) are not analyzed. In general, if two or more signals are received by such prior art signal analyzers simultaneously, then not only are the characteristics of the additional signals not determined, even the presence of such additional signals arriving simultaneously with a first signal at the
30 signal analyzer may sometimes not be known. In addition, many prior art

signal analyzers cannot analyze pulsed signals which have a short pulse width, because of the wide spectrum representing it.

According to the disclosed technique, a signal analyzer is provided which enables signals in a wide bandwidth to be analyzed at a high SNR. The signal analyzer of the disclosed technique is cost effective as a single system is used to analyze wideband signals as opposed to prior art systems which use multiple narrow band signal analyzers to cover a wide bandwidth of signals. In addition, some of the embodiments of the signal analyzer of the disclosed technique are also cost effective as optical signals are used in a substantial portion of the operations executed by those embodiments of the signal analyzer, as opposed to the electronic domain. In general, optical components tend to have a longer operational life than electronic components, thereby resulting in greater cost effectiveness. In addition, optical components tend to save power and volume as opposed to electronic components, thereby resulting in more reliable handling of and higher accuracy in the signals transferred in the system. Also according to the disclosed technique, the presence of a plurality of signals arriving simultaneously at the signal analyzer of the disclosed technique can be determined and the signal characteristics of each of the plurality of received signals can be determined, even if the plurality of signals arrives at the signal analyzer simultaneously.

Reference is now made to Figure 2, which is a schematic illustration of a signal analyzer, generally referenced 100, constructed and operative in accordance with an embodiment of the disclosed technique.

Signal analyzer includes an antenna 102, an analog front end 104, an analog sampler 106, three digital frequency analyzers 108A, 108B and 108C and a processor 110. Antenna 102 is an optional component in signal analyzer 100. Antenna 102 can be substituted with any signal receiver, signal collector, signal detector or any type of known signal acquiring device, such as a transducer or a probing device. Analog front end 104 may also be an optional component in signal analyzer 100, for

example if incoming signals 112 are provided to signal analyzer 100 instead of being received by signal analyzer 100, as described below. Analog front end 104 is coupled with antenna 102 and with analog sampler 106. Each of digital frequency analyzers 108A, 108B and 108C are respectively coupled with both analog sampler 106 and processor 110. Analog sampler 106 can be embodied as an analog optical sampler, as described in greater detail below in Figures 3A and 3B. Analog sampler 106 can also be embodied as an analog RF sampler, as described in greater detail below in Figures 3E and 3F. Digital frequency analyzers 108A, 108B and 108C are described in greater detail below in Figure 3C. Processor 110 is described in greater detail below in Figure 3D. Arrow heads on the lines coupling the components of signal analyzer 100 show the direction in which signals move through signal analyzer 100. It is noted that signals move between digital frequency analyzers 108A-108C and processor 110 in both directions. This is explained in greater detail below in Figures 3C and 3D.

Antenna 102 received incoming signals 112, shown by a set of arrows 114. Incoming signals 112 may be received by antenna 102, provided to antenna 102 or intercepted by antenna 102. Incoming signals 112 are signals having frequencies which fall in a wideband of frequency ranges. For example, incoming signals 112 may have frequencies as low as 5 KHz or as high as 500 GHz or higher, such as 50 THz. Throughout the description, the term 'wideband signal' is used to describe a received, intercepted or provided signal to signal analyzer 100 which may have a frequency falling in a wideband of frequency ranges, as noted above. Incoming signals 112 may be continuous wave signals or pulsed signals. The pulsed signals may have a short pulse width. It is noted that the frequencies of incoming signals 112 are not known a priori. In addition, antenna 102 may receive a plurality of wideband signals simultaneously. Incoming signals 112 can vary in a wide continuous frequency spectrum. The incoming signals 112 can also be noise signals provided to signal

analyzer 100. In this respect, incoming signals 112 are not received signals but collected signals. It is noted that antenna 102 may be embodied, as mentioned above, as a signal detector, such that antenna 102 is substantially always attempting to detect, or intercept, incoming signals 112. Antenna 102 converts the received signals, which may be electromagnetic signals for example, to analog electrical signals and provides the analog electrical signals to analog front end 104. Analog front end 104 may include at least one of: at least one amplifier (not shown), for amplifying weak signals, a limiter (not shown), for limiting strong signals and an attenuator (not shown), for attenuating strong signals. Analog front end 104 may also include at least one of at least one amplifier, at least one limiter and at least one attenuator. Analog front end 104 may also include various analog filters (not shown) for initially filtering incoming signals 112. Analog front end 104 may further include an external input (not shown) for executing a built-in test or to blank reception of signal analyzer 100. Analog front end 104 provides the analog electrical signals to analog sampler 106.

Analog sampler 106 receives the analog electrical signals and folds each analog electrical signal using at least two different comb frequencies simultaneously. For example, a modulator (as shown in Figure 3A) in analog sampler 106 analog undersamples incoming signals 112 using at least two optical pulse trains, when analog sampler 106 is embodied as an analog optical sampler. This results in a narrowing of the output bandwidth of incoming signals 112 after modulation. As described in Figure 3A, two, three, four or more comb frequencies can be used to fold the received analog electrical signal. It is noted that the received analog electrical signal may include a plurality of signals received simultaneously. In signal analyzer 100, three comb frequencies (not shown in Figure 2) are used merely as an example, where it is clear to the worker skilled in the art that at least two comb frequencies can be used. It is also noted that in the case that incoming signals 112 have frequencies

which are in a defined intermediate frequency band, for example if incoming signals 112 are narrowband signals, then only a single comb frequency is required to fold the received analog electrical signal. The sampling rate of the comb frequencies is in the low GHz rate, for example
5 between 1-5 GHz. Depending on the application of the disclosed technique, the comb frequencies can also be significantly lower than 1 GHz. The different comb frequencies are multiplexed together to form a sampling signal. The multiplexed sampling signal is used to simultaneously sample the analog electrical signal at the different comb
10 frequencies. It is noted, as described below in Figures 3A, 3B, 3E and 3F, that the sampling of the analog electrical signal in analog sampler 106 is not executed using conventional sampling techniques, such as with an analog-to-digital converter. As shown below, a train of analog optical pulses or analog RF pulses is used to sample the analog electrical signals.
15 Such a sampling can be referred to as analog sampling. As the frequency, or frequencies, of incoming signals 112 is not known a priori, each analog electrical signal may be undersampled. Undersampling refers to the process whereby an analog signal is sampled at a sampling rate below the Nyquist frequency of the analog signal (i.e., less than two
20 times the highest frequency in the analog signal). If an analog electrical signal is analog undersampled, then aliasing occurs, whereby different representations of the analog electrical signal become indistinguishable from one another. Analog sampler 106 demultiplexes and converts the sampled analog electrical signal, according to the different comb
25 frequencies, into at least two intermediate frequency (herein abbreviated IF) signals. It is noted that the highest frequency of the IF signals may be lower than the highest frequency of incoming signals 112. Using the example above, if the comb frequencies used to analog sample the received signals are between 1-5 GHz, then the IF signals may have a
30 highest frequency of between 0 to 2.5 GHz. The IF signals are analog electrical signals. In signal analyzer 100, as three different comb

frequencies are used as an example, analog sampler 106 demultiplexes and converts the sampled analog electrical signal, according to the three different comb frequencies, into three analog electrical signals. Each analog electrical signal is outputted as a respective analog electrical signal having a unique intermediate frequency. Analog sampler 106 outputs IF_1 116A, IF_2 116B and IF_3 116C, where each of IF_1 116A, IF_2 116B and IF_3 116C represents a respective electrical signal having a unique IF. As mentioned above, if the frequency of incoming signals 112 is within a defined intermediate frequency band, then only one comb frequency is required to analog sample the received analog electrical signals. In this case, analog sampler 106 will output a single analog electrical signal having a unique intermediate frequency (not shown). As mentioned above, analog sampler 106 is described in greater detail below in Figures 3A and 3E.

Each one of IF_1 116A, IF_2 116B and IF_3 116C is provided to a respective one of digital frequency analyzers 108A, 108B and 108C. Each one of digital frequency analyzers 108A, 108B and 108C substantially digitally samples IF_1 116A, IF_2 116B and IF_3 116C. Each one of IF_1 116A, IF_2 116B and IF_3 116C is an analog signal in a baseband frequency low enough to be sampled by ADCs (not shown in Figure 2) in respective ones of digital frequency analyzers 108A, 108B and 108C at at least their respective Nyquist frequencies. In analog sampler 106, the received signals are analog sampled. In digital frequency analyzers 108A, 108B and 108C, the received signals, which are outputted from analog sampler 106 as analog electrical signals, are digitally sampled. Using the above example, digital frequency analyzers 108A, 108B and 108C may digitally sample the IF signals at a sampling rate of 5 GHz if the highest frequency of the IF signals is between 0-2.5 GHz (i.e. at a sampling rate at least equal to their Nyquist frequencies). In this respect, the IF signals are not down-converted and the IF signals do not suffer any loss of data. After digitally sampling the IF signals, each one of digital frequency analyzers

108A, 108B and 108C then spectrally analyzes a respective one of the digitally sampled signals corresponding to IF_1 116A, IF_2 116B and IF_3 116C. The analysis can involve advanced processing techniques such as using a fast Fourier transform (herein abbreviated FFT). Each one of

5 digital frequency analyzers 108A, 108B and 108C can be embodied as an IF instantaneous spectrum analyzer. IF_1 116A is provided to digital frequency analyzer 108A, IF_2 116B is provided to digital frequency analyzer 108B and IF_3 116C is provided to digital frequency analyzer 108C. The number of digital frequency analyzers in signal analyzer 100

10 corresponds to the number of different comb frequencies used in analog sampler 106. Therefore, if two different comb frequencies are used in analog sampler 106, then signal analyzer 100 will include only two digital frequency analyzers. In the case that a single comb frequency was used in analog sampler 106, then signal analyzer 100 will only include one

15 digital frequency analyzer. If the analog electrical signal provided to analog sampler 106 was undersampled, then aliasing in the analog electrical signals will occur. According to the disclosed technique, the frequency or frequencies of incoming signals 112 can be resolved, even if undersampled, due to the different comb frequencies used. Aliasing in the

20 analog electrical signals can thus be unaliased by using the different comb frequencies, which represent different aliasing frequencies. This is explained in greater detail below in Figure 3A. As such, the frequency, or frequencies, of incoming signals 112 may be represented as linear combinations of the different comb frequencies used to sample the analog

25 electrical signal. According to the different comb frequencies used in analog sampler 106 and their respective measured IF signal frequencies (in digital frequency analyzers 108A, 108B and 108C), processor 110 determines various linear combinations of the measured IF signal frequencies with respect to the different comb frequencies. According to

30 the disclosed technique, a plurality of linear combinations is determined.

Each linear combination of the different comb frequencies can be represented formally as

$$l \cdot Cf_1 \pm \Delta Cf_1 = m \cdot Cf_2 \pm \Delta Cf_2 = n \cdot Cf_3 \pm \Delta Cf_3 = ISf \quad (1)$$

where Cf_1 , Cf_2 and Cf_3 each respectively represent a different comb frequency, ΔCf_1 , ΔCf_2 and ΔCf_3 each respectively represent the frequency of the digitally sampled IF signals received from analog sampler 106, a value proportional to the input frequency as a result of the comb frequency, ISf represents the frequency of incoming signals 112 and l , m and n represent integer coefficients. Equation (1) can be generalized as

$$l \cdot Cf_i \pm \Delta Cf_i = m \cdot Cf_j \pm \Delta Cf_j = ISf \quad (2)$$

$$i \neq j \quad (3)$$

where $l \cdot Cf_i \pm \Delta Cf_i$ and $m \cdot Cf_j \pm \Delta Cf_j$ yield a plurality of determined linear combinations. As described below, when $l \cdot Cf_i \pm \Delta Cf_i$ is evaluated and compared with $m \cdot Cf_j \pm \Delta Cf_j$, a single determined linear combination can be determined for ISf .

As incoming signals 112 were folded in analog sampler 106 using different comb frequencies, each of ΔCf_1 , ΔCf_2 and ΔCf_3 respectively represents an offset or a residual emanating from the fact that incoming signals 112 were not necessarily divided evenly by each of the different comb frequencies. Each of l , m and n in Equation (1) is a natural (i.e. positive integer) number. Determining various linear combinations of the different comb frequencies substantially represents determining various values for l , m and n . It is noted that Equation (1) would need to be modified accordingly if fewer (e.g., two) or more (e.g., four or more) different comb frequencies were used in analog sampler 106. The various linear combinations of the different comb frequencies may be determined after applying Fourier transforms to each of IF_1 116A, IF_2 116B and IF_3 116C. Fourier transforms applied to each of IF_1 116A, IF_2 116B and IF_3 116C result in the determination of ΔCf_1 , ΔCf_2 and ΔCf_3 . It is noted that

the maximal bandwidth for which the original frequency of incoming signals 112 can be resolved for by two comb frequencies is given by

$$\frac{Cf_1 \cdot Cf_2}{2 \cdot \text{GCD}(Cf_1, Cf_2)} \quad (4)$$

where GCD is the greatest common divisor. Equation (4) may need to be modified in the case of three or more comb frequencies, as is known to the worker skilled in the art. Each of the various linear combinations determined in Equation (1) represents a possible frequency of incoming signals 112. Recall that ISf in Equation (1) is not known a priori. The various linear combinations are determined in processor 110.

Based on the determined various linear combinations, processor 110 then determines the frequency, or frequencies, of incoming signals 112 by evaluating the various linear combinations determined. The determined frequency, or frequencies, of incoming signals 112 correspond to particular integer coefficient values of l , m and n as well as particular values of ΔCf_1 , ΔCf_2 and ΔCf_3 in Equation (1) above. Processor 110 thus unaliases the different comb frequencies used to sample incoming signals 112 and determines the frequency of incoming signals 112. It is noted that for a given signal in incoming signals 112, a plurality of linear combinations may be determined. It is also noted that the spectral analysis of IF_1 116A, IF_2 116B and IF_3 116C, which is executed using Fourier transforms in digital frequency analyzers 108A, 108B and 108C, may yield more than one value, respectively for ΔCf_1 , ΔCf_2 and ΔCf_3 , if more than one signal was simultaneously present in incoming signals 112. In general, the maximum number of values for ΔCf_1 , ΔCf_2 and ΔCf_3 determined by digital frequency analyzers 108A, 108B and 108C indicates the number of signals received simultaneously. For example, for a given digital frequency analyzer, such as digital frequency analyzer 108A, these values can be labeled as $\Delta Cf_{1,1}$, $\Delta Cf_{1,2}$, $\Delta Cf_{1,3}$ and so on. As mentioned above, the result of more than one value for any of ΔCf_1 , ΔCf_2 and ΔCf_3 indicates that

more than one signal was received simultaneously by signal analyzer 100. Depending on the comb frequencies used by analog sampler 106, if more than one signal was received simultaneously, a given digital frequency analyzer may still only produce one value for any one of ΔCf_1 , ΔCf_2 and ΔCf_3 if the comb frequencies fold the different signals received simultaneously over the same frequency spectrum. In general, this situation can be avoided if the comb frequencies are properly chosen, as is known to the worker skilled in the art. When the comb frequencies of analog sampler 106 are chosen properly, if a plurality of simultaneous signals is present in incoming signals 112, then signal analyzer 100 can determine that such a plurality of simultaneous signals was received by antenna 102. In addition, processor 110 can then simultaneously determine the frequency as well as the characteristics of each of the signals received simultaneously. Processor 110 may use other data relating to incoming signals 112, such as its arrival time, the outputted IF signals of analog sampler 106 as well as the frequency of the baseband signal used to analog sample incoming signals 112 in analog sampler 106, to determine other characteristics of incoming signals 112, besides its frequency, such as its pulse width, amplitude, bandwidth, variations within the received signal and intrapulse data, such as frequency modulations and/or frequency modulation data, amplitude modulations and/or amplitude modulation data and phase modulations and/or phase modulation data, and the like. Processor 110 may use additional data, such as time stamps of the multiplexed sampling signal, recorded copies of the digitally sampled IF signals in digital frequency analyzers 108A, 108B and 108C to determine the other characteristics of incoming signals 112. The characteristics of incoming signals 112 listed above can also be used to eliminate undesired signals. In addition, filtering mechanisms can also be used by processor 110 for load balancing and for the elimination of undesired signals without interfering with the processing of the received

signals. For example, processor 110 may implement a plurality of digital band reject filters in each of digital frequency analyzers 108A, 108B and 108C. These reject filters may be set to different frequencies for each of digital frequency analyzers 108A, 108B and 108C. In this respect, each one of digital frequency analyzers 108A, 108B and 108C can be tuned to ignore, or reject, specific undesired signals it receives. The ignoring or rejection of specific undesired signals in each of digital frequency analyzers 108A, 108B and 108C can be temporary or permanent.

In the case of a plurality of incoming signals arriving at signal analyzer 100 simultaneously, processor 100 determines the characteristics of each of the incoming signals based on the particular integer coefficient values of l , m and n as well as the values of $\Delta Cf_{1,1}$, $\Delta Cf_{1,2}$, $\Delta Cf_{1,x}$, $\Delta Cf_{2,1}$, $\Delta Cf_{2,2}$, $\Delta Cf_{2,x}$ and $\Delta Cf_{3,1}$, $\Delta Cf_{3,2}$, $\Delta Cf_{3,x}$ representing each unique incoming signal. In the example given above, x is a natural number representing the maximum number of signals received simultaneously by signal analyzer 100. The first reference number for each variable ΔCf represents the digital frequency analyzer which determined the value for that variable, whereas the second reference number represents the different values of ΔCf determined by a given digital frequency analyzer. In the embodiment shown in Figure 2, three digital frequency analyzers are shown, thus the first reference number ranges from 1 to 3. As mentioned above, if the comb frequencies of analog sampler 106 are chosen properly, then x will equal the number of signals arriving simultaneously at signal analyzer 100. Processor 110 outputs a digital description 118 of incoming signal 112 which includes a listing of the determined characteristics of incoming signals 112. Digital description 118 substantially represents a detection of incoming signal 112, i.e., processor 110 can detect incoming signals 112. Digital description 118 of the signal may include the determined characteristics of a plurality of incoming signals 112 received simultaneously, either all at once or separately. Digital description 118 is

substantially a data object which can be processed by a computer. It is noted that analog sampler 106, digital frequency analyzers 108A, 108B and 108C as well as processor 110 all continuously operate in real-time, with no gaps or data loss. Real-time operation of analog sampler 106,
5 digital frequency analyzers 108A, 108B and 108C and processor 110 can be achieved by using VHDL (very-high-speed integrated circuit hardware description language) high speed data transfer protocols, such as the link layer protocol Aurora developed by Xilinx or the PCI Express protocol.

Reference is now made to Figure 3A, which is a schematic
10 illustration of the analog sampler of Figure 2 embodied as an analog optical sampler, generally referenced 140, constructed and operative in accordance with another embodiment of the disclosed technique. Analog optical sampler 140 substantially represents an embodiment of analog sampler 106 (Figure 2). Analog optical sampler 140 substantially
15 represents a signal folder, for example, a radio frequency (RF) signal folder, for folding an incoming signal, which may have a very high frequency, to a lower frequency, while maintaining its bandwidth by sampling the incoming signal with optical pulse trains. Analog optical sampler 140 includes a plurality of optical pulse generators 150A, 150B
20 and 150C (detailed below in Figure 3B), a multiplexer 152, an erbium-doped fiber amplifier (herein abbreviated EDFA) 154, a modulator 156, a demultiplexer 158, a plurality of photodiodes 160A, 160B and 160C, a plurality of low pass filters 162A, 162B and 162C and a plurality of amplifiers 164A, 164B and 164C. EDFA 154 can be substituted with any
25 known fiber amplifier and is brought merely as an example. Plurality of optical pulse generators 150A, 150B and 150C are coupled with multiplexer 152. Multiplexer 152 is coupled with EDFA 154. Modulator 156 is coupled with EDFA 154, demultiplexer 158 and an analog front end 166. Analog front end 166 substantially represents analog front end 104
30 (Figure 2). Demultiplexer 158 is coupled with each one of plurality of photodiodes 160A, 160B and 160C. Low pass filter 162A is coupled with

photodiode 160A and with amplifier 164A. Low pass filter 162B is coupled with photodiode 160B and with amplifier 164B. Low pass filter 162C is coupled with photodiode 160C and with amplifier 164C. Arrow heads on the lines coupling the components of analog optical sampler 140 show the direction in which pulses and signals move through analog optical sampler 140.

Each one of plurality of optical pulse generators 150A, 150B and 150C generates a train of optical pulses at different frequencies. The different frequencies substantially represent different comb frequencies which are used to analog sample an incoming analog signal. Plurality of optical pulse generators 150A, 150B and 150C are described below in Figure 3B. It is noted that in another embodiment of the disclosed technique, plurality of optical pulse generators 150A, 150B and 150C pulse be replaced by a plurality of frequency generators (not shown), each frequency generator generating a different, unique frequency. The different, unique frequency may either be a constant frequency or an alternating frequency. The plurality of frequency generators can be embodied as a plurality of oscillators. In this embodiment, the incoming analog signal is analog sampled by a plurality of different, unique frequencies, thereby generating an intermediate frequency of a certain bandwidth. As mentioned above, according to the disclosed technique at least two different comb frequencies are used to sample an incoming analog signal. As such, in Figure 3A one of plurality of optical pulse generators 150A, 150B and 150C is optional. As an example, Figure 3A is shown and described using three optical pulse generators, although according to the disclosed technique, two or more optical pulse generators can be used. In addition, as mentioned above, if an incoming analog signal is narrow and has a frequency within a defined intermediate frequency band, then a single optical pulse generator can be used to sample the incoming analog signal. Likewise, if the disclosed technique is embodied using frequency generators instead of optical pulse generators,

then if the incoming analog signal is narrow, a single comb generator, fed from a single frequency generator, can be used to sample the incoming analog signal. Furthermore, as described below, the number of photodiodes, low pass filters and amplifiers in analog optical sampler 140 correspond to the number of optical pulse generators used. Therefore, since at least two optical pulse generators are used in analog optical sampler 140, at least two photodiodes, at least two low pass filters and at least two amplifiers, each respectively coupled to one another, are also used in analog optical sampler 140. If a single optical pulse generator is used in analog optical sampler 140, then a single photodiode, a single low pass filter and a single amplifier, each respectively coupled to one another, are also used in analog optical sampler 140. Also, in such an embodiment, since only a single comb frequency is generated, multiplexer 152 and demultiplexer 158 are not required and EDFA 154 would be coupled with each one of plurality of optical pulse generators 150A, 150B and 150C and modulator 156 would be coupled with each one of plurality of photodiodes 160A, 160B and 160C. In general, the train of optical pulses generated by each one of plurality of optical pulse generators 150A, 150B and 150C has a frequency in the low GHz range, for example, between 1-5 GHz. The frequency of the train of optical pulses substantially represents the pulse frequency at which the train of optical pulses is emitted from each one of plurality of optical pulse generators 150A, 150B and 150C. The train of optical pulses generated by each one of plurality of optical pulse generators 150A, 150B and 150C is simultaneously provided to multiplexer 152 which multiplexes the plurality of optical pulse trains into a multiplexed optical pulse train. The multiplexed optical pulse train can also be referred to as a multiplexed sampling signal, as mentioned above in Figure 2.

Multiplexer 152 provides the multiplexed sampling signal to EDFA 154 which amplifies the multiplexed sampling signal. EDFA 154 provides the amplified multiplexed sampling signal to modulator 156,

which also receives an incoming analog signal from analog front end 166. The amplified multiplexed sampling signal is an optical signal. The incoming analog signal may be a signal from incoming signals 112 (Figure 2). Modulator 156 may be any known optoelectronic modulator such as a Mach-Zehnder modulator in the embodiment of the analog sampler of the disclosed technique as an analog optical sampler. In the case of an embodiment of the analog sampler of the disclosed technique as an analog RF sampler, as described below in Figures 3E and 3F, the function of modulator 156 can be executed by any RF mixer, any sample and hold circuit or any track and hold circuit. Modulator 156 substantially analog samples the received incoming analog signal, which is an electrical signal, with the amplified multiplexed sampling signal, which is an optical signal, thereby generating an analog sampled electrical signal. The amplified multiplexed sampling signal is substantially modulated by the received incoming analog signal which is electrical. Modulator 156 substantially converts the incoming analog signal into an optical signal. As the multiplexed sampling signal includes three optical pulse trains, each having a different frequency, modulator 156 substantially samples the incoming analog signal at three different sampling frequencies simultaneously. In the case that the incoming analog signal has a relatively high frequency, such as a frequency above 2.5 GHz, modulator 156 will undersample the incoming analog signal. Modulator 156 substantially folds the incoming analog signal to a baseband frequency whereby the folded incoming analog signal can be sampled at least at its Nyquist frequency. For example, the baseband frequency may be 2.5 GHz. Yet since the incoming analog signal will be undersampled by the multiplexed sampling signal at different sampling rates which are below the Nyquist frequency, aliasing will occur in the sampled signal. As different sampling rates are used to undersample the incoming analog signal, aliasing occurs as some of the samples from different sampling rates of the incoming analog signal may overlap, thereby generating, for

example, two or more samples of the incoming analog signal each having an identical sampling time stamp but being sampled at two or more different sampling rates. As explained above and below, digital frequency analyzers and a processor are used to unalias the frequencies of the incoming analog signal, and thereby determine the frequency of the incoming analog signal. This unaliasing is possible, as shown below in Figure 4, since the samples of the incoming analog signal are aliased to two different places according to the different sampling rates (i.e., comb frequencies), thereby enabling unaliasing by a linear determination.

Unaliasing is executed by the digital frequency analyzers and the processor by determining linear combinations of the different comb frequencies used to generate the different optical pulse trains, such that the frequency, or frequencies, of the incoming analog signal can be determined. It is also noted that since modulator 156 is substantially an optoelectronic modulator and modulates optical signals using electrical signals, modulator 156 can operate with various electrical signals at various signal strengths simultaneously. For example, modulator 156 can operate with weak electrical signals as well as strong electrical signals simultaneously since the incoming analog signal, an electrical signal, is used to modulate the multiplexed optical signal. Amplitude modulation can be executed on the multiplexed optical signal with the carrier signal being the multiplexed optical signal. Modulator 156 can thus operate using weak and strong electrical signals with the only substantial limitation being the ability of modulator 156 to sense the weak or strong electrical signal provided to it by analog front end 166.

Demultiplexer 158 receives the sampled optical signal, and demultiplexes the sampled optical signal according to the wavelengths, which are known, of the generated optical pulse trains of plurality of optical pulse generators 150A, 150B and 150C. As three different optical pulse trains are generated in analog optical sampler 140, demultiplexer 158 demultiplexes the sampled optical signal into three sampled optical

signals, each one at a respective wavelength of plurality of optical pulse generators 150A, 150B and 150C. Demultiplexer 158 provides each of the demultiplexed sampled optical signals to a respective one of plurality of photodiodes 160A, 160B and 160C. Each one of plurality of photodiodes 160A, 160B and 160C converts a respective one of the sampled optical signals into a respective electrical signal and provides each respective electrical signal to a respective one of plurality of low pass filters 162A, 162B and 162C.

Each one of plurality of low pass filters 162A, 162B and 162C is an electrical filter and attenuates high frequencies in the respective electrical signals, thereby generating respective filtered electrical signals in an intermediate frequency band. The intermediate frequency band is in such a range that the respective filtered electrical signals can be respectively sampled in digital frequency analyzers (not shown) at not more than their respective Nyquist frequencies. For example, the intermediate frequency band may be up to 2.5 GHz. Plurality of low pass filters 162A, 162B and 162C substantially eliminate all images of the electrical signal, which has been aliased, retaining only the aliased image of the electrical signal in the baseband frequency. Each one of plurality of low pass filters 162A, 162B and 162C provides a respective filtered electrical signal to respective ones of plurality of amplifiers 164A, 164B and 164C. Each one of plurality of amplifiers 164A, 164B and 164C is an electrical amplifier. Each one of plurality of amplifiers 164A, 164B and 164C amplifies a respective one of the filtered electrical signals and outputs a respective one of the amplified electrical signals as IF_1 168A, IF_2 168B and IF_3 168C. Amplifier 164A outputs IF_1 168A, amplifier 164B outputs IF_2 168B and amplifier 164C outputs IF_3 168C. IF_1 168A corresponds to IF_1 116A (Figure 2), IF_2 168B correspond to IF_2 116B (Figure 2) and IF_3 168C corresponds to IF_3 116C (Figure 2). Each one of IF_1 168A, IF_2 168B and IF_3 168C has a frequency which is significantly lower than the frequency of the incoming analog signal provided by analog

front end 166 to modulator 156, yet all three IF signals retain the original bandwidth of the incoming analog signal provided by analog front end 166. In general, in analog optical sampler 140, each respective optical pulse train from a respective one of plurality of optical pulse generators 150A, 150B and 150C is eventually demultiplexed, converted into an electrical signal, filtered and then amplified before being outputted as an intermediate frequency (IF) signal. Therefore, the number of photodiodes, low pass filters and amplifiers used in analog optical sampler 140 corresponds to the number of optical pulse generators used in analog optical sampler 140.

It is noted that in the case that the incoming analog signal provided by analog front end 166 to modulator 156 has a relatively low carrier frequency, such as less than 1 GHz, then the multiplexed amplified sampling signal, when modulated by modulator 156, will not be folded. In such a case, aliasing in the sampling signal will not occur and the frequency of the received incoming signal can be determined. In this case, the integer coefficients in Equation (1) will be equal to zero.

Reference is now made to Figure 3B, which is a schematic illustration of one of the optical pulse generators of Figure 3A, generally referenced 200, constructed and operative in accordance with a further embodiment of the disclosed technique. Optical pulse generator 200 is substantially similar to each one of optical pulse generators 150A (Figure 3A), 150B (Figure 3A) and 150C (Figure 3A). Optical pulse generator 200 includes a continuous wave laser 202, an electro-absorption modulator 204 and a comb generator 206. Electro-absorption modulator 204 is coupled with both continuous wave laser 202 and comb generator 206. Electro-absorption 204 is also coupled with a multiplexer 208. Multiplexer 208 is substantially similar to multiplexer 152 (Figure 3A). Optical pulse generator 200 generates a train of optical pulses. Continuous wave laser 202 generates continuous wave laser light and provides the continuous wave laser light to electro-absorption modulator 204. The laser light

generated by continuous wave laser 202 may be in the C-band, such as at a wavelength of 1550 nanometers. Continuous wave laser 202 may be any laser exhibiting low laser noise. Comb generator 206 generates a unique comb frequency, represented as an electrical signal. The comb frequency generated by comb generator 206, which is substantially a pulse train, should consist of optical pulses being as narrow and as accurate as possible. Ideally each optical pulse should be an impulse, although practically, a very narrow optical pulse is sufficient. In Figure 3A, each of optical pulse generators 150A (Figure 3A), 150B (Figure 3A) and 150C (Figure 3A) includes a respective comb generator. Each respective comb generators generates a unique comb frequency. The unique comb frequency generated by each respective comb generator enables signal analyzer 100 (Figure 2) to substantially unalias the incoming analog signal in the case that it is undersampled by analog sampler 106 (Figure 2). The comb frequency generated by comb generator 206 is in the lower GHz range, for example between 1-5 GHz. Comb generator 206 may provide the generated comb frequency to electro-absorption modulator 204 or to an analog mixer (not shown). Electro-absorption modulator 204 substantially modulates the continuous wave laser light of continuous wave laser 202 with the comb frequency generated by comb generator 206 to generate a train of optical pulses having a frequency substantially equivalent to the comb frequency of comb generator 206. Electro-absorption modulator 204 provides the train of optical pulses to multiplexer 208 which multiplexes the train of optical pulses with other optical pulse trains from other optical pulse generators (not shown), whereby each optical pulse train which is multiplexed has a unique frequency.

As mentioned above in Figure 3A, the optical pulse generators of the disclosed technique can be replaced by frequency generators. In such a case, optical pulse generator 200 (Figure 3B) is modified to be a frequency generator by replacing comb generator 206 with a plurality of

frequency oscillators for generating a train of pulses (not shown). Each one of the plurality of frequency oscillators generates a frequency which is amplified to saturation, thereby resulting in the generation of harmonic frequencies as well. The generated frequency and harmonic frequencies
5 together form a set of frequencies which is provided to each electro-absorption modulator 204. The frequency oscillators may also include a frequency combiner, capable of combining constant and alternating frequencies. The optical pulse generators of the disclosed technique, such as optical pulse generator 200 and optical pulse
10 generators 150A, 150B and 150C (Figure 3A), can also be replaced by pulsed lasers.

Reference is now made to Figure 3C, which is a schematic illustration of the digital frequency analyzers of Figure 2, generally referenced 220, constructed and operative in accordance with another
15 embodiment of the disclosed technique. Digital frequency analyzer 220 is equivalent to any one of digital frequency analyzers 108A, 108B and 108C (all from Figure 2). Digital frequency analyzer 220 is coupled with an analog sampler 221 and a processor 223. Analog sampler 221 is equivalent to analog sampler 106 (Figure 2) and processor 223 is
20 equivalent to processor 110 (Figure 2). Digital frequency analyzer 220 includes a digital sampler 222, a logic layer 224 and a Fourier transformer 226. It is noted that digital frequency analyzer 220 may include a plurality of Fourier transformers (not shown). Digital sampler 222 may include at least one ADC (not shown). Logic layer 224 and Fourier transformer 226
25 can be embodied as a field-programmable gate array (herein abbreviated FPGA) 228. In the case of a plurality of Fourier transformers, logic layer 224 and the plurality of Fourier transformers can be embodied as an FPGA. FPGA 228 can also be embodied as a digital signal processor (herein abbreviated DSP) or an FPGA with a DSP. Digital sampler 222
30 can be embodied as a sampler having a sampling rate of 1 Gsps (giga sample per second) or higher. Digital sampler 222 is coupled with analog

sampler 221 and with logic layer 224 in FPGA 228. Logic layer 224 is also coupled with Fourier transformer 226 and with processor 223. In the case of a plurality of Fourier transformers, logic layer 224 is coupled with each of the plurality of Fourier transformers. If digital frequency analyzer 220 does not include FPGA 228, then digital sampler 222 is either coupled with logic layer 224 or with logic layer 224 and with Fourier transformer 226. It is noted that arrow heads in Figure 3C represent the general flow of signals in digital frequency analyzer 220.

Digital sampler 222 receives a plurality of IF signals (not shown) from analog sampler 221. As mentioned above, the IF signals are electrical signals which were analog sampled. Digital sampler 222 digitally samples the IF signals at at least their Nyquist frequencies and outputs the digitally sampled signals as multiplexed fast serial communication signals. An example of such signals is low voltage differential signals (herein abbreviated LVDS). The multiplexed fast serial communication signals which are digitally sampled are then provided to logic layer 224 in FPGA 228. For example, the multiplexed LVDS digitally sampled signals are then provided to logic layer 224 in FPGA 228. Fourier transformer 226 receives the digitally sampled signals from logic layer 224 and executes an FFT on the digitally sampled signals to determine their discrete Fourier transforms (herein abbreviated DFT). It is noted that Fourier transformer 226 continuously executes an FFT on the digitally sampled signals it receives. Each DFT chunk determined is overlapped with the following DFT chunk to be determined by at least a predetermined amount. This predetermined amount may be for example 20%. This overlapping results in a smooth set of DFTs representing the digitally sampled signals. This overlapping can also be executed by using a plurality of Fourier transformers, wherein each Fourier transformer executes an FFT on a portion of the digitally sampled signals. Fourier transformer 226 provides a complete smooth set of DFTs, or at least a portion of the complete smooth set of DFTs back to logic layer 224 which provides them to

processor 223. It is noted that logic layer 224 may manipulate the smooth set of DFTs before providing it to processor 223. For example, the manipulation may involve filtering DFT chunks from the DFT set which are below a predetermined amplitude. The manipulation may also include, for example, executing a process of peak picking which is used to dilute data, such as a set of DFTs or a portion of the set of DFTs, provided by logic layer 224 to processor 223. The process of peak picking enables a lower band width to be used by logic layer 224.

As shown in Figure 3C, instructions are provided by processor 223 to logic layer 224. These instructions may relate to the moving and ordering of data in logic layer 224 as well as the implementation of digital band reject filters in digital frequency analyzer 220, as described above in Figure 2, which in particular is implemented in logic layer 224. As described below in Figure 3D, processor 223 may provide a synchronization signal (not shown) to digital frequency analyzer 220. The signal analyzer of the disclosed technique includes at least two digital frequency analyzers, although as mentioned above, in some embodiments of the disclosed technique, a single digital frequency analyzer may suffice. According to the disclosed technique, the DFTs determined by each digital frequency analyzer may be synchronized. As such, processor 223 may provide a synchronization signal simultaneously to the logic layer of each digital frequency analyzer in order to synchronize the DFTs determined. In this respect, smooth DFT sets are provided to processor 223 by each digital frequency analyzer simultaneously.

Reference is now made to Figure 3D, which is a schematic illustration of the processor of Figure 2, generally referenced 230, constructed and operative in accordance with a further embodiment of the disclosed technique. Processor 230 is equivalent to processor 110 (Figure 2) and processor 223 (Figure 3C). Processor 230 includes a frequency determinator 232, a characteristics determinator 234 and a clock 236. Frequency determinator 232 is coupled with characteristics

determinator 234 and with each digital frequency analyzer (not shown) of the signal analyzer of the disclosed technique, shown by an arrow 231. Clock 236 is coupled with each digital frequency analyzer (not shown) of the signal analyzer of the disclosed technique, shown by an arrow 233. In particular, clock 236 is coupled with the logic layer of each digital frequency analyzer. Also in particular, frequency determinator 232 is coupled with the logic layer of each digital frequency analyzer for receiving the smooth DFT sets described above in Figure 3C. It is noted that arrow heads in Figure 3D represent the general flow of signals in processor 230.

Clock 236 may provide a synchronization signal (not shown) to the logic layer in each digital frequency analyzer to synchronize the determination of the smooth sets of DFTs. Frequency determinator 232 receives a smooth set of DFTs from each digital frequency analyzer simultaneously. Based on the smooth set of DFTs, frequency determinator 232 unaliases the smooth set of DFTs, using for example Equation (1), and determines the frequency of the incoming signals (not shown). As mentioned above in reference to Equation (1), if more than one value is determined for ΔCf , then a plurality of simultaneous signals are present in the incoming signals. In such a case, frequency determinator 232 determines the frequencies of the simultaneously received incoming signals (not shown). Frequency determinator 232 provides the determined frequency or frequencies, as well as timing data, synchronization data, or both, to characteristics determinator 234 which determines other characteristics of the received incoming signals, as mentioned above. These other characteristics can include the pulse width, frequency spread, time of arrival, presence of another incoming signal received simultaneously, variations and modulations in amplitude, phase or frequency within and between individual pulses of the incoming signal, time of end, power level parameters relating to the received incoming signal and amplitude level parameters relating to the received

signal. These characteristics are outputted by characteristics determinator 234 as a digital description 235. These characteristics are determined for each incoming signal (which may be a pulse or a continuous wave) independently, simultaneously and continuously as mentioned above.

5 Reference is now made to Figure 3E, which is another schematic illustration of the analog sampler of Figure 2 embodied as an analog RF sampler, generally referenced 340, constructed and operative in accordance with another embodiment of the disclosed technique. Analog RF sampler 340 substantially represents another embodiment of
10 analog sampler 106 (Figure 2), although analog RF sampler 340 does not use optical signals but rather RF signals. Analog RF sampler 340 substantially represents a signal folder for folding an incoming signal, which may have a very high frequency, to a lower frequency, while maintaining its bandwidth by sampling the incoming signal with RF pulse
15 trains. Analog RF sampler 340 includes a plurality of RF comb generators 342A, 342B and 342C (detailed below in Figure 3F), a power splitter 344, a plurality of RF mixers 348A, 348B and 348C, a plurality of low pass filters 350A, 350B and 350C and a plurality of amplifiers 352A, 352B and 352C. Plurality of RF mixers 348A, 348B and 348C can each be
20 embodied as an analog RF mixer. Power splitter 344 can also be a power divider. Plurality of RF comb generators 342A, 342B and 342C are each respectively coupled with plurality of RF mixers 348A, 348B and 348C. Power splitter 344 is coupled with each of plurality of RF mixers 348A, 348B and 348C and with an analog front end 346. Analog front end 346
25 substantially represents analog front end 104 (Figure 2) and receives an incoming electrical signal. RF mixer 348A is coupled with low pass filter 350A. Amplifier 352A is coupled with low pass filter 350A and with a DFA (not shown). RF mixer 348B is coupled with low pass filter 350B. Amplifier 352B is coupled with low pass filter 350B and with a DFA (not
30 shown). RF mixer 348C is coupled with low pass filter 350C. Amplifier 352C is coupled with low pass filter 350C and with a DFA (not shown).

Arrow heads on the lines coupling the components of analog RF sampler 340 show the direction in which pulses and signals move through analog RF sampler 340.

Each one of plurality of RF comb generators 342A, 342B and 342C generates a train of RF pulses at unique different frequencies as mentioned above. The different frequencies substantially represent different comb frequencies which are used to analog sample an incoming analog signal. The different comb frequencies are used to fold the received incoming electrical signal over each of the frequencies in a comb generator (not shown in Figure 3E) included in each of RF comb generators 342A, 342B and 342C. Each different, unique frequency may either be a constant frequency or an alternating frequency. An example of plurality of RF comb generators 342A, 342B and 342C is described below in Figure 3F. As mentioned above, according to the disclosed technique at least two different comb frequencies are used to sample an incoming analog signal. As such, in Figure 3E one of plurality of RF comb generators 342A, 342B and 342C is optional. In addition, as mentioned above, if an incoming analog signal is narrow and has a frequency within a defined intermediate frequency band, then a single RF comb generator can be used to sample the incoming analog signal. Furthermore, as described below, the number of RF mixers, low pass filters, amplifiers and ADCs in analog RF sampler 340 correspond to the number of RF comb generators used. Therefore, since at least two RF comb generators are used in analog RF sampler 340, at least two RF mixers, at least two low pass filters and at least two amplifiers, each respectively coupled to one another, are also used in analog RF sampler 340. In the case that a single RF mixer is used, power splitter 344 is not required and analog front end 346 would be directly coupled with that single RF mixer. In general, the train of RF pulses generated by each one of plurality of RF comb generators 342A, 342B and 342C has a frequency in the low GHz range, for example, between 1-5 GHz. The train of RF pulses generated by each

one of plurality of RF comb generators 342A, 342B and 342C are respectively provided to plurality of RF mixers 348A, 348B and 348C. The train of RF pulses generated by each one of plurality of RF comb generators 342A, 342B and 342C represents a sampling signal used to
5 analog sample the received incoming electrical signal.

Analog front end 346 provides the received incoming electrical signal to power splitter 344, which splits the received incoming electrical signal into a plurality of electrical signals having the same characteristics as the received incoming electrical signals yet each having a lower power
10 level. Power splitter 344 provides each one of the plurality of electrical signals of the received incoming electrical signal to a respective one of plurality of RF mixers 348A, 348B and 348C. Power splitter 344 may split the received incoming electrical signal evenly or unevenly, in terms of power level, to each one of plurality of RF mixers 348A, 348B and 348C.
15 Each RF mixer substantially represents a modulator for analog sampling the received incoming electrical signal. In this respect, plurality of RF mixers 348A, 348B and 348C are similar to modulator 156 (Figure 3A). Unlike modulator 156 though, each one of plurality of RF mixers 348A, 348B and 348C converts a full band electrical signal or signals into a full
20 band folded signal or signals. The conversion is based upon the respective comb frequency of the RF comb generator respectively coupled with the RF mixer and providing it with an analog RF sampling signal. In addition, unlike modulator 156 and analog optical sampler 140 (Figure 3A), in analog RF sampler 340, the sampling signals generated from the
25 RF comb generators cannot be multiplexed and then demultiplexed but are kept as separate signals along different channels therein. The analog sampled electrical signals are outputted by plurality of RF mixers 348A, 348B and 348C as full band folded signals. Plurality of RF mixers 348A, 348B and 348C simultaneously analog sample the received incoming
30 electrical signal at three different frequencies in parallel.

The outputted full band folded signals from plurality of RF mixers 348A, 348B and 348C are respectively provided to plurality of low pass filters 350A, 350B and 350C for low pass filtering, thereby respectively outputting analog IF signals, shown in Figure 3E respectively as IF signals 356A (IF_1), 356B (IF_2) and 356C (IF_3). The IF signals are then provided to amplifiers 352A, 352B and 352C for amplification. The amplified IF signals are then respectively provided to digital frequency analyzers (also abbreviated DFAs) 358A, 358B and 358C for conversion into digital signals as described above in Figure 3C. DFAs 358A, 358B and 358C are substantially similar to digital frequency analyzers 108A-108C (Figure 2) and digital frequency analyzer 220 (Figure 3C). The processing of IF signals 356A, 356B and 356C in analog RF sampler 340 is substantially similar to the processing of the respective electrical signals in analog optical sampler 140 (Figure 3A) after plurality of photodiodes 160A-160C (Figure 3A). In general, analog RF sampler 340 operates in a manner similar to analog optical sampler 140 except for the differences noted above.

Reference is now made to Figure 3F, which is a schematic illustration of one of the RF comb generators of Figure 3E, generally referenced 380, constructed and operative in accordance with a further embodiment of the disclosed technique. It is noted that the RF comb generator shown in Figure 3F is merely an example of a possible RF comb generator for use in analog RF sampler 340 (Figure 3E) and that other embodiments of RF comb generators are possible and known to the worker skilled in the art. RF comb generator 380 is substantially similar to each one of RF comb generators 342A (Figure 3E), 342B (Figure 3E) and 342C (Figure 3E). RF comb generator 380 includes a phase-locked (herein abbreviated PL) oscillator 382, a first amplifier 384, a comb generator 386 and a second amplifier 388. First amplifier 384 is coupled with PL oscillator 382 and comb generator 386. Second amplifier 388 is coupled with comb generator 386 and with an RF mixer 390. RF mixer

390 is substantially similar to one of plurality of RF mixers 348A-348C (Figure 3E). RF comb generator 380 generates a train of RF pulses, which spectrally represents a comb of frequencies, each frequency being a harmonic of the original frequency generated by PL oscillator 382. In particular, PL oscillator 382 generates an RF signal having a unique frequency in the low GHz range. It is noted that other devices can be used in RF comb generator 380 instead of PL oscillator 382 for generating an RF signal having a unique frequency, like an RF signal generator coupled with a comb generator, a crystal or any other implementation of a stable oscillator, such as an amplifier. The unique frequency is then provided to first amplifier 384 for amplification. First amplifier 384 amplifies the RF signal such that it is provided to comb generator 386 as a saturated RF signal. Comb generator 386 receives the saturated RF signal and generates harmonic signals of the RF signal generated by PL oscillator 382. Using these harmonic signals, comb generator 386 in turn also generates a plurality of signals, each of which have frequencies which are integer multiples of the frequency of the RF signal generated by PL oscillator 382. Comb generator 386 may include a plurality of oscillators (not shown). Comb generator 386 substantially sums the output of the plurality of oscillators thereby forming a comb in the frequency domain having a base frequency which is substantially equivalent to the frequency of the RF signal generated by PL oscillator 382. The base frequency of comb generator 386 is provided to second amplifier 388, which amplifies the comb signals in the frequency domain to required levels of RF comb generator 380. The amplified comb signals are then provided it to RF mixer 390. The comb signals represent the sampling operator which is introduced to RF mixer 390 as an IF input. The incoming electrical signal (not shown) which is provided to RF mixer 390 is thus sampled by the RF signal generated in RF comb generator 380 which is provided to RF mixer 390. Comb generator 386 substantially modulates the unique comb frequency as an RF pulse train. The comb frequency generated by comb

generator 386, which is substantially a pulse train in the time domain, should consist of RF pulses being as narrow and as accurate as possible. Ideally each RF pulse should be an impulse, although practically, a very narrow RF pulse is sufficient. In Figure 3E, each of RF comb generators 342A (Figure 3E), 342B (Figure 3E) and 342C (Figure 3E) includes a respective comb generator. Each respective comb generator generates a unique comb frequency. The unique comb frequency generated by each respective comb generator enables the signal analyzer of the disclosed technique to substantially unalias the incoming analog signal in the case that it is undersampled by the analog RF sampler of the disclosed technique. The RF signal generated by PL oscillator 382 is in the lower GHz range, for example between 1-5 GHz, whereas the comb frequency generated by comb generator 386 is in a wider range, for example, between the lower GHz to THz range. Comb generator 386 provides the generated comb frequency to second amplifier 388, which amplifies the generated comb frequency and provides it to RF mixer 390. The generated comb frequency is substantially a train of RF pulses. RF mixer 390 mixes the train of RF pulses with the incoming analog signal as described above in Figure 3E. The output of RF mixer 390 will include many aliases in the frequency domain according to the comb frequency of RF comb generator 380. The relevant signal alias will be the signal aliased to the baseband frequency, which can be defined in an intermediate frequency band as being from zero to half of the PL oscillator values. The PL oscillator values are chosen in such a way to enable multiples of the comb frequencies generated by comb generator 386 not to collide with one another in the frequency domain.

Reference is now made to Figure 4, which is a schematic illustration showing a plurality of frequency diagrams of the signals generated by either one of the analog optical sampler of Figure 3A or the analog RF sampler of Figure 3E, generally referenced 250, constructed and operative in accordance with another embodiment of the disclosed

technique. Figure 4 includes frequency diagrams 252, 254, 256, 258, 260, 262, 264, 266 and 268. Each of frequency diagrams 252-268 shows signals, either received or generated, on a relative frequency scale. Frequency diagram 252 shows a signal 270. Signal 270 is the received incoming signal, which might be a pulse or a continuous wave (herein abbreviated CW) signal. The frequency of signal 270 is unknown and is determined according to the disclosed technique. As such, the frequency of signal 270 is not denoted in Figure 4. It is noted that this is unlike the case in known down-converters where the frequency or frequency band of an incoming signal must be known in order to properly down-convert the incoming signal into a selected processing band. Signal 270 is an example of incoming signals 112 (Figure 2) received by signal analyzer 100 (Figure 2). Signal 270 is an analog signal.

In general, an ideal optical pulse train, or ideal RF pulse train in the time domain having a comb frequency of f_{1c} can be represented as the sum of its harmonics. Therefore, in the frequency domain, such an ideal optical pulse train or RF pulse train can be represented as an equivalent impulse train. Frequency diagram 254 shows an impulse train in the frequency domain which is substantially equivalent to the optical pulse train or RF pulse train in the time domain generated by a first optical pulse generator, such as optical pulse generator 150A (Figure 3A) or by a first RF comb generator, such as RF comb generator 342A (Figure 3E). As shown, frequency diagram 254 shows a first train of impulses 272A generated at a comb frequency f_{1c} .

Frequency diagram 256 shows the impulse train in the frequency domain which is substantially equivalent to the optical pulse train or RF pulse train in the time domain generated by a second optical pulse generator, such as optical pulse generator 150B (Figure 3A) or by a second RF comb generator, such as RF comb generator 342B (Figure 3E). As shown, frequency diagram 256 shows a second train of impulses 272B generated at a comb frequency f_{2c} . As can be seen, f_{1c} and f_{2c} are in

the same general band range but represent different comb frequencies. As mentioned above, at least two different comb frequencies are used to sample the incoming signal. In some embodiments of the disclosed technique a single comb frequency can be used to sample the incoming
5 signal. As such, only the frequency diagram representations for two optical pulse trains or two RF pulse trains are shown in Figure 4. It is obvious to the worker skilled in the art that more than two optical pulse trains or more than two RF pulse trains can be used to analog sample the received signals which may enhance and improve the analog sampling of
10 the received signals and any further processing executed on the received signal.

Frequency diagram 258 shows the frequency representation of the optical pulse trains generated by the first optical pulse generator and the second optical pulse generator multiplexed together as a multiplexed
15 optical pulse train 274. For purposes of clarity, frequency diagram 258 shows only a part of the frequency representation. Frequency diagram 258 represents the output of a multiplexer, for example multiplexer 152 (Figure 3A). As shown, f_{1c} and f_{2c} have a common baseband frequency, shown as a section 280 in Figure 4, such that they overlap at the
20 baseband frequency. Frequency diagram 260 shows multiplexed impulse train 274 modulated by signal 270, which represents the incoming signal, thereby producing a multiplexed sampling signal 276. As mentioned above, the incoming signal is used to modulate the multiplexed optical pulse train. Frequency diagram 260 shows the output of a modulator,
25 such as modulator 156 (Figure 3A). By modulating signal 270 over multiplexed impulse train 274, signal 270 is substantially folded over a plurality of frequencies and is not just down-converted to a baseband frequency as in prior art signal analyzers. In addition, once modulated, the discrete signals of multiplexed impulse train 274 are represented as a
30 frequency band having a bandwidth equal to the bandwidth of signal 270 and not as a unique singular frequency. As can be seen at various integer

multiples of f_{1c} and f_{2c} , the modulated optical pulse trains which form multiplexed sampling signal 276 overlap. Due to the sampling rate of comb frequencies f_{1c} and f_{2c} , if the bandwidth of pulse 270 is substantially larger than f_{1c} and f_{2c} , then when it is used to modulate multiplexed impulse train 274, the signals generated will be aliased. This is shown more clearly in frequency diagrams 262 and 264. In general, frequency diagrams 258 and 260 only apply to the case where optical pulse trains are used.

Frequency diagram 262 shows multiplexed sampling signal 276 demultiplexed according to comb frequency f_{1c} of the first optical pulse generator, thereby forming first demultiplexed signal 278A. As shown, first demultiplexed signal 278A is aliased as two images, with two images of the demultiplexed signal being present at each integer multiple of comb frequency f_{1c} . Frequency diagram 264 shows multiplexed sampling signal 276 demultiplexed according to comb frequency f_{2c} of the second optical pulse generator, thereby forming second demultiplexed signal 278B. As shown, second demultiplexed signal 278B is aliased as two images, with two images of the demultiplexed signal being present at each integer multiple of comb frequency f_{2c} . Frequency diagrams 262 and 264 show the output of a demultiplexer, such as demultiplexer 158 (Figure 3A). For example, the output of the demultiplexer represented in frequency diagram 262 may be provided to a first photodiode, such as photodiode 160A (Figure 3A), whereas the output of the demultiplexer represented in frequency diagram 264 may be provided to a second photodiode, such as photodiode 160B (Figure 3A). Frequency diagram 266 shows first demultiplexed signal 278A after it has passed through a low pass filter, such as low pass filter 162A (Figure 3A). As shown, passing first demultiplexed signal 278A through a low pass filter substantially eliminates the folded images of first demultiplexed signal 278A from $-Nf_{1c}$ to Nf_{1c} , leaving only the baseband frequency image, shown as a folded first signal 282A. Frequency diagram 268 shows second demultiplexed signal 278B

after it has passed through a low pass filter, such as low pass filter 162B (Figure 3A). As shown, passing second demultiplexed signal 278B through a low pass filter substantially eliminates the folded images of second demultiplexed signal 278B from $-Nf_{2c}$ to Nf_{2c} , leaving only the baseband frequency image, shown as a folded second signal 282B. First folded signal 282A and second folded signal 282B are then provided to respective digital frequency analyzers (not shown) and a processor (not shown), which then unalias each folded signal and determine characteristics, such as the frequency, of the original signal (i.e., signal 270). In that multiplexed impulse train 274 is aliased to two different places at each integer multiple of f_{1c} and f_{2c} , shown as multiplexed sampling signal 276, unaliasing of first folded signal 282A and second folded signal 282B is possible via simple linear determinations.

According to another embodiment of the disclosed technique, Figure 4 can also be understood as showing a plurality of frequency diagrams of the signals generated by the analog RF sampler of Figure 3E. Frequency diagram 254 shows first train of impulses 272A generated at comb frequency f_{1c} by a first comb generator (not shown) and frequency diagram 256 shows second train of impulses 272B generated at comb frequency f_{2c} by a second comb generator (not shown). These impulse trains are substantially equivalent to pulse trains in the time domain. Signal 270 is multiplexed with comb frequency f_{1c} , thereby generating a first folded signal as shown in frequency diagram 262. Signal 270 is multiplexed with comb frequency f_{2c} , thereby generating a second folded signal as shown in frequency diagram 264. The folded signals are filtered by low pass filters (not shown), as shown in frequency diagrams 266 and 268. In the analog RF sampler of the disclosed technique, signal 270 is first amplified and split, or divided into at least two equal signals using a power splitter (not shown). Each split signal is then respectively multiplexed by one of comb frequencies f_{1c} and f_{2c} as shown in frequency diagrams 262 and 264. Using low pass filters (not shown), first folded

signal 282A and second folded signal 282B are generated, as shown in frequency diagrams 266 and 268, according to the baseband frequencies of comb frequencies f_{1c} and f_{2c} , as shown in section 280.

Reference is now made to Figure 5, which is a schematic illustration of a method for analyzing a plurality of signals simultaneously, operative in accordance with a further embodiment of the disclosed technique. In a procedure 300, at least one signal is received or collected. The signal may be received, provided, collected or intercepted. The signal may include a plurality of signals received simultaneously. The signal may be a noise signal. The signal may have a wide frequency band. The signal is an analog signal. With reference to Figure 2, antenna 102 (Figure 2) receives incoming signals 112 (Figure 2). Incoming signals 112 may be received by antenna 102, collected by antenna 102, provided to antenna 102 or intercepted by antenna 102. Incoming signals 112 are signals, for example EM signals, having frequencies which fall in a wideband of frequency ranges. In a procedure 302, the at least one signal received is analog filtered. Analog filtering may include passing the at least one signal through a plurality of analog filters. With reference to Figure 2, antenna 102 (Figure 2) converts the received EM signals to analog electrical signals and provides the analog electrical signals to analog front end 104 (Figure 2). Analog front end 104 may also include various analog filters (not shown) for initially processing incoming signals 112 (Figure 2). In a procedure 304, the at least one signal received is analog processed. Analog processing may include at least one of amplifying weak signals, limiting strong signals and attenuating strong signals. With reference to Figure 2, analog front end 104 (Figure 2) may include at least one of an amplifier (not shown), for amplifying weak signals, a limiter (not shown), for limiting strong signals and an attenuator (not shown) for attenuating strong signals.

In a procedure 306, the received at least one signal is folded using at least two different comb frequencies simultaneously, thereby

generating at least two intermediate frequency signals. Folding the received at least one signal by using at least two different comb frequencies simultaneously represents analog sampling the received at least one signal. The comb frequencies may be optical pulse trains. As explained above in Figures 2, 3A and 3B, the received at least one signal is folded by multiplexing at least two different comb frequencies simultaneously into a multiplexed signal and modulating the multiplexed signal with the received at least one signal. The modulated multiplexed signal is then demultiplexed according to the at least two different comb frequencies into at least two folded sampling signals. The folded sampling signals are converted into electrical signals. The at least two electrical signals are then low pass filtered to eliminate high frequency images of the at least two electrical signals, thereby generating the at least two intermediate frequency signals. The at least two electrical signals may optionally be amplified. With reference to Figure 2, analog sampler 106 (Figure 2) receives the analog electrical signals and folds each analog electrical signal using at least two different comb frequencies simultaneously. The different comb frequencies are multiplexed together to form a sampling signal. The multiplexed sampling signal is used to simultaneously sample the analog electrical signal at the different comb frequencies. Analog sampler 106 demultiplexes and converts the sampled analog electrical signal, according to the different comb frequencies, into at least two intermediate frequency (herein abbreviated IF) signals. The IF signals are electrical signals. Each electrical signal is outputted as a respective electrical signal having a unique intermediate frequency.

It is noted that each of procedures 302 and 304 are optional procedures and that after procedure 300, the method can proceed directly to procedure 306. It is also noted that after procedure 302, the method may proceed directly to procedure 306 and that after procedure 304, the method may proceed directly to procedure 306. Procedures 302 and 304

may also both be executed, in any order, before procedure 306 is executed.

In a procedure 308, each of the at least two intermediate frequency signals are digitally sampled. With reference to Figure 2, each one of digital frequency analyzers 108A (Figure 2), 108B (Figure 2) and 108C (Figure 2) substantially digitally samples a respective one of IF_1 116A (Figure 2), IF_2 116B (Figure 2) and IF_3 116C (Figure 2). In a procedure 310, the sampled at least two intermediate frequency signals are digitally processed. With reference to Figure 2, each one of IF_1 116A (Figure 2), IF_2 116B (Figure 2) and IF_3 116C (Figure 2) is provided to a respective one of digital frequency analyzers 108A (Figure 2), 108B (Figure 2) and 108C (Figure 2). Each one of digital frequency analyzers 108A, 108B and 108C then processes a respective one of IF_1 116A, IF_2 116B and IF_3 116C using advanced digital processing techniques. A portion of the advanced processing techniques may use IF_1 116A, IF_2 116B and IF_3 116C prior to their sampling by digital frequency analyzers 108A, 108B and 108C, provided that IF_1 116A, IF_2 116B and IF_3 116C are in digital format. In a procedure 312, the sampled at least two IF signals are spectrally analyzed. Spectral analysis can include executing FFTs on the digitally sampled at least two IF signals, thereby determining at least two sets of DFTs. In each set of DFTs, each DFT chunk may overlap a neighboring DFT chunk by at least a predetermined amount. This predetermined amount may be for example 20%. It is noted that the spectral analysis may also define a predetermined threshold for amplitude such that DFT results in each set of DFTs below the predetermined threshold are discarded. With reference to Figure 2, each one of digital frequency analyzers 108A (Figure 2), 108B (Figure 2) and 108C (Figure 2) substantially samples and then spectrally analyzes a respective one of IF_1 116A (Figure 2), IF_2 116B (Figure 2) and IF_3 116C (Figure 2). A portion of the advanced processing techniques may use the aforementioned sampled IF signals.

It is noted that procedures 310 and 312 can be executed simultaneously. In a procedure 314, each intermediate frequency signal is processed, thereby determining at least one characteristic of the received at least one signal. The digitally sampled and processed intermediate frequency signals from procedure 310, the digitally sampled and spectrally analyzed intermediate frequency signals from procedure 312, or both, may be processed in procedure 314. The processing may include determining linear combinations of the IF signals with respect to the at least two different comb frequencies used to fold the received at least one signal, using a modified version of Equation (1) according to the actual number of comb frequencies used, as described above. The processing may also include evaluating the determined linear combinations. Based on the processing, characteristics of the received at least one signal can be determined, such as its frequency, pulse width, amplitude, bandwidth, variations within the received signal and intrapulse data, such as frequency modulations and/or frequency modulation data, amplitude modulations and/or amplitude modulation data and phase modulations and/or phase modulation data, and the like, as well as how many signals were received simultaneously with the received at least one signal, if more than one signal was received simultaneously. With reference to Figure 2, according to the different comb frequencies used in analog sampler 106 (Figure 2) and their respective measured IF signal frequencies, processor 110 (Figure 2) determines various linear combinations of the different comb frequencies. The various linear combinations of the different comb frequencies may be determined after applying Fourier transforms to each of IF_1 116A (Figure 2), IF_2 116B (Figure 2) and IF_3 116C (Figure 2). Processor 110 determines the frequency, or frequencies, of incoming signals 112 (Figure 2) by evaluating the various linear combinations determined. Processor 110 also determines if more than one incoming signal arrived at signal analyzer 100 (Figure 2) simultaneously as well as its characteristics.

It will be appreciated by persons skilled in the art that the disclosed technique is not limited to what has been particularly shown and described hereinabove. Rather the scope of the disclosed technique is defined only by the claims, which follow.

CLAIMS

1. System for collecting at least one signal simultaneously comprising:

an analog sampler, for receiving said at least one signal as at least one analog electrical signal, for folding said at least one analog electrical signal using at least two different comb frequencies simultaneously into at least one sampled analog electrical signal and for demultiplexing said at least one sampled analog electrical signal into at least two respective intermediate frequency (IF) signals respectively according to said at least two different comb frequencies;

at least two digital frequency analyzers, each respectively coupled with said analog sampler, each one of said at least two digital frequency analyzers for digitally sampling a respective one of said at least two respective IF signals into at least one respective digital signal and for spectrally analyzing said at least one respective digital signal; and

a processor, coupled with each one of said at least two digital frequency analyzers, for determining a plurality of linear combinations of said at least two respective IF signals with respect to said at least two different comb frequencies used in said analog sampler and for determining at least one frequency of said at least one signal by evaluating said plurality of linear combinations of said at least two respective IF signals.

2. The system according to claim 1, further comprising:

a signal collector, for collecting said at least one signal and converting said at least one collected signal into said at least one analog electrical signal; and

an analog front end, coupled with said signal collector and with said analog sampler.

3. The system according to claim 1, wherein a sampling rate of said at least two different comb frequencies is in the low gigahertz range.

4. The system according to claim 1, wherein said processor determines said plurality of linear combinations according to

$$l \cdot Cf_i \pm \Delta Cf_i = m \cdot Cf_j \pm \Delta Cf_j = ISf$$

wherein Cf_i and Cf_j respectively represent said at least two different comb frequencies,

wherein ΔCf_i and ΔCf_j respectively represent a frequency of said at least one respective digital signal,

wherein l and m represent integer coefficients,

wherein i does not equal j , and

wherein ISf represents said determined at least one frequency of said at least one signal.

5. The system according to claim 1, wherein said processor determines a plurality of characteristics of said at least one signal based on said determined at least one frequency of said at least one signal.

6. The system according to claim 5, wherein said processor outputs a digital description of said at least one signal, said digital description comprising said plurality of characteristics.

7. The system according to claim 1, wherein said analog sampler, said at least two digital frequency analyzers and said processor continuously operate in real-time.

8. The system according to claim 2, said analog sampler comprising:
a plurality of optical pulse generators, for generating said at least two different comb frequencies;

a multiplexer, coupled with each one of said plurality of optical pulse generators, for multiplexing said at least two different comb frequencies into a multiplexed sampling signal;

a fiber amplifier, coupled with said multiplexer, for amplifying said multiplexed sampling signal;

a modulator, coupled with said fiber amplifier and with said analog front end, for analog sampling said at least one signal with said multiplexed sampling signal, thereby generating at least one sampled analog optical signal;

a demultiplexer, coupled with said modulator, for demultiplexing said at least one sampled analog optical signal according to respective wavelengths of said plurality of optical pulse generators;

a respective plurality of photodiodes, each one of said respective plurality of photodiodes respectively coupled with said demultiplexer, for converting said at least one sampled analog optical signal into said at least one sampled analog electrical signal;

a respective plurality of low pass filters, each one of said respective plurality of low pass filters coupled with a respective one of said respective plurality of photodiodes, for attenuating high frequencies in said at least one sampled analog electrical signal and generating said at least two respective IF signals; and

a respective plurality of amplifiers, each one of said respective plurality of amplifiers coupled with a respective one of said respective plurality of low pass filters and with a respective one of said at least two digital frequency analyzers, for amplifying said at least two respective IF signals,

wherein each of said at least two different comb frequencies is an optical pulse train.

9. The system according to claim 8, each one of said plurality of optical pulse generators comprising:

a continuous wave laser, for generating laser light;
an electro-absorption modulator, coupled with said continuous wave laser and with said multiplexer; and
a comb generator, coupled with said electro-absorption modulator, for generating a unique comb frequency,
5 wherein said electro-absorption modulator substantially modulates said laser light with said unique comb frequency thereby generating said optical pulse train.

- 10 10. The system according to claim 2, said analog sampler comprising:
a plurality of frequency generators, for generating said at least two different frequencies;
a multiplexer, coupled with each one of said plurality of frequency generators, for multiplexing said at least two different frequencies into a multiplexed sampling signal;
15 a fiber amplifier, coupled with said multiplexer, for amplifying said multiplexed sampling signal;
a modulator, coupled with said fiber amplifier and with said analog front end, for analog sampling said at least one signal with said multiplexed sampling signal, thereby generating at least one sampled analog optical signal;
20 a demultiplexer, coupled with said modulator, for demultiplexing said at least one sampled analog optical signal according to respective frequencies of said plurality of frequency generators;
25 a respective plurality of photodiodes, each one of said respective plurality of photodiodes respectively coupled with said demultiplexer, for converting said at least one sampled analog optical signal into said at least one sampled analog electrical signal;
a respective plurality of low pass filters, each one of said respective plurality of low pass filters coupled with a respective one of said respective plurality of photodiodes, for attenuating high
30

frequencies in said at least one sampled analog electrical signal and generating said at least two respective IF signals; and

a respective plurality of amplifiers, each one of said respective plurality of amplifiers coupled with a respective one of said respective plurality of low pass filters and with a respective one of said at least two digital frequency analyzers, for amplifying said at least two respective IF signals,

wherein each of said at least two different frequencies is a pulse train.

11. The system according to claim 10, each one of said plurality of frequency generators comprising:

a continuous wave laser, for generating laser light;

an electro-absorption modulator, coupled with said continuous wave laser and with said multiplexer;

a frequency combiner, coupled with said electro-absorption modulator; and

a plurality of frequency oscillators, coupled with said frequency combiner, for generating a plurality of frequencies,

wherein said frequency combiner combines said plurality of frequencies,

wherein said electro-absorption modulator substantially modulates said laser light with said plurality of frequencies thereby generating said pulse train.

12. The system according to claim 1, each one of said at least two digital frequency analyzers comprising:

a digital sampler, coupled with said analog sampler, for digitally sampling said respective one said at least two respective IF signals as respective multiplexed fast serial communication signals;

a logic layer, coupled with said digital sampler and with said processor; and

at least one Fourier transformer, coupled with said logic layer, for determining a plurality of discrete Fourier transforms (DFTs) of said fast serial communication signals,

wherein said plurality of DFTs is comprised of a plurality of discrete Fourier transform (DFT) chunks,

wherein a given one of said DFT chunks overlaps a subsequent one of said DFT chunks by at least a predetermined amount, and

wherein said logic layer filters said plurality of DFT chunks.

13. The system according to claim 12, wherein said logic layer and said at least one Fourier transformer are a field-programmable gate array (FPGA).

14. The system according to claim 12, wherein said plurality of DFTs determined in each one of said at least two digital frequency analyzers is determined synchronously.

15. The system according to claim 12, wherein said processor implements a plurality of digital band reject filters in each of said at least two digital frequency analyzers.

16. The system according to claim 12, where said logic layer dilutes said plurality of DFTs by a process of peak picking.

17. The system according to claim 12, said processor comprising:
a frequency determinator, coupled with said logic layer, for receiving and unaliasing said filtered plurality of DFT chunks and for determining said at least one frequency of said at least one signal;

a characteristics determinator, coupled with said frequency determinator, for determining a plurality of characteristics of said at least one signal; and

a clock, coupled with said logic layer, for providing a synchronization signal to said logic layer for synchronizing said at least one Fourier transformer.

18. System for collecting at least one signal simultaneously, a frequency of said at least one signal being within a defined intermediate frequency (IF) band, comprising:

an analog sampler, for receiving said at least one signal as at least one analog electrical signal, for folding said at least one analog electrical signal using at least one comb frequency into at least one sampled analog electrical signal and for converting said at least one sampled analog electrical signal into at least one respective IF signal according to said at least one comb frequency;

at least one digital frequency analyzer, coupled with said analog sampler, said at least one digital frequency analyzer for digitally sampling said at least one respective IF signal into at least one respective digital signal and for spectrally analyzing said at least one respective digital signal; and

a processor, coupled with said at least one digital frequency analyzer, for determining a plurality of linear combinations of said at least one respective IF signal with respect to said at least one comb frequency used in said analog sampler and for determining at least one frequency of said at least one signal by evaluating said plurality of linear combinations of said at least one respective IF signal,

wherein said at least one respective IF signal has a frequency within said IF band.

19. The system according to claim 18, said analog sampler further comprising:

an optical pulse generator, for generating said at least one comb frequency;

5 a fiber amplifier, coupled with said optical pulse generator, for amplifying said at least one comb frequency;

a modulator, coupled with said fiber amplifier and with said analog front end, for analog sampling said at least one signal with said at least one comb frequency, thereby generating at least one
10 sampled analog optical signal;

a photodiode, coupled with said modulator, for converting said at least one sampled analog optical signal into said at least one sampled analog electrical signal;

15 a low pass filter, coupled with said photodiode, for attenuating high frequencies in said at least one sampled analog electrical signal and generating said at least one respective IF signal; and

an amplifier, coupled with said low pass filter and with said at least one digital frequency analyzer, for amplifying said at least one respective IF signal,

20 wherein said at least one comb frequency is an optical pulse train.

20. Method for collecting at least one signal simultaneously comprising the procedures of:

25 collecting at least one signal;

folding said collected at least one signal using at least two different comb frequencies simultaneously, thereby generating at least two respective intermediate frequency (IF) signals;

30 digitally sampling each one of said at least two respective IF signals, thereby generating at least two respective sampled IF signals;

spectrally analyzing said at least two respective sampled IF signals; and

processing each one of said at least two respective sampled IF signals, thereby determining at least one characteristic of said collected at least one signal.

21. The method according to claim 20, further comprising the procedures of:

analog filtering said collected at least one signal; and
analog processing said collected at least one signal.

22. The method according to claim 20, wherein said procedure of folding comprises the sub-procedures of:

multiplexing said at least two different comb frequencies simultaneously into a multiplexed signal;

modulating said multiplexed signal with said collected at least one signal;

demultiplexing said modulated multiplexed signal according to said at least two different comb frequencies into at least two folded sampling signals;

converting said at least two folded sampling signals into at least two electrical signals; and

low pass filtering said at least two electrical signals, thereby eliminating high frequency images of said at least two electrical signals and generating said at least two respective IF signals.

23. The method according to claim 20, wherein said procedure of spectrally analyzing comprises the sub-procedure of executing a plurality of fast Fourier transforms on said at least two respective sampled IF signals, thereby determining at least two sets of discrete Fourier transforms (DFTs),

wherein each one of said two sets of DFTs comprises a plurality of discrete Fourier transform (DFT) chunks, and

wherein a given one of said plurality of DFT chunks overlaps a subsequent one of said plurality of DFT chunks by at least a predetermined amount.

24. The method according to claim 20, wherein said procedure of processing comprises the sub-procedures of:

determining a plurality of linear combinations of said at least two different comb frequencies used in said procedure of folding; and

evaluating said plurality of linear combinations, thereby determining at least one frequency of said collected at least one signal.

25. The method according to claim 20, further comprising the procedure of digitally processing said at least two respective sampled IF signals after said procedure of digitally sampling each one of said at least two respective IF signals.

26. Method for collecting at least one signal simultaneously comprising the procedures of:

collecting at least one signal;

folding said collected at least one signal using at least two different comb frequencies simultaneously, thereby generating at least two respective intermediate frequency (IF) signals;

digitally sampling each one of said at least two respective IF signals, thereby generating at least two respective sampled IF signals;

digitally processing said at least two respective sampled IF signals; and

processing each one of said at least two respective sampled IF signals, thereby determining at least one characteristic of said collected at least one signal.

5 27. System for collecting at least one signal simultaneously comprising:

an analog sampler, for receiving said at least one signal as at least one analog electrical signal, for folding said at least one analog electrical signal using at least two different comb frequencies simultaneously into at least two respective intermediate frequency (IF) signals respectively according to said at least two different comb frequencies;

at least two digital frequency analyzers, each respectively coupled with said analog sampler, each one of said at least two digital frequency analyzers for digitally sampling a respective one of said at least two respective IF signals into at least one respective digital signal and for spectrally analyzing said at least one respective digital signal; and

a processor, coupled with each one of said at least two digital frequency analyzers, for determining a plurality of linear combinations of said at least two respective IF signals with respect to said at least two different comb frequencies used in said analog sampler and for determining at least one frequency of said at least one signal by evaluating said plurality of linear combinations of said at least two respective IF signals.

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28. The system according to claim 27, said analog sampler comprising:

a plurality of radio frequency (RF) generators, for generating said at least two different comb frequencies;

a respective plurality of RF mixers, each one being respectively coupled with one of said plurality of RF generators;

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a power splitter, coupled with each one of said respective plurality of RF mixers and with an analog front end, for splitting said at least one analog electrical signal into at least two analog electrical signals, wherein each one of said plurality of RF mixers mixes a
5 respective one of said at least two different comb frequencies with a respective one of said at least two analog electrical signals, thereby generating at least two respective full band folded signals;

a respective plurality of low pass filters, each one of said respective plurality of low pass filters coupled with a respective one of
10 said respective plurality of RF mixers, for attenuating high frequencies in said at least two respective full band folded signals thereby generating said at least two respective IF signals; and

a respective plurality of amplifiers, each one of said respective plurality of amplifiers coupled with a respective one of said respective
15 plurality of low pass filters, for amplifying said at least two respective IF signals,

wherein each of said at least two different comb frequencies is an RF pulse train.

20 29. The system according to claim 28, each one of said plurality of RF generators comprising:

an RF signal generator, for generating an RF signal;

a first amplifier, coupled with said RF signal generator, for
amplifying said RF signal;

25 a comb generator, coupled with said first amplifier, for generating a comb frequency at the frequency of said RF signal, said comb frequency having a baseband frequency; and

a second amplifier, coupled with said comb generator and with a
respective one of said respective plurality of RF mixers, for amplifying
30 said baseband frequency of said comb frequency,

wherein said comb generator modulates said RF signal, thereby generating said RF pulse train.

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