

**A DEVICE FOR PERFORMING SIGNAL PROCESSING AND A SIGNAL
PROCESSING METHOD WHICH APPLIES TIME EXPANSION TECHNIQUE**

[0001] The present application claims the benefit of the Singapore patent application 201002196-2 (filed on 30 March 2010), the entire contents of which are incorporated herein by reference for all purposes.

Technical Field

[0002] Embodiments relate generally to devices for performing signal processing and signal processing methods. By way of example, embodiments relate to waveform recovery of ultra-wideband (UWB) radio frequency (RF) pulses for high precision ranging and positioning.

Background

[0003] In the field of localization of a mobile device by a base station, for example, the base station may be configured to determine the location of the mobile device based on the received radio frequency (RF) signals, e.g. UWB signals, transmitted from the mobile device. In order to have a high timing resolution at the base station side, it may be preferred that received radio frequency signals are sampled at high sampling rate. In this context, the timing resolution may refer to the minimum time duration between two consecutive sampling points. However, the cost goes up exponentially with higher sampling rate device, and more importantly, the sampling rate required may be way too fast and cannot be found in any existing commercial device.



Summary of the Invention

[0004] Various embodiments provide a device for processing signals which solves at least partially the above mentioned problems.

[0005] In one embodiment, a device for performing signal processing is provided. The device may include a receiver configured to receive a first periodic signal with a first pulse repetition frequency (PRF). The device may further include a first generator configured to generate a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency. The device may further include a second generator configured to generate a first delayed signal corresponding to the second periodic signal. The device may further include a multiplier. The multiplier may be configured to, during a first predetermined time period, multiply the first periodic signal and the second periodic signal to acquire an output signal. The multiplier may be further configured to, during a second predetermined time period, multiply the first periodic signal and the first delayed periodic signal to acquire the output signal.

[0006] In one embodiment, a signal processing method is provided. The method may include receiving a first periodic signal with a first pulse repetition frequency (PRF). The method may further include generating a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency. The method may further include generating a first delayed signal corresponding to the second periodic signal. The method may further include, during a first predetermined time period, multiplying the first periodic signal and the second periodic signal to acquire an output signal. The method may further include, during a second predetermined time period,

multiplying the first periodic signal and the first delayed periodic signal to acquire the output signal.

[0007] It should be noted that the embodiments described in the dependent claims of the independent device claim are analogously valid for the corresponding method claim where applicable, and vice versa.

Brief Description of the Drawings

[0008] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the invention are described with reference to the following drawings, in which:

FIG. 1 shows a communication system which includes a first radio communication device and a second radio communication device;

FIG. 2 (a) shows the waveforms of the received radio frequency (RF) signal, the local oscillator (LO) signal, the output signal from the mixer sampler, and the time expanded signal of the second radio communication device shown in FIG. 1, respectively;

FIG. 2 (b) shows the waveforms of the received RF signal, the local oscillator signal, and the time expanded signal of the second radio communication device shown in FIG. 1, respectively;

FIG. 3 shows a device for signal processing in one embodiment;

FIG. 4 illustrates a signal processing method in one embodiment;

FIG. 5 illustrates a communication system which includes a first radio communication device and a second radio communication device in one exemplary embodiment;

FIG. 6 illustrates the output signal from the RF block in the second radio communication device shown in FIG. 1 and FIG. 5, the output signal from the pulse generator 113 in the second radio communication device shown in FIG. 1, the output signal 215 from the filter 115 in the time domain the second radio communication device shown in FIG. 1, the output signal 613 from the pulse generator 513 in the second radio communication device shown in FIG. 5, and the output signal from the filter 515 the second radio communication device shown in FIG. 5, respectively;

FIG. 7 illustrates a delay line in one exemplary embodiment;

FIG. 8 (a) illustrates the waveform of the single local oscillator (LO) signal for the systems shown in FIG. 1 and FIG. 5;

FIG. 8 (b) illustrates the waveform of the single time expanded signal for the systems shown in FIG. 1 and FIG. 5;

FIG. 9 (a) illustrates the LO signals for the system shown in FIG. 1;

FIG. 9 (b) illustrates the LO signals for the system shown in FIG. 5;

FIG. 10 (a) illustrates the time expanded signals for the system shown in FIG. 1;

FIG. 10 (b) illustrates the time expanded signals for the system shown in FIG. 5;

FIG. 11 (a) illustrates an enlarged view of FIG. 10 (a); and

FIG. 11 (b) illustrates an enlarged view of FIG. 10 (b).

Description

[0009] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. In this regard, directional terminology, such as "top", "bottom", "front", "back", "leading", "trailing", etc, is used with reference to the orientation of the Figure(s) being described. Because components of embodiments can be positioned in a number of different orientations, the directional terminology is used for purposes of illustration and is in no way limiting. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments. The following detailed description therefore, is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims.

[0010] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration". Any embodiment or design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or designs.

[0011] The device as described herein may include a memory which is for example used in the processing carried out by the device. A memory used in the embodiments may be a volatile memory, for example a DRAM (Dynamic Random Access Memory) or a non-volatile memory, for example a PROM (Programmable Read Only Memory), an EPROM (Erasable PROM), EEPROM (Electrically Erasable PROM), or a flash memory,

e.g., a floating gate memory, a charge trapping memory, an MRAM (Magnetoresistive Random Access Memory) or a PCRAM (Phase Change Random Access Memory).

[0012] In an embodiment, a "circuit" may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing software stored in a memory, firmware, or any combination thereof. Thus, in an embodiment, a "circuit" may be a hard-wired logic circuit or a programmable logic circuit such as a programmable processor, e.g. a microprocessor (e.g. a Complex Instruction Set Computer (CISC) processor or a Reduced Instruction Set Computer (RISC) processor). A "circuit" may also be a processor executing software, e.g. any kind of computer program, e.g. a computer program using a virtual machine code such as e.g. Java. Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a "circuit" in accordance with an alternative embodiment.

[0013] In the field of processing of radio communication signals, the time expansion sampling technique may be used at a receiver side when high timing resolution is needed in sampling periodic signals coming from a transmitter. For example, in the application of localization or positions, a higher sampling resolution may result in a more accurate location of an object.

[0014] Briefly, according to the time expansion technique, a received signal consisting of or including repetitive waveforms may be expanded in time domain without changing the overall shape of the waveforms before the received signal is sampled by an analogue-to-digital circuit (ADC) for further processing. For example, assuming a received signal is expanded in the time domain by 10000 times at a receiver side before

sampling by the ADC, the equivalent timing resolution would be about 10000 times higher compared with the timing resolution obtained when the signal is sampled at the same sampling rate but without time expansion. In other words, for example, when an ADC sampling rate of 50 MHz is used, if the timing resolution without time expansion is 20 ns, with 10000 times time expansion of the received periodic signal, an equivalent timing resolution of 2 ps may be obtained. For an application such as localization, for example, the improvement in the timing resolution allows for a proportional improvement by the localization system, to resolve the distance traversed by a signal from a transmitter or in other words, it leads to an equivalent improvement in the ranging resolution. Assuming that the signal is traveling at the speed of light in free space of 300,000 km per second or 0.3 m per ns. So when the timing resolution improves from 20 ns to 2 ps, the ranging resolution improves from $(20 \text{ ns} \times 0.3 \text{ m/ns}) = 6 \text{ m}$ to $(0.002 \text{ ns} \times 0.3 \text{ m/ns}) = 0.0006 \text{ m}$.

[0015] In an ultra-wideband (UWB) system, the pulse width is generally short in duration due to the very wide bandwidth. The pulse repetition rate (PRR) or pulse repetition frequency (PRF) refers to the number of repetitive waveforms or pulses within one second duration of the signal. The main reason for using pulsed signals in applications such as localization is due to the spacing or silent period between the repetitive waveforms in the signal. The silent period between the waveforms allows for reflections or multipath signals to sufficiently settle down before the next pulse arrives at a receiver. This allows the direct signal from the transmitter to be differentiated from the reflected signals bouncing off nearby objects, hence mitigating the ill-effects of multipath on ranging or positioning accuracy. The silent period between the waveforms becomes

shorter as the PRF is increased. Typical PRFs for localization applications for example range between 1 kHz to 100 MHz. So for example, in the case of a typical 20 MHz PRF and a 1 ns pulse width, the duty cycle is only 2%.

[0016] With time expansion sampling technique of say 10000 expansion factor (or expansion ratio) and 20 MHz PRF, the normal time expanded waveform may give only one time expanded pulse per 500 μ s ($50 \text{ ns} \times 10000$). The period of 500 μ s may be referred to as the time expanded period in this context. This may cause any update that requires the time expanded waveform to be limited to 2 kHz, meaning, 2000 updates per second. As the pulse only spans 10 μ s (with 1 ns UWB pulse) with the rest of the 490 μ s containing no useful information, it is generally felt that time is wasted on useless signal.

[0017] FIG. 1 illustrates a radio communication system 100 which applies time expansion technique.

[0018] The system 100 may include a first radio communication device 101 and a second radio communication device 102. For example, the first radio communication device 101 may be a mobile device. For a concrete example, the first radio communication device may be configured to transmit a UWB signal with a first pulse repetition frequency (PRF), e.g. 20 MHz.

[0019] The second radio communication device 102 may be a base station (BS) which is configured to receive the UWB signal transmitted by the mobile device 101. The BS 102 may include an antenna 110 for receiving the UWB signal. The BS 102 may further include a radio frequency (RF) block 111, consisting typically of front-end filters for rejecting unwanted signals and amplifiers for amplifying the wanted signal. The BS 102 may further include a clock signal source 112 which is configured to generate a

periodic signal. The clock signal source 112 may generate a periodic signal with a second pulse repetition frequency, e.g. 19.998 MHz, for example. The BS 102 may further include a pulse generator (i.e. sampling pulse generator) 113. The output of the clock signal source 112 may be connected to the input of the pulse generator 113, such that the pulse generator 113 generates pulses at the same rate as the frequency of the input signal into the pulse generator 113. For example, with the input clock signals at a frequency of 19.998 MHz into the pulse generator 113, a pulsed signal with a pulse repetition frequency of 19.998 MHz is generated from the pulse generator 113. The signal output from the pulse generator 113 may be referred to as a local oscillator (LO) signal in this context. The BS 102 may further include a mixer sampler 114. The mixer sampler 114 may be configured to perform a multiplication operation of the output signal from the RF block 111 and the output signal of the pulse generator 113. The BS 102 may further include an active filter 115 for filtering and amplifying the output signal of the mixer sampler 114. The output signal from the filter 115 has the overall shape of waveforms of the received UWB signal but has been expanded in time domain. The output signal from the filter 115 may be referred to as the time expanded signal in this context. The time expanded signal may be further processed by an analogue-digital converter (ADC) (not shown) for sampling, and later sent to a field-programmable gate array (FPGA) (not shown) for further processing. The FPGA may be equipped with the knowledge of the time expanded waveform timing. For example, the mobile device 101 may transmit PRF at 20 MHz, whereas at the base station 102, the received signal is first sampled by the LO signal with a PRF of 19.998 MHz. Accordingly, a $20\text{M}/(20\text{M}-19.998\text{M}) = 10000$ times expansion of the received signal from the mobile device 101 in the time domain may be

achieved. With this expansion of received signal in the time domain, the sampling resolution of about 10000 times higher may be achieved. For example, with this expansion and 20 MHz ADC sampling rate, the equivalent timing resolution becomes $(1/20\text{M})/10,000 = 5 \text{ ps}$. That is, if the received signal is used in the application of localization or positioning, the corresponding ranging resolution in resolving the distance traversed by the signal from the transmitter would be $(0.005 \text{ ns} \times 0.3 \text{ m/ns}) = 1.5 \text{ mm}$, which is equivalent to sampling at a 200 GHz ADC sampling rate if time expansion is not carried out before the ADC sampling.

[0020] FIG. 2 (a) illustrates the waveforms of the received RF signal 211, the LO signal 213 (e.g. the output signal from the pulse generator (i.e. sampling pulse generator) 113), the output signal 214 from the mixer sampler 114, and the time expanded signal 215 (e.g. the output signal from the filter 115), respectively. The RF signal 211 consists of a series of repetitive waveforms with a silent period between each two consecutive waveforms. The length of the silent period depends on the pulse duration (i.e. pulse width or waveform duration) t_1 and pulse to pulse period t_2 . Each waveform 225 of the time expanded signal 215 has the shape of each waveform 221 of the received RF signal 211, but has been expanded in the time domain. The expansion factor may depend on the values of the pulse repetition frequencies of the received RF signal and the LO signal. The example values given herein are only for illustration purpose. For example, the RF signal 211 may correspond to a series of sinusoidal pulses or monocycles. A waveform in this context may refer to any repetitive portion of the received signal such as the portion 221 in signal 211 shown in FIG. 2.

[0021] Generally UWB refers to the use of a sufficiently narrow RF pulses with wide frequency bandwidths typically of at least 500 MHz. The time expansion technique is however not limited to signal with any particular bandwidth or occupying any particular band of the electromagnetic frequency spectrum. The type of RF pulse, the bandwidth and frequency spectrum used may be chosen by the user of the technique based on various conditions such as the regulatory requirements, the availability of frequency spectrum, the channel conditions, multipath environment, etc.

[0022] For the time expansion technique used, the use of 20 MHz for the PRF of the received signal and 19.998 MHz for the sampling pulse frequency is only illustrative. The time expansion technique is independent of the PRF of the received signal, and the PRF used for the sampling signal may depend on the PRF of the received signal and the desired time expansion factor. For the case illustrated herein, for the 20 MHz PRF, in order to achieve a 10000 times time expansion, a corresponding 19.998 MHz may be used for the PRF of the sampling signal.

[0023] FIG. 2 (b) illustrates the output signal 211 from the RF block 111, the output signal 213 from the pulse generator 113, and the output signal 215 from the filter 115 in the time domain, respectively. In this example, it is assumed that the pulse width of the RF signal received is 1 ns. As can be seen, when the mobile device 101 transmits at a first pulse repetition frequency (PRF) of 20 MHz, whereas the received signal is sampled by the LO signal with a second pulse repetition frequency (PRF) of 19.998 MHz at the base station 102, the resulted time expanded waveform, i.e. the output signal of the filter 105, includes one time expanded pulse per 500 μ s (i.e. 50 ns $\times$ 10000). Each time expanded pulse occupies a time span of 10 μ s followed by a silence period of 490 μ s as a

consequence of time expanding the 49 ns of silent period between the pulses in the original signal.

[0024] Having more time expanded pulses per second can provide faster updates about the target/mobile device that is tracked by a radar/localization system. One way to increase to the number of time expanded pulses per second or the update rate is to decrease the time expansion factor. But this will reduce the equivalent timing resolution which in turn will affect the ranging resolution.

[0025] Another conventional method is to increase the PRF. Increasing PRF may lead to two problems. The first problem arises when the signal power is limited by the regulatory authorities. With higher PRF, the amplitude of each pulse may have to be smaller in order to keep within the allowed power levels. Reducing the amplitude of the pulses would likely lead to a reduction in the maximum distance possible between the transmitter and receiver. The other problem that could arise when the PRF is raised higher is that there will be less time for the multipath signals bouncing off nearby objects to settle down and so the multipath signals may overlap on the subsequent pulses arriving at the receiver, causing signal distortion.

[0026] FIG. 3 illustrates a device 300 for performing signal processing in one embodiment, and which may, when applying the time expansion technique, increase the update rate without sacrificing any other parameters.

[0027] The device 300 may include a receiver 301 which is configured to receive a first periodic signal with a first pulse repetition frequency. The device 300 may further include a first generator 302 which is configured to generate a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition

frequency. The device 300 may further include a second generator 303 which is configured to generate a first delayed signal corresponding to the second periodic signal. The device 300 may further include a multiplier 304. The multiplier 304 may be configured to, during a first predetermined time period, multiply the first periodic signal and the second periodic signal to acquire an output signal. The multiplier 304 may be further configured to, during a second predetermined time period, multiply the first periodic signal and the first delayed periodic signal to acquire the output signal. The receiver 301, the first generator 302, the second generator 303, the multiplier 304 may be coupled with each other, e.g. via an electrical connection 310 such as e.g. a cable or a computer bus or via any other suitable electrical connection to exchange electrical signals.

[0028] In one embodiment, in other words, the device 300 may be configured to receive the first periodic signal and to further process the first periodic signal. The time expansion technique may be applied by the device 300. That is, the device 300 may be configured to first expand the received first periodic signal in the time domain and later use an analogue-to-digital converter (ADC) to sample the time expanded signal in order to achieve a higher timing resolution. In order to obtain a time expanded signal, the device 300 may generate a second periodic signal, and then sample the first periodic signal by the second periodic signal. The sampling of the first periodic signal by the second periodic signal may be achieved by a multiplier which is configured to perform a multiplication operation of the first periodic signal and the second periodic signal. The pulse repetition frequency of the second periodic signal may be different from the pulse repetition frequency of the first periodic signal, e.g. the pulse repetition frequency of the

second periodic signal may be lower or higher than the pulse repetition frequency of the first periodic signal or the pulse repetition frequency of the second periodic signal may be higher than the pulse repetition frequency of the first periodic signal. As illustrated in FIG. 2, when the time expansion technique is applied, there could be a long time period (silent period) with no useful information in each time expanded period, e.g. 490 μs out of 500 μs in the time expanded signal shown in FIG. 2 (b) carries no useful information. In order to make good use of the silent period between every two time expanded waveforms in the time expanded signal and to increase the update rate, in one embodiment, after a time expanded waveform resulted from the sampling of the first periodic signal by the second periodic signal (e.g. a waveform 225 as shown in FIG. 2 (a)) has been recovered and before the start of the recovery of a consecutive time expanded waveform resulted from the sampling of the first periodic signal by the second periodic signal, the first periodic signal may be sampled by a delayed periodic signal corresponding to the second periodic signal such that at least an additional time expanded waveform may be recovered. For example, the device 300 may be configured to generate a first delayed signal corresponding to the second periodic signal by the second generator 303. During a first pre-determined time period, the first periodic signal may be sampled by the second periodic signal such that at least one time expanded waveform is recovered. Thereafter, during a second pre-determined time period which is before the start of the recovery of a next time expanded waveform resulted from the sampling of first periodic signal by the second periodic signal, the first periodic signal may be sampled by a first delayed signal that corresponds to the second periodic signal so as to recover at least one additional time expanded waveform.

[0029] The first periodic signal may include a plurality of waveforms. Each waveform may have a first pulse width (or waveform duration), and there may be a timing interval between any two consecutive waveforms in the first periodic signal. For example, the first periodic signal may be a UWB signal that includes a plurality of pulses. For another example, the first periodic signal may be the signal 211 as shown in FIG. 2 (a), which includes a plurality of waveforms 221, each waveform 221 having a first pulse width t_1 , and there is a timing interval 230 between any two consecutive waveforms 221.

[0030] In one embodiment, the second periodic signal may include a plurality of waveforms. Each waveform may have a second pulse width, and there may be a timing interval between any two consecutive waveforms. For example, the second periodic signal may include a plurality of pulses. For another example, the second periodic signal may be the signal 213 as shown in FIG. 2 (a), which includes a plurality of pulses 223, each waveform 223 of the signal 213 having a second pulse width t_3 , and there is a timing interval 231 between any two consecutive waveforms 223. In one embodiment, each waveform of the second periodic signal may be or may include a pulse.

[0031] In one embodiment, the second pulse width is shorter than the first pulse width. For example, as illustrated in FIG. 2 (a), the first pulse width t_1 is longer than the second pulse width t_3 . In an alternative embodiment, the first pulse width, t_1 , as illustrated in Fig. 2(a), may be shorter than the second pulse width t_3 . In a further alternative embodiment, the first pulse width t_1 may be the same as the second pulse width t_3 .

[0032] In one embodiment, the second pulse width t_3 , illustrated in Fig. 2(a) may be so long that the periodic waveforms 223 follow one after another in time, with no time

duration between the completion of one waveform and the start of the next waveform, effectively making signal 213 a continuous but periodic signal with no breaks between the waveforms.

[0033] In one embodiment, the second pulse repetition frequency is lower than the first pulse repetition frequency. In an alternative embodiment, the second pulse repetition frequency is higher than the first pulse repetition frequency.

[0034] In one embodiment, the first delayed signal may correspond to the second periodic signal delayed by a predetermined delay. In a further embodiment, the predetermined delay may be selected from a plurality of selectable delays. The predetermined delay may be set in such a way that, at least one additional time expanded waveform resulted from the sampling of the first periodic signal by the first delayed signal may be recovered between the recovery of two consecutive time expanded waveforms resulted from the sampling of the first periodic signal by the second periodic signal.

[0035] In one embodiment, the multiplier 304 may be configured to, during a third predetermined period, multiply the first periodic signal and the second periodic signal to acquire the output signal. In other words, after at least one time expanded waveform resulted from the sampling of the first periodic signal by the first delayed signal is recovered, a time expanded waveform resulted from the sampling of the first periodic signal by the second periodic signal may be recovered.

[0036] In one embodiment, the device 300 may further include a third generator 305 which is configured to generate a second delayed signal corresponding to the second periodic signal. The receiver 301, the first generator 302, the second generator 303, the

multiplier 304 and the third generator 305 may be coupled with each other, e.g. via the electrical connection 310. In this embodiment, the multiplier 304 may be configured to, during a fourth predetermined time period, multiply the first periodic signal and the second delayed periodic signal to acquire the output signal. For example, after the recovery of at least one time expanded waveform resulted from the sampling of the first periodic signal by the first delayed signal, at least one time expanded waveform resulted from the sampling of the first periodic signal by the second delayed signal may be recovered.

[0037] In one embodiment, the second predetermined time period starts after the first predetermined time period. For example, the first predetermined time period may be preset in such a way that the sampling of the first periodic signal by the second periodic signal may enable the recovery of at least one time expanded waveform, and after the first predetermined time period, and during the second predetermined time period, the sampling of the first periodic signal by the first delayed signal may begin for the recovery of a further time expanded waveform.

[0038] In one embodiment, the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1 kHz and 100 MHz. In one exemplary embodiment, the first pulse repetition frequency is 20 MHz. In one exemplary embodiment, the second pulse repetition frequency is 19.998 MHz. It is however noted that the range of frequencies between 1 kHz and 100 MHz is not limited thereto. In actual fact, the frequency range may depend on the application and poses no direct limitation on the proposed time expansion technique.

[0039] In one embodiment, the output signal includes a first output waveform during the first predetermined time period. In a further embodiment, the first output waveform may include a pulse. During the first predetermined time period, the first periodic signal is sampled by the second periodic signal. Such sampling may be realized by the multiplier 304 which is configured to perform a multiplication operation of the first periodic signal and the second periodic signal. The output of the multiplier 304 may include a plurality of waveforms like the signal 214 shown in FIG. 2 (a) which include a plurality of pulses. This plurality of waveforms may be further filtered such that a time expanded waveform like the waveform 225 shown in FIG. 2 (a) may be obtained as an output waveform.

[0040] In one embodiment, the output signal includes a second output waveform during the second predetermined time period. In a further embodiment, the second output waveform may include a pulse. During the second predetermined time period, the first periodic signal is sampled by the first delayed signal which corresponds to the second periodic signal delayed by a predetermined delay. Such sampling may be realized by the multiplier 304 which is configured to perform a multiplication operation of the first periodic signal and the first delayed signal. The output of the multiplier 304 may include a plurality of waveforms like the signal 214 shown in FIG. 2 (a) which include a plurality of pulses. This plurality of waveforms may be further filtered such that a time expanded waveform like the waveform 225 shown in FIG. 2 (a) may be obtained as an output waveform.

[0041] FIG. 4 shows flow diagram 400 illustrating a signal processing method according to one embodiment. The signal processing method as described herein may correspond to the device 300 as described above.

[0042] In 401, a first periodic signal with a first pulse repetition frequency is received. In 402, a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency is generated. In 403, a first delayed signal corresponding to the second periodic signal is generated. In 404, during a first predetermined time period, the first periodic signal and the second periodic signal are multiplied to acquire an output signal. In 405, during a second predetermined time period, the first periodic signal and the first delayed periodic signal are multiplied to acquire the output signal.

[0043] In one embodiment, the first periodic signal may include a plurality of waveforms, each waveform having a first pulse width, and there is a timing interval between any two consecutive waveforms.

[0044] In one embodiment, the second periodic signal may include a plurality of waveforms, each waveform having a second pulse width, and there is a timing interval between any two consecutive waveforms. In a further embodiment, each waveform of the second periodic signal may be or may include a pulse.

[0045] In one embodiment, the second pulse width is shorter than or longer than or the same as the first pulse width.

[0046] In one embodiment, the second pulse repetition frequency is lower or higher than the first pulse repetition frequency.

[0047] In one embodiment, the first delayed signal corresponds to the second periodic signal delayed by a pre-determined delay. In a further embodiment, the pre-determined delay is selected from a plurality of selectable delays.

[0048] In one embodiment, the method may include during a third predetermined time period, multiplying the first periodic signal and the second periodic signal to acquire the output signal.

[0049] In one embodiment, the method may include generating a second delayed signal corresponding to the second periodic signal, and during a fourth predetermined time period, multiplying the first periodic signal and the second delayed periodic signal to acquire the output signal.

[0050] In one embodiment, the second predetermined time period starts after the first predetermined time period.

[0051] In one embodiment, the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1 kHz and 100 MHz. In one exemplary embodiment, the first pulse repetition frequency is 20 MHz. In one exemplary embodiment, the second pulse repetition frequency is 19.998 MHz.

[0052] In one embodiment, the output signal may include a first output waveform during the first predetermined time period. In a further embodiment, the first output waveform includes a pulse.

[0053] In one embodiment, the output signal includes a second output waveform during the second predetermined time period. In a further embodiment, the second output waveform may include a pulse.

[0054] FIG. 5 illustrates a radio communication system 500 which includes a first communication device 501 and a second communication device 502 according to one exemplary embodiment. For example, the first communication device 501 may be a mobile device and the second communication device 502 may be a base station (BS). The BS 502 may be configured to receive radio frequency signals from the mobile device 501, for example.

[0055] For example, the mobile device 501 may be configured to transmit a UWB signal with a first pulse repetition frequency (PRF), for example 20 MHz. The BS 502 may be configured to receive the UWB signal transmitted by the mobile device 501. The BS 502 may include an antenna 510 for receiving the UWB signal. The BS 502 may further include a radio frequency (RF) block 511, consisting typically of front-end filters for rejecting unwanted signals and amplifiers for amplifying the wanted signal. The BS 502 may further include a clock signal source 512 which is configured to generate a periodic signal. The clock signal source 512 may generate square wave or sinusoidal wave or any other periodic signal with a second pulse repetition frequency, for example, at 19.998 MHz. The BS 502 may further include a delay line 520 which receives the output signal from the clock signal source 512. In this context, the delay line generally refers to a component that delays a signal by a certain amount of time. The delay line 520 may for example be a typical 'tapped delay line integrated circuit (IC)' which has various outputs where the input signal can be tapped out with various delays. An example of such an IC is the DS1100Z series of delay lines from MAXIM. Alternately the tapped delay line and external switch may be replaced by a programmable delay line IC. An example of a programmable delay line IC that may be used is DS1123L from MAXIM. The delay

line 520 may be configured to delay the output signal of the clock signal source 512 by a predetermined delay, e.g. 20 ns. The BS 502 may further include a switch 521 and a pulse generator 513. The switch 521 may be a single-pole double-throw (SPDT) switch, for example. The single pole of the switch 521 may be connected to the input of the pulse generator 513. A first terminal (or throw) 531 of the switch 521 may be electrically connected to an output 541 of the delay line 520 which is configured to output a first delayed signal of the input signal into the delay line 520, wherein the first delayed signal may correspond to the input signal into the delay line 520 delayed by a first predetermined delay. A second terminal (or throw) 532 of the switch 521 may be connected to an output 542 of the delay line 520 which is configured to output a second delayed signal corresponding to the input signal into the delay line 520 delayed by a second predetermined delay. The second predetermined delay may be different from the first predetermined delay, such that the second delayed signal may correspond to the first delayed signal delayed by a predetermined delay. Accordingly, when the single pole of the switch 521 is connected to the first terminal 531, the first delayed signal from the clock signal source 512 is input into the pulse generator 513. When the single pole of the switch 521 is connected to the second terminal 532, the second delayed signal corresponding to the signal from the clock signal source 512 delayed by a second predetermined delay is input into the pulse generator 513. Assuming the clock signal source 512 is configured to generate a periodic signal at a second pulse repetition frequency of 19.998 MHz, the pulse generator 513 is configured to output pulses at a second pulse repetition frequency of 19.998 MHz with a first predetermined delay or a second predetermined delay depending on the connection of the switch 521. The control

of the switch 521 may be via a field-programmable gate array (FPGA) (not shown). The signal output from the pulse generator 513 may be referred to as a local oscillator (LO) signal in this context. The BS 502 may further include a mixer sampler 514. The mixer sampler 514 may be configured to perform a multiplication operation of the output signal from the RF block 511 and the output signal of the pulse generator 513. The BS 502 may further include a filter 515, e.g. an active filter, for filtering the output signal of the mixer sampler 514. The output signal from the filter 515 may have the overall shape of waveforms of the received UWB signal but has been expanded in the time domain. The output signal from the filter 515 may be referred to as the time expanded signal in this context. The time expanded signal may be further processed by an analogue-digital converter (ADC) (not shown) for sampling, and later sent to the field-programmable gate array (FPGA) for processing. The FPGA may be equipped with the knowledge of the time expanded waveform timing and thus perform the control of the switch 521.

[0056] When a complete time expanded waveform is received or recovered at the output of the filter 515, the FPGA may toggle the SPDT switch 521. The LO signal output from the pulse generator 513 may be then delayed by, for example, 20 ns or 40 ns, causing the LO signals to arrive 20 ns or 30 ns earlier in the mixer sampler 514.

[0057] As described with reference to FIG. 5, the LO signal from the pulse generator 513 may be controlled so that time containing the silence period at the output end of the mixer sampler 514 may be skipped. In one embodiment, the delay of the LO signal may be controlled via switching the delay of the clock signal source 512. The usage of the delay line 520 and the switch 521 does not involve high frequency RF components, thus the circuitry is simple and cheap.

[0058] In a further embodiment, the switch 521 may not be limited to a SPDT switch, and may be a single-pole multi-throw switch, for example. The pole may be switched to be connected with more than two outputs of the delay line 520 in the device 502. In an exemplary embodiment, during a first predetermined time period, the output 541 of the delay line 520 may be connected to the input of the pulse generator 513; during a second predetermined time period, the output 542 of the delay line 520 may be connected to the input of the pulse generator 513; during a third predetermined time period, the output 543 of the delay line 520 may be connected to the input of the pulse generator 513; and during a fourth predetermined time period, the output 541 of the delay line 520 may be connected to the input of the pulse generator 513, and so on.

[0059] In a further embodiment, the switch 521 and the delay line 520 may be replaced by a programmable delay line. The programmable delay line may be configured to delay the clock signal by a time period that is controlled by the FPGA.

[0060] FIG. 6 illustrates the output signal 211 from the RF block 111 in the device 102 shown in FIG. 1, the output signal 213 from the pulse generator 113 in the device 102 shown in FIG. 1, the output signal 215 from the filter 115 in the time domain in the device 102 shown in FIG. 1, the output signal 613 from the pulse generator 513 in the device 502 shown in FIG. 5, and the output signal from the filter 515 in the device 502 shown in FIG. 5, respectively.

[0061] In this example, the pulse width of the RF signal received is assumed to be 1 ns for illustration purpose. The sampling of the RF signal 211 by the LO signal 213 may lead to the recovery of time expanded waveforms 250, 252, etc. In one embodiment, the delay of the LO signal in the device 502 may be switched to avoid the time when no RF

pulse is present at the output of the mixer sampler 514, thereby raising the efficiency. That is, for example, the pulses of the LO signal 613 during time period T_a in the LO signal 613 may be identical with those in the LO signal 213. The sampling of the RF signal 211 by the LO signal 213 or 613 during time period T_a may lead to the recovery of a time expanded waveform 250 in signal 215 or a time expanded waveform 650 in signal 615, wherein the waveforms 250 and 650 are identical. After time period T_a , the LO signal 613 may be delayed by a predetermined delay as shown in the circled portion 660. Consequently, the time when no RF pulse is present at the output of the mixer sampler 514 may be skipped. After the LO signal 613 is delayed, the sampling of the RF signal 211 by the delayed LO signal 613 during time period T_b may lead to the recovery of another time expanded waveform 651. After time period T_b , the delayed LO signal 613 may be restored in order to recover a next time expanded signal 652 which corresponds to the time expanded signal 252. As can be seen, the time expanded waveform, i.e. the signal 615, which may be realized with time delay control of the clock signal (or sampling signal or LO) as illustrated in FIG. 5, has double waveform information in comparison to the time expanded waveform, i.e. the signal 215, without time delay control. In one embodiment, the amount of waveform may be increased multiple times depending on the amount of the delay and switches.

[0062] As also can be seen, by making good use of the $490\ \mu\text{s}$ of the time expanded signal in the time expanded signal 215, the update rate may be increased without sacrificing any other parameters.

[0063] FIG. 7 illustrates a delay line 700 which may be used in the second communication device 502 shown in FIG. 5 according to one exemplary embodiment.

[0064] A signal may be input to the input 701 of the delay line 700. For example, the delay line 700 may have several outputs each outputting a delayed signal corresponding to the input signal by a predetermined delay. For example, there may be a first output 702, a second output 703, a third output 704, a fourth output 705, and a fifth output 706. For a concrete example, signal output from the first output 702 may be a delayed signal corresponding to the input signal delayed by 20 ns. Signal output from the second output 703 may be a delayed signal corresponding to the input signal delayed by 40 ns. Signal output from the third output 704 may be a delayed signal corresponding to the input signal delayed by a further 20 ns, and so on.

[0065] A person skilled in the art would appreciate that the predetermined delay given above is only for illustration purpose and is not limited thereto. Depending on the specific application requirement, any suitable predetermined delay may be selected.

[0066] When the delay line 700 is used in the second communication device 502, for example, the input 701 of the delay line 700 may be connected to the output of the clock signal source 512, the first output 702 of the delay line 700 may be connected to the first terminal 531 of the switch 521, and the second output 703 of the delay line 700 may be connected to the second terminal 532 of the switch 521. For another example, the output of the clock signal source 512 may be connected to both the input 701 of the delay line and the first terminal 531 of the switch 521, and the first output 702 of the delay line 700 may be connected to the second terminal 532 of the switch 521. A skilled person would appreciate that the connection of the clock signal source, the delay line, and the switch as described herewith is only for illustrative purpose and there may be numerous variations

to the arrangement, the connections, and the type of delay lines and switches used depending on the specific requirement of the application.

[0067] In various embodiments, the switch and the delay line as illustrated in FIG. 5 may not affect the waveform of the LO pulse output from the pulse generator 513.

[0068] Thus, the single LO pulse is the same for both devices 102 and 502 (with or without switching). As a result, the single time expanded pulse is the same for both devices 102 and 502.

[0069] FIG. 8 (a) illustrates single LO pulse for both devices 102 and 502. FIG. 8 (b) illustrates the single time expanded pulse for devices 102 and 502.

[0070] FIG. 9 (a) shows the LO signal in device 102 without switching. The LO signal has constant ~ 50 ns in between the pulses (because of the 19.998MHz pulse repetition rate); whereas as shown in FIG. 9 (b), even though the LO signal in device 502 with switching has also 19.998 MHz pulse repetition rate, the time between each pulse is occasionally 20 ns or 30 ns when the switch is toggled.

[0071] FIG. 10 (a) shows the time expanded signal for device 102 without switching. As expected, the normal time expanded waveform give only one time-expanded pulse per 500 μ s (i.e. 20 pulses in 10 ms).

[0072] FIG. 10 (b) shows the time expanded signal for device 502 with delay control. The time expanded signal gives 40 pulses in 10 ms, equivalent to double the pulse rate.

[0073] FIG. 11 shows a close-up view of FIG. 10. FIG. 11 (a) illustrates a graphical plot for device 102 without switching, and FIG. 11 (b) shows the result for device 502 with delay control. In this example, the delay line 520 is set to provide 20 ns delay and 40 ns at two outputs of the delay line 520, and the pulse is either 200 μ s or 300 μ s (500 μ s

minus 200 μ s) away from the next pulse. As can be seen in FIG. 11 (a), a time expanded waveform 1101 is recovered every 500 μ s. As can be seen in FIG. 11 (b), each recovered time expanded waveform 1102 may correspond to a waveform 1101 in FIG. 11 (a). Additional time expanded waveforms 1103 may be recovered as a result of the delay of the LO signal, e.g. 613.

[0074] In various embodiments, a method of waveform recovery of repetitive signals is provided. More particularly, according to various embodiment, for the recovery of UWB pulses at a receiver side (e.g. at a BS), the quiet or silent periods during which the multiplier (or mixer sampler) outputs no useful signal, may be shortened or even completely skipped by delaying the sampling instances of the LO signals, which advantageously permits more waveforms or pulses to be recovered in a given time from equivalent time sampling. A system of waveform recovery according to various embodiments of the invention is also provided.

[0075] In various embodiments, the method of controlled delay of sampling pulses in the LO signal is provided which includes delaying sampling pulse after a full recovery of one time expanded waveform such that at least an additional time expanded waveform may be recovered. In this aspect, by removing the delay, the original time expanded waveform per time expanded period may be recovered. By controlling the delay of the sampling pulse, at least twice the number of recovered time expanded waveforms may be obtained.

[0076] In various embodiments, a simple digital delay circuit, such as a tapped delay line IC, may be used to achieve the controlled delay, and to improve the efficiency of the waveform sampling technique where more waveforms may be recovered compared to conventional time expansion receiver systems such as that illustrated in FIG. 1.

[0077] By working on the low frequency signals from the clock signal source, for example at 19.998 MHz, instead of the received RF signal typically occupying bands above 1 GHz, the simple delay circuit can be of low cost and complexity.

[0078] In various embodiments, the device for performing signal processing and signal processing method as described herein may be implemented in a similar fashion by delaying the first periodic signal (e.g. received RF signal). That is, instead of generating a delayed signal corresponding to the second periodic signal, a delayed signal corresponding to the first periodic signal (e.g. the RF signal) may be generated. The RF signal which is generally from higher frequency bands, will need high frequency components/parts to delay the RF signal. By delaying the clock signal source for the second periodic signal which is generally of lower frequency spectrum, only low frequency components/parts are needed.

[0079] In various embodiments, a programmable delay circuit is provided to achieve the controlled delay, and to improve the efficiency of the waveform sampling technique where more waveforms may be recovered compared to conventional time expansion receiver systems such as that illustrated in FIG. 1. By working on the low frequency signals from the clock signal source, for example at 19.998 MHz, instead of the received RF signal typically occupying bands above 1 GHz, the programmable delay circuit can be of low cost and complexity. The controlled delay may be implemented using a programmable IC instead of the switch and tapped delay line IC combination.

[0080] In various embodiments, because more waveforms per second are recovered through the proposed method, less time would be taken to average and output the results from a given number of recovered pulses.

[0081] Various embodiments of the invention is applicable to all equivalent time sampling applications such as ranging, positioning and radar applications that is capable of taking advantage of the greater timing accuracy achievable.

[0082] A person skilled in the art would appreciate that although device for signal processing and the signal processing method as described herein has been illustrated with respect to periodic RF signals or UWB signals, the application of the technique is not limited thereto. The device for signal processing and the signal processing method may be used for waveform recovery of other type of repetitive signals such as optical signals and acoustic signals as well.

[0083] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

What is claimed is:

1. A device for performing signal processing, comprising:
 - a receiver configured to receive a first periodic signal with a first pulse repetition frequency;
 - a first generator configured to generate a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency;
 - a second generator configured to generate a first delayed signal corresponding to the second periodic signal;
 - a multiplier;
 - wherein the multiplier is configured to, during a first predetermined time period, multiply the first periodic signal and the second periodic signal to acquire an output signal; and
 - wherein the multiplier is configured to, during a second predetermined time period, multiply the first periodic signal and the first delayed periodic signal to acquire the output signal.
2. The device as claimed in claim 1, wherein the first periodic signal comprises a plurality of waveforms, each waveform having a first pulse width, and wherein there is a timing interval between any two consecutive waveforms.

3. The device as claimed in claim 2, wherein the second periodic signal comprises a plurality of waveforms, each waveform having a second pulse width, and wherein there is a timing interval between any two consecutive waveforms.

4. The device as claimed in claim 3, wherein each waveform of the second periodic signal comprises a pulse.

5. The device as claimed in any of claims 1 to 4, wherein the first delayed signal corresponds to the second periodic signal delayed by a pre-determined delay.

6. The device as claimed in any of claim 5, wherein the pre-determined delay is selected from a plurality of selectable delays.

7. The device as claimed in any of claims 1 to 6,
wherein the multiplier is configured to, during a third predetermined period, multiply the first periodic signal and the second periodic signal to acquire the output signal.

8. The device as claimed in any of claims 1 to 7, further comprising:
a third generator configured to generate a second delayed signal corresponding to the second periodic signal;

wherein the multiplier is configured to, during a fourth predetermined time period, multiply the first periodic signal and the second delayed periodic signal to acquire the output signal.

9. The device as claimed in any of claims 1 to 8, wherein the second predetermined time period starts after the first predetermined time period.

10. The device as claimed in any of claims 1 to 9, wherein the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1 kHz and 100 MHz.

11. The device as claimed in any of claim 10, wherein the first pulse repetition frequency is 20 MHz.

12. The device as claimed in any of claims 10 to 11, wherein the second pulse repetition frequency is 19.998 MHz.

13. The device as claimed in any of claims 1 to 12,
wherein the output signal comprises a first output waveform during the first predetermined time period.

14. The device as claimed in claim 13, wherein the first output waveform comprises a pulse.

15. The device as claimed in any of claims 1 to 14,
wherein the output signal comprises a second output waveform during the second predetermined time period.
16. The device as claimed in claim 15,
wherein the second output waveform comprises a pulse.
17. A signal processing method, comprising:
receiving a first periodic signal with a first pulse repetition frequency;
generating a second periodic signal with a second pulse repetition frequency being different from the first pulse repetition frequency;
generating a first delayed signal corresponding to the second periodic signal;
during a first predetermined time period, multiplying the first periodic signal and the second periodic signal to acquire an output signal;
during a second predetermined time period, multiplying the first periodic signal and the first delayed periodic signal to acquire the output signal.
18. The method as claimed in claim 17, wherein the first periodic signal comprises a plurality of waveforms, each waveform having a first pulse width, and wherein there is a timing interval between any two consecutive waveforms.

19. The method as claimed in claim 18, wherein the second periodic signal comprises a plurality of waveforms, each waveform having a second pulse width, and wherein there is a timing interval between any two consecutive waveforms.
20. The method as claimed in claim 19, wherein each waveform of the second periodic signal comprises a pulse.
21. The method as claimed in any of claims 17 to 20, wherein the first delayed signal corresponds to the second periodic signal delayed by a pre-determined delay.
22. The method as claimed in any of claim 21, wherein the pre-determined delay is selected from a plurality of selectable delays.
23. The method as claimed in any of claims 17 to 22, further comprising:
during a third predetermined time period, multiplying the first periodic signal and the second periodic signal to acquire the output signal.
24. The method as claimed in any of claims 17 to 23, further comprising:
generating a second delayed signal corresponding to the second periodic signal;
during a fourth predetermined time period, multiplying the first periodic signal and the second delayed periodic signal to acquire the output signal.

25. The method as claimed in any of claims 17 to 24, wherein the second predetermined time period starts after the first predetermined time period.

26. The method as claimed in any of claims 17 to 25, wherein the first pulse repetition frequency and the second pulse repetition frequency are selected from a frequency range between 1 kHz and 100 MHz.

27. The method as claimed in any of claim 26, wherein the first pulse repetition frequency is 20 MHz.

28. The method as claimed in any of claims 26 to 27, wherein the second pulse repetition frequency is 19.998 MHz.

29. The method as claimed in any of claims 17 to 28,
wherein the output signal comprises a first output waveform during the first predetermined time period.

30. The method as claimed in claim 29, wherein the first output waveform comprises a pulse.

31. The method as claimed in any of claims 17 to 30,
wherein the output signal comprises a second output waveform during the second predetermined time period.

32. The method as claimed in claim 31,
wherein the second output waveform comprises a pulse.