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(54) **Title:** RADAR SYSTEM WITH INTEGRATED COMMUNICATION FUNCTIONALITY

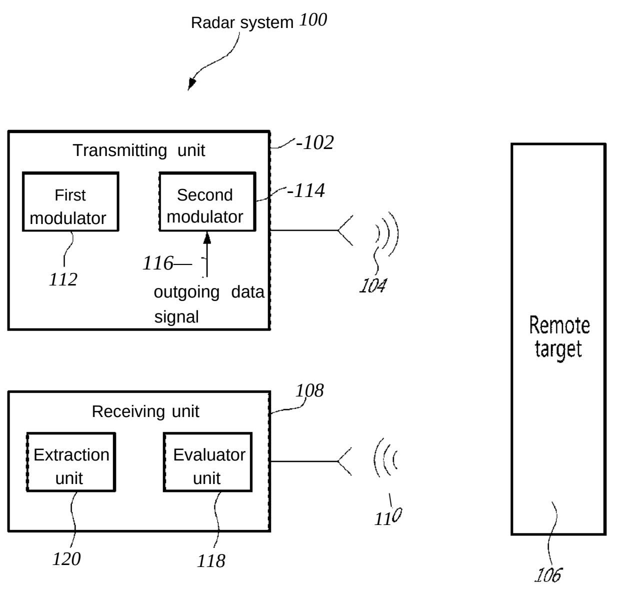

FIG. 1

(57) Abstract: A radar system with integrated communication functionality. The radar system implements a radar-communication modulation scheme that uses at least the rising edge portion and the falling edge portion of each period of the waveform of a radar signal as a radar cycle, while using the constant-frequency portion of each period as a radio cycle during which the radar signal may be modulated with a data signal. This combined sensing (radar) and communication (radio) functionality is indispensable to the development of future radar systems, for example in the field of future intelligent vehicles.

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RADAR SYSTEM WITH INTEGRATED COMMUNICATION FUNCTIONALITY

Technical Field

This invention relates generally to the field of radar systems and more specifically to a radar system with integrated communication functionality.

Background

Every year, millions of people are killed or suffer non-fatal injuries in road traffic accidents and crashes. Such road traffic injuries and deaths have both social and economic costs, which have led to the development of the intelligent transportation system (ITS). Within the ITS framework, intelligent vehicles have to work in an autonomous manner to sense the driving environment and in a cooperative manner to exchange information data between vehicles (e.g. braking and acceleration data), as well as between vehicles and roadside units or beacons (e.g. traffic, road and weather condition data). Therefore, both radar (sensing) functionality and radio (communication) functionality are indispensable to the development of future intelligent vehicles.

Radar systems with communication capability do exist and have been used in various contexts to provide combined radar and radio functionality. In one such prior art system, conventional frequency modulated continuous wave (FMCW) radar waveforms are amplitude-modulated (AM) with communication data in order to achieve simultaneous functions of communication and radar. Unfortunately, this type of system only works in a master-slave manner, which means that the slave side (the AM data receiver) is not able to autonomously transfer data. Moreover, the frequency of the data signal carrier must be carefully chosen in order to reduce mutual interference between the radar and the enabled duplex communication.

In other prior art radar systems, communication capability is added by taking advantage of the fact that radar and communication signals can be separated in the frequency domain. For example, pulse radar with communication capability may be realized by specially allocating the communication channel over the first null of the radar spectrum. Unfortunately, even though a good suppression of the radar signal in the communication receiver can be achieved under the condition of a low data rate, such a spectrum-overlapping scheme is not suitable for high data rate communications.

Radar and communication functionality can also be integrated together using a spread spectrum technique, which provides the advantages of secure and robust (anti-fading) communication, strong resistance to interference and jamming, low probability of intercept and multiple access capability. Different forms of the spread spectrum technique include direct-sequence spread spectrum, code-hopping spread spectrum, time-hopping spread spectrum and chirp spread spectrum. By making use of the orthogonality of pseudo-noise (PN) codes or the quasi-orthogonality of up-chirp and down-chirp waveforms, the radar and communication functions ideally operate simultaneously without interference. Unfortunately, the system design and implementation associated with time/frequency synchronization is very complex and of high cost. Furthermore, the spectrum utilization is insufficient, which makes this technique attractive only for millimetre-wave applications where a large amount of frequency resource is available.

In yet another prior art solution, an orthogonal frequency division multiplexing (OFDM) technique is introduced into the design of the radar waveforms, making independent and unambiguous range and Doppler processing possible. Such a technique also allows for the simultaneous operation of radar and communication functions. Advantageously, the OFDM technique has a higher spectral efficiency than the spread spectrum technique, less complex receiver architecture due to the avoidance of inter-symbol and inter-channel interferences, and more flexible spectrum adaptation and sub-carrier modulation. Unfortunately though, OFDM systems are more sensitive to Doppler spreads than single-carrier modulated systems, such that the frequency synchronization must be very accurate, resulting in complex signal processing and high costs.

Consequently, there exists a need in the industry to provide an improved radar system with integrated communication functionality.

Summary

In accordance with a broad aspect, the present invention provides a radar system with integrated communication functionality. The radar system comprises a transmitting unit for broadcasting radar signals, the transmitting unit including a first modulator and a second modulator. The first modulator is operative to apply a frequency modulation on an outgoing radar signal, the first modulator providing the outgoing radar signal with a periodic waveform in which each period has a rising edge portion, a falling edge portion and a constant-frequency portion. The second modulator is operative to modulate the outgoing radar signal with an outgoing data signal during the constant-frequency portion of at least one period of the waveform, the radar system being capable to communicate with at least one remote receiver on a basis of the modulation by the second modulator, the transmitting unit being operative to broadcast the modulated outgoing radar signal. The radar system also comprises a receiving unit operative to receive from a remote target echo signals of modulated outgoing radar signals broadcast by the transmitting unit. The receiving unit includes an evaluator unit operative to evaluate each received echo signal in a respective region of at least one of the rising edge portion and the falling edge portion of each period of the waveform, the radar system being capable to detect at least one parameter of the remote target on a basis of the evaluation by the evaluator unit.

Advantageously, the use of such a frequency modulation scheme by the radar system provides the possibility of modulating the outgoing radar signals with information data in a specific timeslot of each period of the waveform, while still allowing for the requisite sensing (or radar) functionality to be performed with the remainder of each period of the waveform. This combined sensing (radar) and communication (radio) functionality is indispensable to the development of future radar systems, for example in the field of future intelligent vehicles.

In accordance with another broad aspect, the present invention provides a method for integrating radar and communication functionality in a radar system, the radar system operative to broadcast outgoing radar signals to at least one remote target. The method includes applying a frequency modulation on an outgoing radar signal, thereby providing the outgoing radar signal with a periodic waveform in which each period has a rising edge portion, a constant-frequency portion and a falling edge portion; using at least the rising edge portion and the falling edge portion of each period of the waveform of the outgoing radar signal as a radar cycle; using the constant-frequency portion of each period of the waveform of the outgoing radar signal as a radio cycle, during which the outgoing radar signal can be modulated with an outgoing data signal; and transmitting the modulated outgoing radar signal to at least one remote receiver.

In accordance with yet another broad aspect, the present invention provides a receiver for a radar system. The receiver includes an input for receiving a modulated radar signal from a remote transmitter, the modulated radar signal being characterized by a periodic waveform in which each period has a rising edge portion, a falling edge portion and a constant frequency portion, as well as an extraction unit operative to extract a data signal from the modulated radar signal during the constant frequency portion of at least one period of the waveform.

In accordance with a further broad aspect, the present invention provides a transmitter for a radar system. The transmitter includes a signal generator for generating an outgoing radar signal and a first modulator operative to apply a frequency modulation on the outgoing radar signal, the first modulator providing the outgoing radar signal with a periodic waveform in which each period has a rising edge portion, a falling edge portion and a constant-frequency portion. The transmitter also includes a second modulator operative to modulate the outgoing radar signal with an outgoing data signal during the constant-frequency portion of at least one period of the waveform, as well as an output for transmitting the modulated outgoing radar signal to at least one remote receiver.

Brief Description of the Drawings

The invention will be better understood by way of the following detailed description of embodiments of the invention with reference to the appended drawings, in which:

Figure 1 is a block diagram of a radar system with integrated communication functionality, according to a non-limiting embodiment of the present invention;

Figure 2 illustrates different possible modulation waveforms for the outgoing radar signals of Fig. 1, according to non-limiting embodiments of the present invention;

Figure 3 illustrates the functionality requirements of future intelligent vehicles;

Figure 4 illustrates a radar-radio modulation scheme for the radar system of Figure 1, in which the radar signal is characterized by a periodic trapezoidal frequency modulated continuous waveform, according to a non-limiting example of implementation of the present invention;

Figure 5 is a block diagram of a transceiver architecture for the radar system, according to a non-limiting example of implementation of the present invention;

Figure 6 is a block diagram of a simulation of the radar system, according to a non-limiting example of implementation of the present invention;

Figure 7 illustrates the simulated modulated signals, in different time intervals, output by the sweeping signal generator module of Fig. 6;

Figure 8 illustrates a comparison between the bit-error-rate (BER) simulation result for the radio mode and a well-known BER theoretical result, according to a non-limiting example of implementation of the present invention;

Figure 9 illustrates a BER measurement setup for the receiving unit of the radar system, according to a non-limiting example of implementation of the present invention;

Figure 10 illustrates a comparison between the BER measurement result for the radio mode and a well-known BER theoretical result, according to a non-limiting example of implementation of the present invention;

Figure 11 illustrates a performance measurement setup for the radar system when in the radar mode, according to a non-limiting example of implementation of the present invention;

Figure 12 illustrates the measured results of the radar system when in the radar mode, according to a non-limiting example of implementation of the present invention;

Figure 13 illustrates a typical waveform of the received echo signal in the case of a static object, according to a non-limiting example of implementation of the present invention; and

Figure 14 illustrates a comparison between the transmitted data, the received data and the recovered data for the radio mode of the radar system, according to a non-limiting example of implementation of the present invention.

Detailed Description

The present invention is directed to a radar system with integrated communication functionality.

In Figure 1, there is shown a simplified block diagram of the radar system 100, according to a non-limiting embodiment of the present invention. The radar system includes a transmitting unit 102 that is operative to broadcast radar signals 104 for echoing by a remote target 106, and a receiving unit 108 that is operative to receive from the remote target 106 echo signals 110 of the radar signals 104. The remote target 106 may take any form, alive or inanimate, stationary or moving, including for example a vehicle, a person, a tree or an animal, among many other possibilities.

As per well known principles of radar functionality, the receipt of echo signals 110 back from the remote target 106 allows the radar system 100 to sense parameters of the remote target 106, such as range, velocity, environment and many other possible parameters known by those skilled in the art.

Note that the transmitting unit 102 and the receiving unit 108 may be implemented by a same device (e.g. a transceiver) or by two separate devices, without departing from the scope of the present invention. Furthermore, the transmitting unit 102 and receiving unit 108 may be implemented on a same platform or on separate platforms, whether designed in hardware, software, firmware or a combination thereof, without departing from the scope of the present invention.

Specific to the present invention, the transmitting unit 102 includes a first modulator 112 that applies a frequency modulation on each outgoing radar signal

104, in order to provide the outgoing radar signals 104 with a periodic waveform in which each period has a rising edge portion, a falling edge portion and at least one constant-frequency portion.

Figure 2 illustrates examples of different possible modulation waveforms that can be applied by the first modulator 112 on the outgoing radar signals 104. Many other waveform shapes having the requisite rising edge portion 200, falling edge portion 202 and constant-frequency portion 204 can also be contemplated and could be applied by the first modulator 112 without departing from the scope of the present invention.

The transmitting unit 102 also includes a second modulator 114 that is operative to modulate an outgoing radar signal 104 with an outgoing data signal 116 during at least one of the constant-frequency portions of at least one period of the waveform, whereby the radar system 100 is capable to send information to at least one remote receiver (not shown) on a basis of this modulation by the second modulator 114. Each such remote receiver would be operative to receive these modulated outgoing radar signals 104 transmitted by the radar system 100 and to extract therefrom the outgoing data signals 116.

In a specific, non-limiting example, the second modulator 114 uses one of a combination of a phase-shift keying (PSK) modulation scheme, a frequency-shift keying (FSK) modulation scheme and an amplitude-shift keying (ASK) modulation scheme. Note however that other possible modulation schemes and combinations thereof may be applied by the second modulator 114 for modulating an outgoing radar signal with information data without departing from the scope of the present invention.

Note that a remote target 106 may include a remote receiver. In a specific, non-limiting example, the remote target 106 is a vehicle with a built-in receiver adapted to receive and process the modulated outgoing radar signals 104 broadcasted by the radar system 100.

The receiving unit 108 of the radar system 100 includes an evaluator unit 118 that is operative to evaluate each received echo signal 110 in a respective region of at least one of the rising edge portion and the falling edge portion of each period of the waveform, whereby the radar system 100 is capable to detect at least one parameter of the remote target 106 on a basis of this evaluation by the evaluator unit 118.

The receiving unit 108 is also operative to receive a modulated incoming radar signal from a remote transmitter (not shown), where this modulated incoming radar signal is characterized by the same properties as that of the modulated outgoing radar signals 104 (i.e. periodic frequency waveform that may be modulated with a data signal in a specific period timeslot). The receiving unit 108 therefore also includes an extraction unit 120 that is operative to process the modulated incoming radar signal and to extract therefrom an incoming data signal during the respective constant-frequency portion of a period of the waveform. As such, in addition to being able to transmit information data to one or more remote receivers, the radar system 100 is able to receive information data from one or more remote transmitters.

Thus, the radar system 100 implements a radar-communication modulation scheme that uses at least the rising edge portion 200 and the falling edge portion 202 of each period of the waveform of a radar signal as a radar cycle, while using the constant-frequency portion 204 of each period as a radio cycle during which the radar signal may be modulated with a data signal. In the modulation waveform examples shown in Figure 2, the solid line of each waveform represents the radar cycle, while the dashed line represents the radio cycle.

Each cycle occupies a respective adjustable time interval within the waveform period of the modulated outgoing radar signal 104, where the time interval of a cycle can be adjusted down to 0 seconds or up to a maximum corresponding to the entire duration of a period. In a specific example of implementation, the first modulator 112 of the transmitting unit 102 is adapted to set the time intervals of the radio and radar cycles prior to applying the predefined frequency modulation on an outgoing radar signal. It therefore becomes possible to set the respective time interval (or duration) of one of the radio and radar cycles to 0 seconds, thereby eliminating one of radio and radar functionality from the modulated outgoing radar signal 104 for a specific application.

Advantageously, the use of such a frequency modulation scheme by the radar system 100 provides the possibility of modulating the outgoing radar signals with information data in a specific timeslot of each period of the waveform, while still allowing for the requisite sensing (or radar) functionality to be performed with the remainder of each period of the waveform. This combined sensing (radar) and communication (radio) functionality is indispensable to the development of future radar systems, for example in the field of future intelligent vehicles. Furthermore, the radar-radio integration technique provided by the present invention is of low complexity with versatile functionality and can be realized using a same transceiver hardware platform, at a much lower cost than when realized by two independent and separate systems.

In the specific example of implementing the radar system of the present invention in an automobile, it becomes possible to exchange video between cars, receive beacon communications at a car, implement wireless Internet among the cars, receive road conditions at a car, avoid collisions and overcome poor driving conditions (e.g. fog), among many other possibilities.

Note that, although examples of implementation of the invention will be described herein with reference to the automotive industry and, more specifically, with reference to the field of future intelligent transportation systems, it should be understood that the scope of the invention encompasses various other industries and applications as well, including for example military applications and mobile Internet applications.

In a particular, non-limiting embodiment of the present invention, the first modulator 112 of the transmitting unit 102 applies a predefined frequency modulation on each outgoing radar signal 104, in order to provide the outgoing radar signals 104 with a periodic waveform in which each period has a rising edge portion, a first constant-frequency portion, a falling edge portion and a second constant-frequency portion (see for example the waveforms of Figures 2(c), 2(d) and 4(a)). Depending on the particular waveform geometry, one or both of the constant-frequency portions may be used for the radio cycle of each period. Furthermore, the radar cycle may include a constant-frequency portion, in addition to the rising edge and falling edge portions, in which case the evaluator unit 108 of the receiving unit 108 may be operative to evaluate a received echo signal 110 in a respective region of the respective constant-frequency portion as well.

It follows that the modulation waveform applied by the first modulator 112 may include two or more constant-frequency portions per period, without departing from the scope of the present invention.

Note that, when the evaluator unit 108 evaluates a received echo signal 110 in a respective region of at least two of the rising edge portion, the falling edge portion and the constant-frequency portion of the radar cycle of each period, it is possible to evaluate both the velocity and range of the remote target 106, as discussed in further detail below.

In a specific, non-limiting example of implementation of the present invention, the radar system 100 is implemented as a multifunctional transceiver for an intelligent transportation system. Figure 3 illustrates the well known functionality requirements of future intelligent vehicles, including both radar (sensing) mode shown in Fig. 3a and radio (communication) mode shown in Fig. 3b.

In order to reduce system cost and design complexity, and also to minimize interference between radar and radio signals as well as to increase system flexibility and reliability, a novel radar-radio modulation scheme composed of a radar cycle and a radio cycle arranged sequentially in the time domain has been designed. The radar cycle utilizes a trapezoidal frequency modulation continuous wave (TFMCW) modulation scheme and the radio cycle is located in a constant-frequency period of the waveform. In this way, both radar and radio functions can be realized by making use of a single transceiver platform. As will be discussed in further detail below, an experimental system prototype was studied and developed for use as a 5.9-GHz Dedicated Short Range Communication (DSRC) system of the Federal Communications Commission (FCC) of the United States. Measured results of the system prototype show very good performance. The transceiver system embeds both radar and radio functions within the same circuitry and it provides a cost-effective solution for applications in future intelligent vehicles and transportation systems.

Figure 4 shows the above-mentioned two cycles of a periodic trapezoidal frequency modulation waveform 400 for the multifunctional transceiver, according to the non-limiting example of implementation of the present invention. In Fig. 4a, a solid line represents the transmitted signal while a dashed line represents for the received signal. The beat frequencies obtained at the output of the receiving front-end are depicted in Fig. 4b.

In Fig. 4a, each operation cycle of *7* is divided into two time slots which are dedicated to the radar mode and the radio mode, respectively. The radar cycle 402 has a total time interval of 3 7s, including a leading edge portion 406 (an up-chirp), a first constant-frequency portion 408 (at *ft)* and a falling edge portion 410 (a down-chirp), each having the same duration of 7s. In the up-chirp 406, the frequency is linearly swept from f_1 to f_2 while it is linearly decreased from f_2 to f_1 in the down-chirp 410. Immediately following the radar cycle 402, the radio cycle 404 is located in the second constant-frequency portion 412 (at f_1), whose duration is set to *Ts* for the purpose of simplicity and demonstration in the experimental system. In fact, all possible time durations may be adaptively deployed for different application scenarios.

It is important to note that the time intervals or durations of each cycle 402, 404 within the waveform period are adjustable, all the way down to 0 seconds. In the case of a radar or radio cycle duration that is set to 0 seconds, this would correspond to a waveform 400 in which radar or radio functionality is eliminated.

In the non-limiting example of implementation shown in Fig. 4a, the radar cycle 402 is formed of the up-chirp portion 406, the first constant-frequency portion

408 (at f_2) and the down-chirp portion 410, while the radio cycle 404 consists of the second constant-frequency portion 412 (at f_1), where each period T of the waveform begins with the up-chirp portion. Alternatively, each period T of the waveform may begin with the down-chirp portion, in which case the radar cycle would be formed of the down-chirp portion 410, the second constant-frequency portion 412 (at f_1) and the up-chirp portion 406, while the radio cycle would consist of the first constant-frequency portion 408 (at f_2).

Note that, in a variant embodiment of the present invention, the radio cycle may precede the radar cycle within each period of the trapezoidal waveform. Taking for example the schematic of Fig. 4a, each period T could be shifted to the right by a duration of T_s along the time axis. In this case, the first constant-frequency portion 408 (at f_2) would be used as the radio cycle, while the falling edge portion 410 (down-chirp), second constant-frequency portion 412 (at f_1) and rising edge portion 406 (up-chirp) that follow the first constant-frequency portion 408 would be used as the radar cycle. In another example, each period T could be shifted to the right by a duration of $3T_s$ along the time axis, in which case each period T of the waveform would begin with the second constant-frequency portion 412 (at f_1), which would be used as the radio cycle, while the up-chirp portion 406, the first constant-frequency portion 408 (at f_2) and the down-chirp portion 410 that follow the second constant-frequency portion 412 would be used as the radar cycle within the respective period T.

As shown in Fig. 4b, in the radar mode, one beat frequency can be obtained in each interval of T_s, which is further denoted respectively as f_{bU}, f_{bC}, and f_{bD}. A quadrature demodulator is implemented in the present system, in order to determine the sign of the beat frequencies, as will be discussed below. Simple expressions for those three beat frequencies can be derived as follows,

$$\begin{cases} f_{bU} = f_{vU} + f_{rU} = f_1 2v/c_0 + K_U 2R_U/c_0 \\ f_{bC} = f_{vC} = f_2 2v/c_0 \\ f_{bD} = f_{vD} - f_{rD} = f_2 2v/c_0 - K_D 2R_D/c_0 \end{cases} \quad (1)$$

where f_{vi} (i = U, C and D) are the beat frequencies related to target velocity v (assumed to be constant in this proof-of-concept study) while f_{ri} (i = U and D) are the beat frequencies related to initial target range R_i (i = U and D) at the beginning of the up-chirp and the down-chirp, respectively. K_U and K_D are the up-chirp rate and the down-chirp rate, respectively, and they are set to be equal in the experimental system.

It is indicated in (1) that after the up-chirp and the constant-frequency portion, we can find the target velocity v and the initial target range R_U. Additionally, the initial target range R_D can be calculated after the down-chirp. In the detection of a multi-target environment, the total radar cycle can be used to determine the real targets and eliminate the ghost targets. In order to enhance the resolving capability in a low-mobility environment, the chirp rate can also be made variable in a number of consecutive operation cycles.

In the radio mode, the output frequency of the transmitted signal is kept constant over the entire radio cycle, and therefore the transmitted signal is actually a constant carrier which can be modulated by information data using modulation techniques such as ASK, FSK, PSK, or even a number of combinations among them.

The radar mode and the radio mode can also operate in a joint manner. For example, the target velocity and range that are obtained in the radar mode can be used in the radio mode to compensate the Doppler spreading caused by the mobility of the radio units. On the other hand, by making use of the radio communication capability, different onboard transceivers can exchange such information data as velocity and range, and as a result, a radar network is formed. The benefits of such data fusion platform are seen in its range increment and accuracy enhancement of the target finding.

The system clocks of different onboard transceivers in a network environment can be synchronized either by the timing information of global positioning system (GPS), or by other techniques such as network time protocol (NTP). After the synchronization, these transceivers will have the same time reference. Note that in the present system, all the transceivers use the same frequency for data communication.

In the radio cycle, each onboard unit works in a time division duplex (TDD) mode, which means it cannot transmit and receive data simultaneously. Let us take now two onboard units for example. If unit 1 transmits data to unit 2, the instant output sweeping signal on unit 2 is unmodulated and it is then used as a reference signal for demodulating the received signal from unit 1. In a multi-user environment, time division multiple access (TDMA) can be applied.

To prove the proposed system concept, an experimental system prototype was designed over the 5.9-GHz band that has been assigned for DSRC applications by FCC of the United States. DSRC is a short-to-medium range wireless protocol in the application scenarios of roadside-to-vehicle and vehicle-to-vehicle communications, and this term has also been identified with dedicated Intelligent Transportation System (ITS) spectrum allocations in various regions of the world. According to the FCC's DSRC ruling, the total 75 MHz spectrum is divided into eight channels, including one 5 MHz channel and seven 10 MHz channels that consist of one control channel and six service channels (see Table I below). However, channels CH174 and CH176 as well as CH180 and CH182 can be combined to provide two channels (CH175 and CH181) with 20 MHz bandwidth. Moreover, the maximum radiation power for DSRC devices (Class-D) is 28.8 dBm while the maximum Effective Isotropic Radiation Power (EIRP) cannot go beyond 44.8 dBm.

TABLE I: Channel Allocation of DSRC

		CH175			CH181		
Reserved	CH172	CH174	CH176	CH178	CH180	CH182	CH184
	Service (Vehicle-to-Vehicle)	Service	Service	Control	Service	Service	Service (High Power)
5 MHz	10 MHz	10 MHz	10 MHz	10 MHz	10 MHz	10 MHz	10 MHz

5850 5855 5865 5875 5885 5895 5905 5915 5925

Based on the FCC's rules and practical requirements of automotive detection, a series of system specifications listed in Table II below are defined for the present radar/radio data fusion system.

TABLE II: System Specifications for the Experimental DSRC Prototype

Mode	Specifications	Values
	Frequency Range	5850 to 5925 MHz
	Channel Bandwidth	20 MHz

Radar	Maximum Detectable Range	300 m
	Range Resolution	7.5 m
	Maximum Detectable Velocity	±250 km/h (64.44 m/s)
	Velocity Resolution	±10 km/h (2.78 m/s)
	Probability of False Alarm	1e-6
	Probability of Detection	0.9
Radio	Maximum Communication Range	1000 m
	Maximum Data Rate	10 Mbps
	Bit Error Rate for BPSK	1e-6

In the radar mode, the range resolution ΔR is related to sweeping bandwidth ΔB by,

$$\Delta R = \frac{c}{2\Delta B} \qquad (2)$$

From the above expression, it can be seen that the greater the available sweeping bandwidth, the smaller the range resolution that can be provided by the radar system. For example, if the full bandwidth of the FCC-defined DSRC is used for frequency sweeping, the range resolution will be reduced down to 2 m. Furthermore, if the present system is implemented in another frequency band, such as the license-free ISM (Industrial, Scientific and Medical) band at 24 GHz, the available bandwidth of up to 250 MHz can provide a range resolution easily going down to 0.6 m.

A link budget analysis is carried out for both radar and radio functions, respectively. The analysis results are listed in Table III below. Note that in Table III, certain system parameters such as transmitting power and gains of both transmitting and receiving antennas, as well as receiver noise figure, are set to be the same for both radar and radio modes because the same transceiver is used.

TABLE III: Link Budget Analysis for Both Radar and Radio Modes

Parameters	Radar Mode	Radio Mode
Function Range	300 m	1000 m
Total Cycle	60 ms	20 ms
Receiver Bandwidth	100 KHz	20 MHz
Transmitting Power	28.8 dBm	28.8 dBm
Transmitting Antenna Gain	16 dBi	16 dBi
Path Loss	194.8 dB	107.8 dB
Radar Cross Section Gain of a Car	36.8 dB	—
Receiving Antenna Gain	16 dBi	16 dBi
Signal Power at the Receiver Input	-97.2 dBm	-47.0 dBm
Noise Power at the Receiver Input	- 124.0 dBm	- 101.0 dBm
SNR at the Receiver Input	26.8 dB	54.0 dB
Receiver Noise Figure	5 dB	5 dB

SNR at the Receiver Output	21.8 dB	49.0 dB
Data Rate	—	10 Mbps
EtJNo	—	52.0 dB
Required SNR *(EtJNo* for radio mode)	15 dB	10.5 dB
Link Margin	6.8 dB	41.5 dB

From Table III, the following observations can be obtained. First of all, despite the presence of a radar cross section (RCS) gain of the target, the path loss of the radar mode is much larger than the radio mode due to the round-trip signal propagation. Therefore, the receiver should be able to compensate the amplitude fluctuation of the incoming signal with a wide range of gain control. Second, since the beat frequencies of the radar mode are much lower than the radio channel bandwidth, tuneable low-pass filters are required for achieving optimal performance. Third, the required signal-to-noise ratio (energy per bit to noise spectrum density *{EtJNo)* ratio in the radio mode) is different for radar and radio functions. The total system link margin is 6.8 dB for the radar mode and 41.5 dB for the radio mode. These link margins include potential implementation loss and atmospheric loss, as well as fading loss that is more pronounced in the case of the radio mode operation.

Figure 5 shows a heterodyne transceiver architecture of the radar-radio data fusion system 500, according to one possible, non-limiting example of implementation. A pair of transmitting and receiving array antennas (502, 504) was designed on the basis of a microstrip technology in order to increase the isolation between the transmitting and receiving channels (501, 503). The modulation waveform can be generated by direct digital synthesizer (DDS) 506 since it can control amplitude, frequency and phase of the output signal very easily and precisely through software programming. Moreover, it is also able to realize different modulation such as ASK, FSK, PSK, and a number of combinations among them.

In the transmitting channel 501, the control signals and the frequency-sweeping signals of the DDS 506, as well as the information data, are sent by an advanced RISC machine (ARM) board 508. Both in-phase (I) and quadrature-phase (Q) components of the modulated signals generated by the DDS 506 are filtered by two low-pass filters (LPFs) 510, respectively, and they are firstly up-converted to intermediate frequency (IF) through a quadrature modulator 512. Subsequently, the IF signal is divided into two portions, one of which is further up-converted to radio frequency (RF) by a single sideband up-converter and radiated by the transmitting array antenna 502 after amplification. An automatic level control (ALC) loop 513 with a gain control range of 5 1.5 dB is introduced in order to provide power back-off capability.

For the receiving channel 503, in the radar cycle, the reflected wave from the target is firstly amplified and down-converted by an image reject mixer 514. Then the reflected signal is demodulated using a quadrature architecture 516 with a reference signal 518 (the other portion of the IF signal) from the transmitter 501. Three beat frequencies are obtained during the up-chirp, the constant-frequency period and the down-chirp, respectively. On the other hand, in the radio cycle, no modulation takes place in the transmitter 501, and thus the reference signal 518 is a pure carrier with constant frequency. In this case, the information data from other transmitting units can be successfully recovered. Both I and Q components of the beat signal are digitized by two analog-to-digital converters (ADCs) 520 embedded within the ARM board 508, which communicates with a laptop 522 through the universal serial bus (USB) interface 524. An automatic gain control (AGC) circuit 525 is implemented after the IF BPF 526 in order to compensate channel attenuation variations for both radio and radar signals. The receiver 503 has an overall gain control capability of 75 dB, with the AGC circuit 525 of 40 dB and the demodulator 516 of 35 dB.

The performance of system 500 is modeled and analyzed using the Ptolemy simulator platform in the Agilent's Advanced Design System (ADS) package, which is based on a time synchronous flow and enables the co-simulation of the digital back-ends together with the RF front-ends. A block diagram of the system simulation 600 is illustrated in Figure 6. In this figure, the modulated waveform is generated by Sweeping Signal Generator module 602. Typical modulated signals at the output of this module 602 are plotted in Figure 7. The transceiver front-end module is designed based on the heterodyne architecture as described in Figure 5.

Note that the channel model is different between the radar mode and the radio mode. In the case of the radio mode, under the condition of additive white Gaussian noise (AWGN) channel, the channel impulse response is simply a Dirac's delta function, of which only two parameters (attenuation and delay) are derived from the communication range. Let us suppose the complex envelope of the transmitted signal is $s(t)e^{j2\pi f_c t}$, the received radio signal can be expressed by

$$r_{radio}(t) = \mathrm{Re}\left\{A_{radio} s\left(t-\tau_{radio}\right) e^{j2\pi f_c\left(t-\tau_{radio}\right)}\right\} \tag{3}$$

where A_{radio} is the amplitude attenuation and τ_{radio} is the time delay of the radio channel response.

When it comes to the radar mode, the received signal of the radar mode can be described by the following expression,

$$r_{radar}(t) = \mathrm{Re}\{A_{radar}e^{-j2\pi f_d t}s(t-\tau_{radar})e^{j2\pi f_c(t-\tau_{radar})}\} \quad (4)$$

where A_{radar} is the amplitude attenuation and τ_{radar} is the time delay of the radar channel response. From (4), it can be found that in addition to the amplitude attenuation and time delay, the frequency of the transmitted signal is shifted by f_d due to the Doppler effect involved in the process. In the simulation of the proposed radar system, the transmitted signal is firstly attenuated and delayed corresponding to the target range, and then, the Doppler frequency shift which is associated with the target velocity is applied to the transmitted signal through a quadrature modulation.

In order to evaluate the performance of the prototype system 600 shown in Figure 6, the output signals of the receiver 503 front-ends are sent to two individual signal processing modules according to the operation mode select signal. The beat frequencies of the radar mode are estimated using a fast Fourier transform (FFT) 604 with zero padding. Simulation results of the radar mode are summarized in Table IV below. In order to reduce the simulation time, the time duration T_s is set to 1 ms. The simulation obtains the same results as the predefined range and velocity, which has effectively demonstrated proper system functionality.

TABLE IV: Simulation Results of the Radar Mode

Simulation parameters		Simulation results	
T_s	1 ms	f_{bU}	37.5 KHz
ΔB	20 MHz	f_{bC}	2.5 KHz

f_{RF}	5875 MHz	f_{bD}	42.5 KHz
R	300 m	Calculated R	300 m
V	63.83 m/s	Calculated V	63.83 m/s

The radio mode is simulated by applying a BPSK modulation 606 with a data rate of 10 Mbps. The bit-error-rate (BER) simulation result for the radio mode is compared with a well-known theoretical result, as shown in Figure 8. It can be seen from Figure 8 that, under the condition of an AWGN (additive white Gaussian noise) channel, the system performance matches well with the theoretical results.

The multifunctional transceiver of the present invention has been prototyped with the use of commercial off-the-shelf components. As discussed above, the major difference between the radar and radio communication systems is their channel models. In one example, a multi-channel emulator (EB Propsim C8) may be used in a measurement setup, together with additional attenuators for extending the attenuation range of the channel emulator.

A non-limiting example of a possible BER measurement setup 900 of the receiver is illustrated in Figure 9. The BER tester 902 (Anritsu MP1630B) generates a 10-Mbps pseudorandom bit sequence (PRBS) with a maximum length of $2^{23}-1$, which is modulated by a vector signal generator 904 (Agilent E4438C) and then fed into the channel emulator 906 (EB Propsim C8) with the configuration of an AWGN channel. The output of the channel emulator 906 is injected into the receiver 908, and then the demodulated signal is sent back to the BER tester 902 which calculates the BER by comparing the transmitted data and the received data. In Figure 9, two signal generators 910, 912 (Anritsu MG3694A and Rohde & Schwarz SMR40) are used as the IF LO and RF LO, respectively.

The measured BER is compared with the theoretical values in Figure 10. It can be observed that they agree pretty well, except for a small deviation at high E_b/N_0 when the measured BER is too low and thus difficult to detect. Another reason is the theoretical BER is derived from the ideal system model, which is not obtainable in this practical implementation due to phase noise degradation and nonlinear distortion involved in the experiments.

The system performance in the radar mode is measured using the test setup 1100 shown in Figure 11. This test setup is arranged in a way corresponding to Figure 5. The modulated signal generated by the DDS 1102 is sent to the transmitter 1104, and then after being amplified and up-converted, the transmitted signal is fed into the channel emulator 1106. The channel emulator 1106 is configured to have a set of time delays from 1500 ns to 5000 ns and a set of target velocities from 10 m/s to 80 m/s, which fully covers the requirements in practical applications. The transmitted signal is attenuated by the channel emulator 1106 and two additional external attenuators 1108. The input signal level at the receiver 1110 is -100 dBm. The received signal is then down-converted and amplified, and sampled by ADCs in the ARM board 1112. The digitized signal is sent to the laptop 1114 for signal processing through the USB interface. The FFT algorithm with zero padding is used to estimate the beat frequencies, from which the time delay and the velocity configured in the channel emulator 1106 are finally calculated.

Table V below lists both the predefined and measured time delays and target velocities, which are also plotted in Figure 12 in order to provide a better visualization. Very good agreement is observed, which fully demonstrates excellent target finding capability of the novel multifunctional transceiver.

TABLE V: Comparison between Predefined and Measured Results

Predefined values		Measured results	
Delays (ns)	Velocities (m/s)	Delays (ns)	Velocities (m/s)
1500	10	1500.95	10.00
1500	20	1503.92	19.84
1500	30	1497.99	29.99
1500	40	1497.99	39.99
1500	50	1495.02	49.99
1500	60	1497.99	59.83
1500	70	1500.95	69.83
1500	80	1497.99	79.83
2000	10	1996.33	10.15
2000	20	1996.33	19.99
2000	30	1996.33	29.99
2000	40	1996.33	39.99
2000	50	1996.33	49.83
2000	60	1996.33	59.83
2000	70	1996.33	69.83
2000	80	1996.33	79.67
3000	10	2995.97	10.00
3000	20	2995.97	19.99
3000	30	2993.00	29.99
3000	40	2993.00	39.99
3000	50	2993.00	49.99
3000	60	2993.00	59.83
3000	70	2998.94	69.83
3000	80	2993.00	79.97
4000	10	4001.55	9.85
4000	20	3995.62	19.99
4000	30	3995.62	29.99
4000	40	3989.69	40.14
4000	50	3992.65	49.99
4000	60	3995.62	59.83
4000	70	3995.62	69.83

4000	80	3995.62	79.67
5000	10	4992.30	10.00
5000	20	4992.30	19.99
5000	30	4989.33	29.99
5000	40	4989.33	39.99
5000	50	4992.30	49.83
5000	60	4992.30	59.83
5000	70	4989.33	69.83
5000	80	4989.33	79.98

The same test setup in Figure 11 is also used to perform an overall evaluation of the system performance. Figure 13 shows a typical waveform of the received signal in the case of a static object. The top and middle waveforms 1300, 1302 represent the output signals of the receiver front-end at both I and Q channels, respectively. The bottom waveform 1304 shows the mode select signal of the DDS 1102.

In the radio mode, the ADCs are running at four times of the bit rate in the implementation. The Gardner synchronization algorithm is applied for three reasons. The first is that the ADCs' clock is not synchronized with the received data sequence. The second is the existence of the ADC time jitter. The third is that a timing recovery loop in the synchronization algorithm can provide the best timing for sampling the matched filter output at the peaks, where the signal-to-noise ratio is the highest and the signal detection will have the lowest error. The recovered data is compared together with the transmitted data and the received data in Figure 14, from which it can be seen that the transmitted data can be successfully recovered.

The above-described transceiver platform with integrated radar and radio functionality is incredibly versatile and reconfigurable through software programming. Its various components can be implemented in hardware, firmware and/or software, without departing from the scope of the present invention. In one possible variant, software can be used by the transmitting unit 102 of the radar system 100 to control and/or define programming of the frequency modulation waveform, and specifically of its timeslots, in a non-uniform format. This would provide the radar system 100 with a mechanism for secure transmission of the outgoing radar signals.

Although various embodiments have been illustrated, this was for the purpose of describing, but not limiting, the present invention. Various possible modifications and different configurations will become apparent to those skilled in the art and are within the scope of the present invention, which is defined more particularly by the attached claims.

What is claimed is:

1. A radar system with integrated communication functionality, said radar system comprising:

   a. a transmitting unit for broadcasting radar signals, said transmitting unit including:

      i. a first modulator operative to apply a frequency modulation on an outgoing radar signal, said first modulator providing said outgoing radar signal with a periodic waveform in which each period has a rising edge portion, a falling edge portion and a constant-frequency portion; and

      ii. a second modulator operative to modulate said outgoing radar signal with an outgoing data signal during said constant-frequency portion of at least one period of the waveform, said radar system being capable to communicate with at least one remote receiver on a basis of said modulation by said second modulator;

      iii. said transmitting unit being operative to broadcast said modulated outgoing radar signal;

   b. a receiving unit operative to receive from a remote target echo signals of modulated outgoing radar signals broadcast by said transmitting unit, said receiving unit including an evaluator unit operative to evaluate each received echo signal in a respective region of at least one of said rising edge portion and said falling edge portion of each period of the waveform, said radar system being capable to detect at least one parameter of the remote target on a basis of said evaluation by said evaluator unit.

2. A radar system as defined in claim 1, wherein said evaluator unit is operative to evaluate each received echo signal in a respective region of each of said rising edge portion and said falling edge portion of each period of the waveform, whereby said at least one parameter of the remote target detected by said radar system on a basis of said evaluation includes a velocity and a range of the remote target.

3. A radar system as defined in claim 1, wherein said constant-frequency portion is a first constant-frequency portion, said first modulator providing said outgoing radar signal with a periodic waveform in which each period has said rising edge portion, said falling edge portion, said first constant-frequency portion and a second constant-frequency portion.

4. A radar system as defined in claim 3, wherein said evaluator unit is further operative to evaluate each received echo signal in a respective region of said second constant-frequency portion, said at least one parameter of the remote target including a velocity and a range of the remote target.

5. A radar system as defined in claim 3 or 4, wherein said periodic waveform is a periodic trapezoidal waveform.

6. A radar system as defined in claim 1, wherein said second modulator modulates said outgoing radar signal with an outgoing data signal during said constant-frequency portion of at least one period of the waveform by using one or a combination of a phase-shift keying modulation scheme, a

frequency-shift keying modulation scheme and an amplitude-shift keying modulation scheme.

7. A radar system as defined in any one of claims 1 to 6, wherein said transmitting unit of said radar system transmits said modulated outgoing radar signal to the at least one remote receiver, each remote receiver operative to receive said modulated outgoing radar signal from said radar system and to extract therefrom said outgoing data signal.

8. A radar system as defined in claim 1, wherein said receiving unit of said radar system is further operative to receive a modulated incoming radar signal from a remote transmitter, said modulated incoming radar signal being characterized by said periodic waveform, said receiving unit operative to extract an incoming data signal from said modulated incoming radar signal during said constant-frequency portion of at least one period of the waveform.

9. A radar system as defined in any one of claims 1 to 8, wherein said transmitting unit and said receiving unit are implemented by a single transceiver.

10. A radar system as defined in claim 9, wherein said transmitting unit and said receiving unit are implemented within a single platform.

11. A radar system as defined in claim 1, wherein each period of said periodic waveform is characterized by a radar cycle and a radio cycle, said radar cycle including said rising edge portion and said falling edge portion, said radio cycle including said constant-frequency portion.

12. A radar system as defined in claim 11, wherein each of said radio cycle and said radar cycle occupies a respective adjustable time interval within the period, said first modulator adapted to set the time intervals of said radio and radar cycles prior to applying said frequency modulation on said outgoing radar signal.

13. A radar system as defined in claim 12, wherein the respective time interval of one of said radio and radar cycle is set to 0 seconds for eliminating one of radio and radar functionality from said modulated outgoing radar signal.

14. A method for integrating radar and communication functionality in a radar system, the radar system operative to broadcast outgoing radar signals to at least one remote target, said method comprising:

a. applying a frequency modulation on an outgoing radar signal, thereby providing the outgoing radar signal with a periodic waveform in which each period has a rising edge portion, a constant-frequency portion and a falling edge portion;

b. using at least the rising edge portion and the falling edge portion of each period of the waveform of the outgoing radar signal as a radar cycle;

c. using the constant-frequency portion of each period of the waveform of the outgoing radar signal as a radio cycle, during which the outgoing radar signal can be modulated with an outgoing data signal; and

d. transmitting the modulated outgoing radar signal to at least one remote receiver.

15. A method as defined in claim 14, further comprising modulating the outgoing radar signal with an outgoing data signal during at least one radio cycle, whereby said radar system communicates information to the at least one remote receiver on a basis of said modulating during the at least one radio cycle.

16. A method as defined in claim 15, wherein said modulating the outgoing radar signal with an outgoing data signal during at least one radio cycle is performed using one or a combination of a phase-shift keying modulation scheme, a frequency-shift keying modulation scheme and an amplitude-shift keying modulation scheme.

17. A method as defined in any one of claims 14 to 16, further comprising:

a. receiving from a particular one of the at least one remote target an echo signal of the outgoing radar signal;

b. evaluating the received echo signal in a respective region of at least one of the rising edge portion and the falling edge portion of each period of the waveform for detecting at least one parameter of the particular remote target.

18. A method as defined in any one of claims 14 to 16, further comprising:

a. receiving at the radar system a modulated incoming radar signal from a remote transmitter, the modulated incoming radar signal being characterized by said periodic waveform in which each period includes the radar cycle and the radio cycle; and

b. extracting an incoming data signal from the modulated incoming radar signal during at least one radio cycle of the waveform, thereby receiving information from the remote transmitter.

19. A receiverfor a radar system, said receiver comprising:

a. an input for receiving a modulated radar signal from a remote transmitter, said modulated radar signal being characterized by a periodic waveform in which each period has a rising edge portion, a falling edge portion and a constant frequency portion;

b. an extraction unit operative to extract a data signal from said modulated radar signal during said constant frequency portion of at least one period of the waveform.

20. A transmitter for a radar system, said transmitter comprising:

a. a signal generator for generating an outgoing radar signal;

b. a first modulator operative to apply a frequency modulation on said outgoing radar signal, said first modulator providing said outgoing radar signal with a periodic waveform in which each period has a rising edge portion, a falling edge portion and a constant-frequency portion; and

c. a second modulator operative to modulate said outgoing radar signal with an outgoing data signal during said constant-frequency portion of at least one period of the waveform;

d. an output for transmitting said modulated outgoing radar signal to at least one remote receiver.

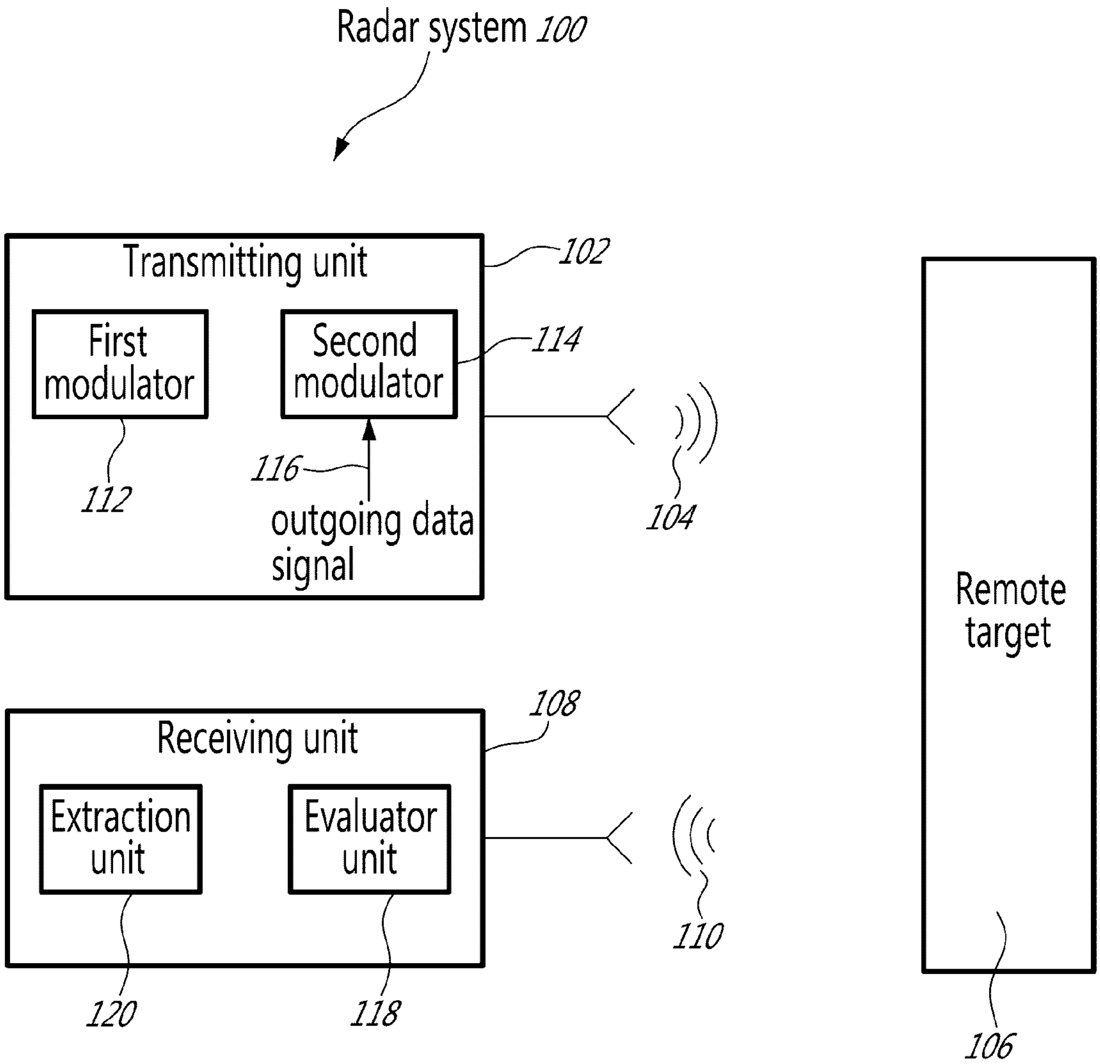
Radar system 100
Transmitting unit
102
First modulator
Second modulator
114
116
112
outgoing data signal
104
Remote target
Receiving unit
108
Extraction unit
Evaluator unit
110
120
118
106

FIG. 1

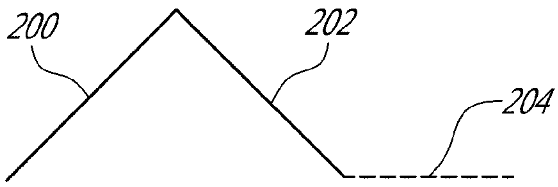

FIG. 2a

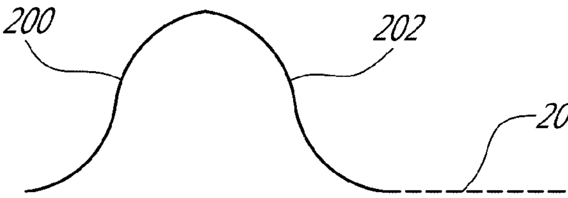

FIG. 2b

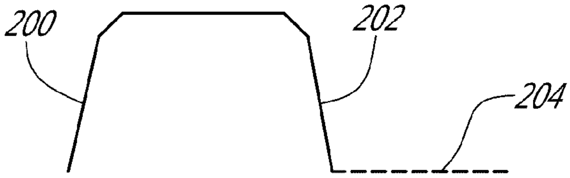

FIG. 2c

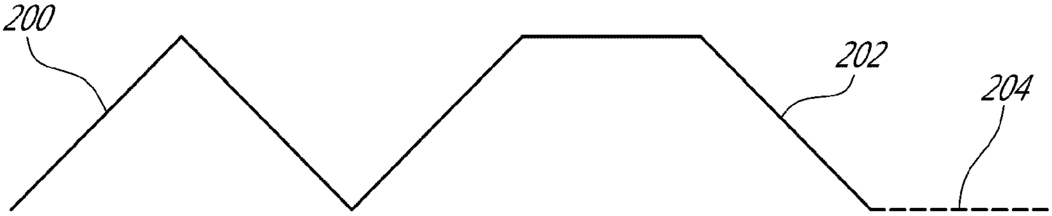

FIG. 2d

FIG. 3a

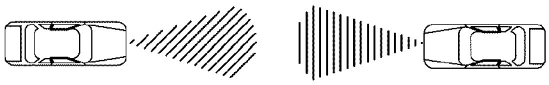

FIG. 3b

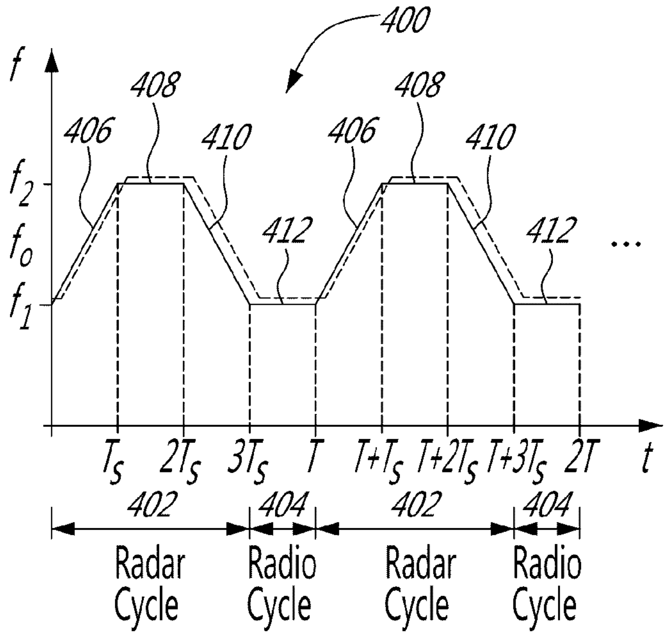

FIG. 4a

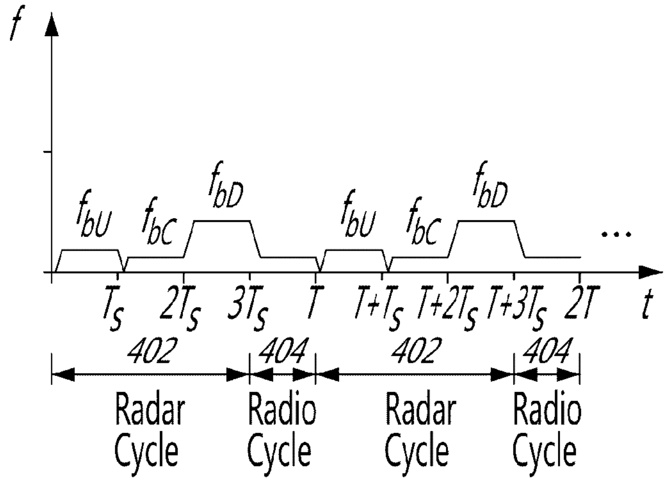

FIG. 4b

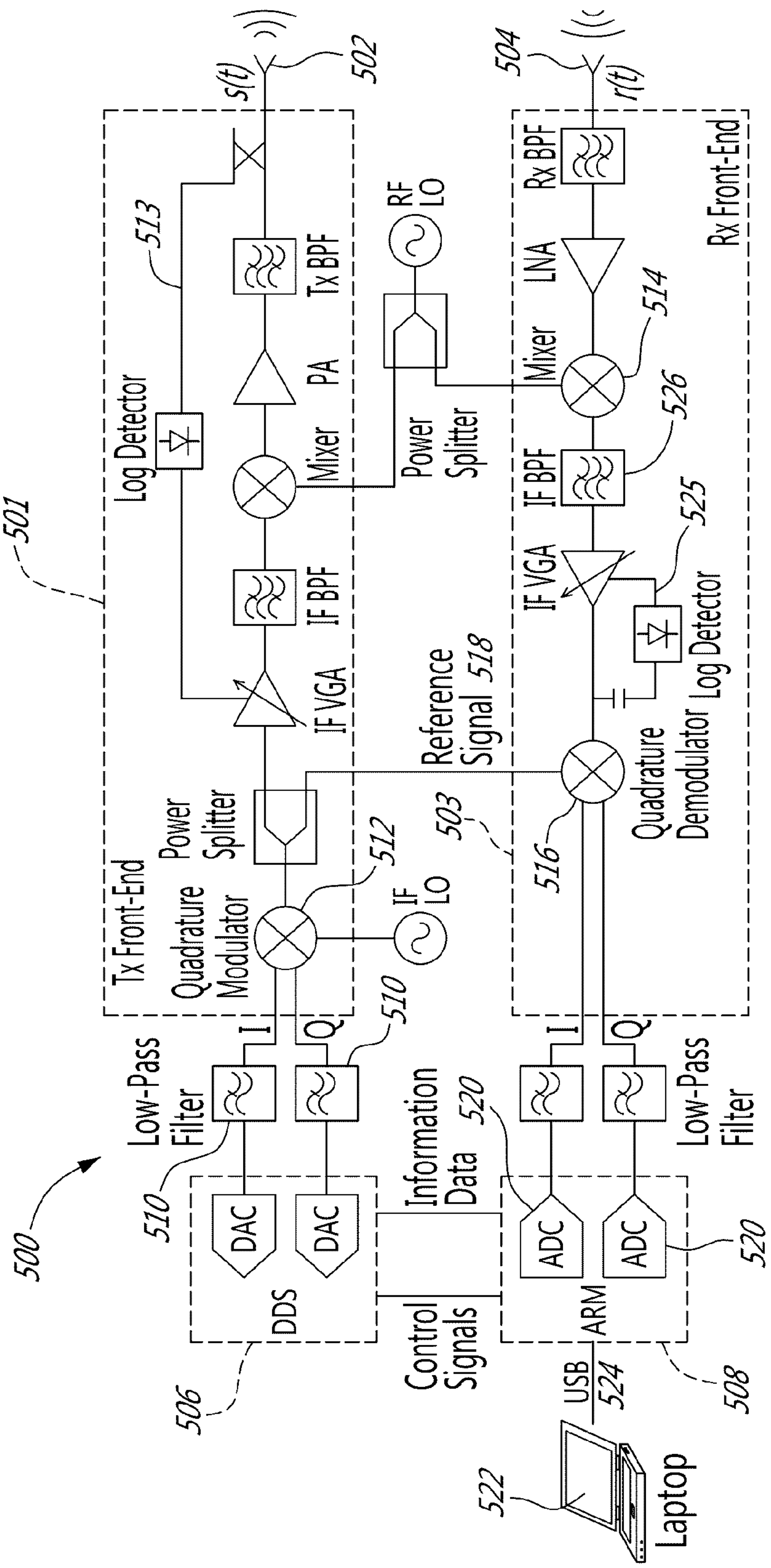
500
501
502
503
504
506
508
510
512
513
514
516
518
520
522
524
525
526
s(t)
r(t)
Tx Front-End
Rx Front-End
Quadrature Modulator
Quadrature Demodulator
Power Splitter
IF VGA
IF BPF
Mixer
PA
Tx BPF
Log Detector
RF LO
IF LO
LNA
Rx BPF
Reference Signal
Low-Pass Filter
I
Q
DAC
DDS
ADC
ARM
Information Data
Control Signals
USB
Laptop

FIG - 5

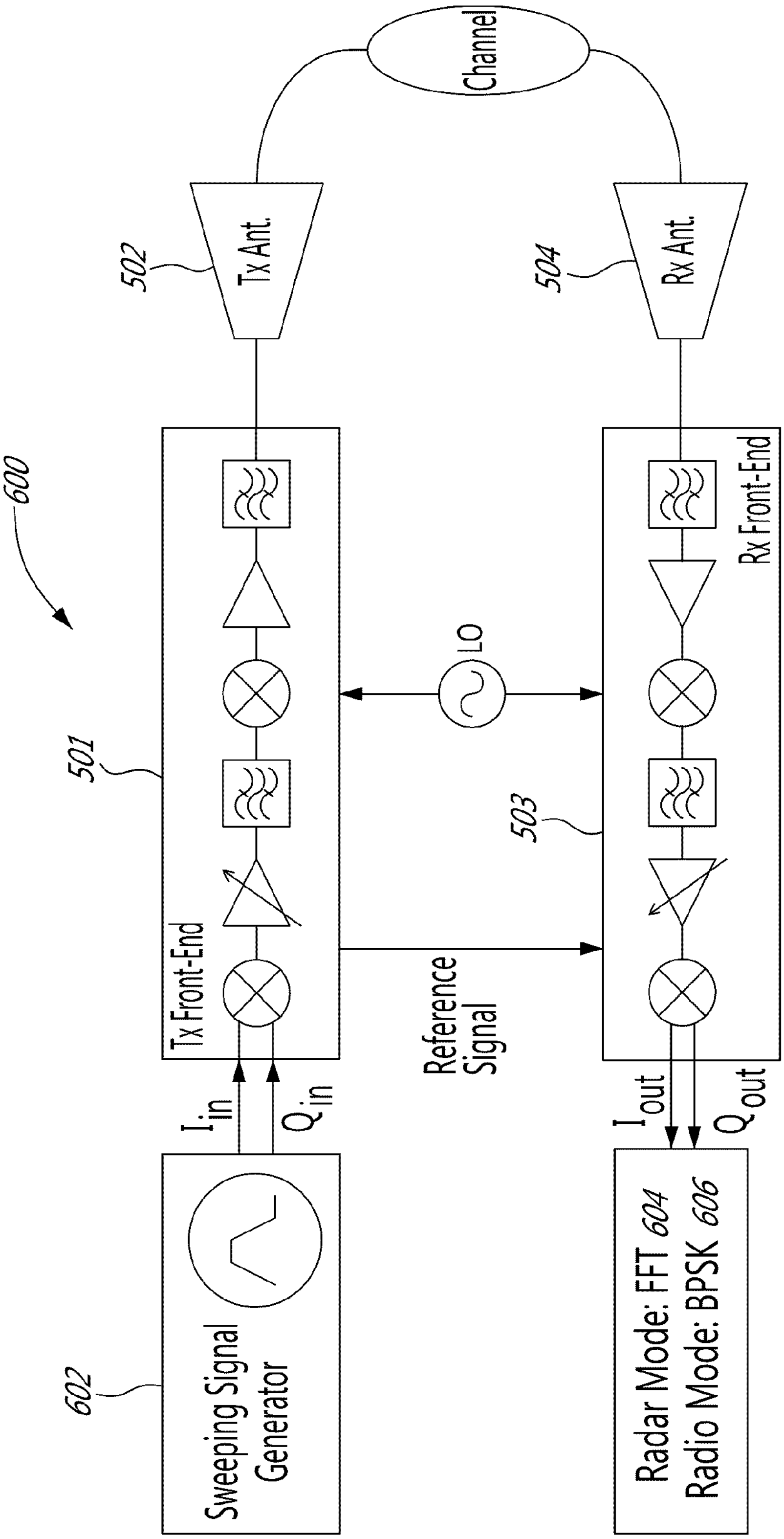
600
Channel
502
Tx Ant.
504
Rx Ant.
501
Tx Front-End
503
Rx Front-End
LO
Reference Signal
I_{in}
Q_{in}
I_{out}
Q_{out}
602
Sweeping Signal Generator
Radar Mode: FFT 604
Radio Mode: BPSK 606

FIG. 6

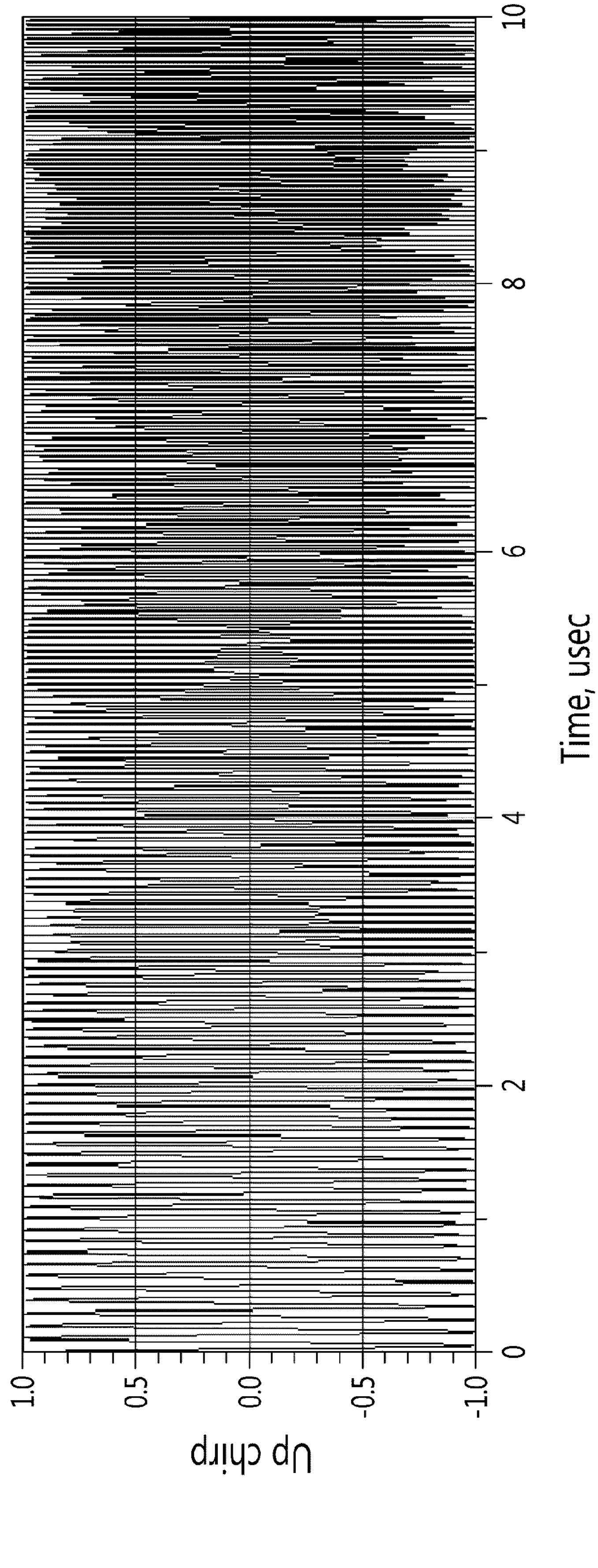

FIG - 7a

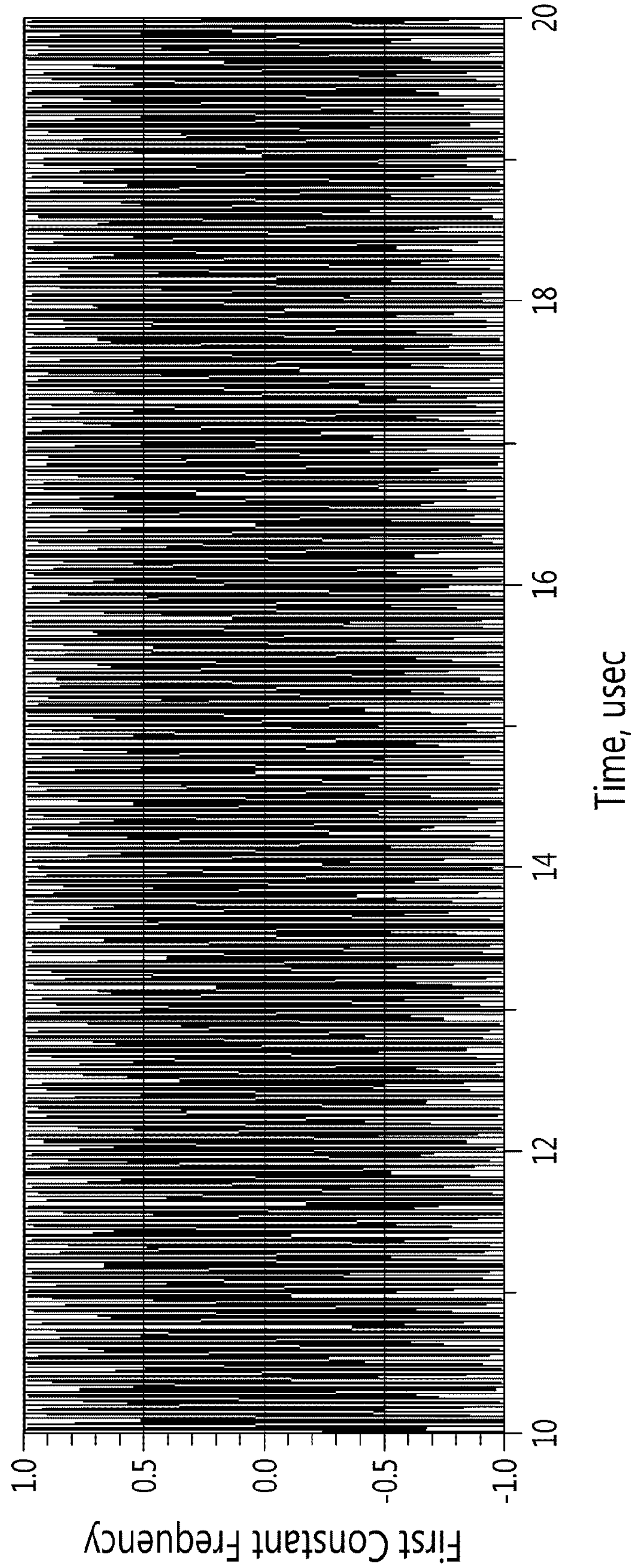
First Constant Frequency
1.0
0.5
0.0
-0.5
-1.0
10
12
14
16
18
20
Time, usec

FIG. 7b

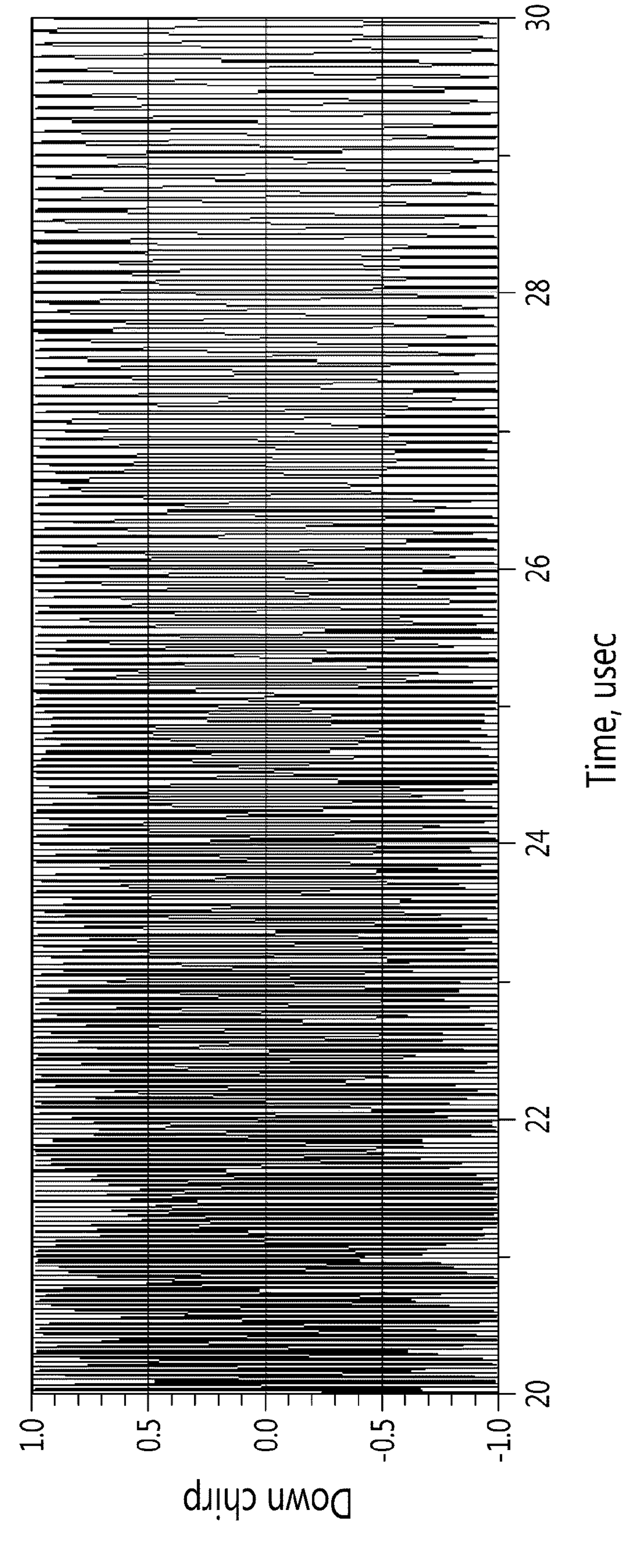

FIG - 7C

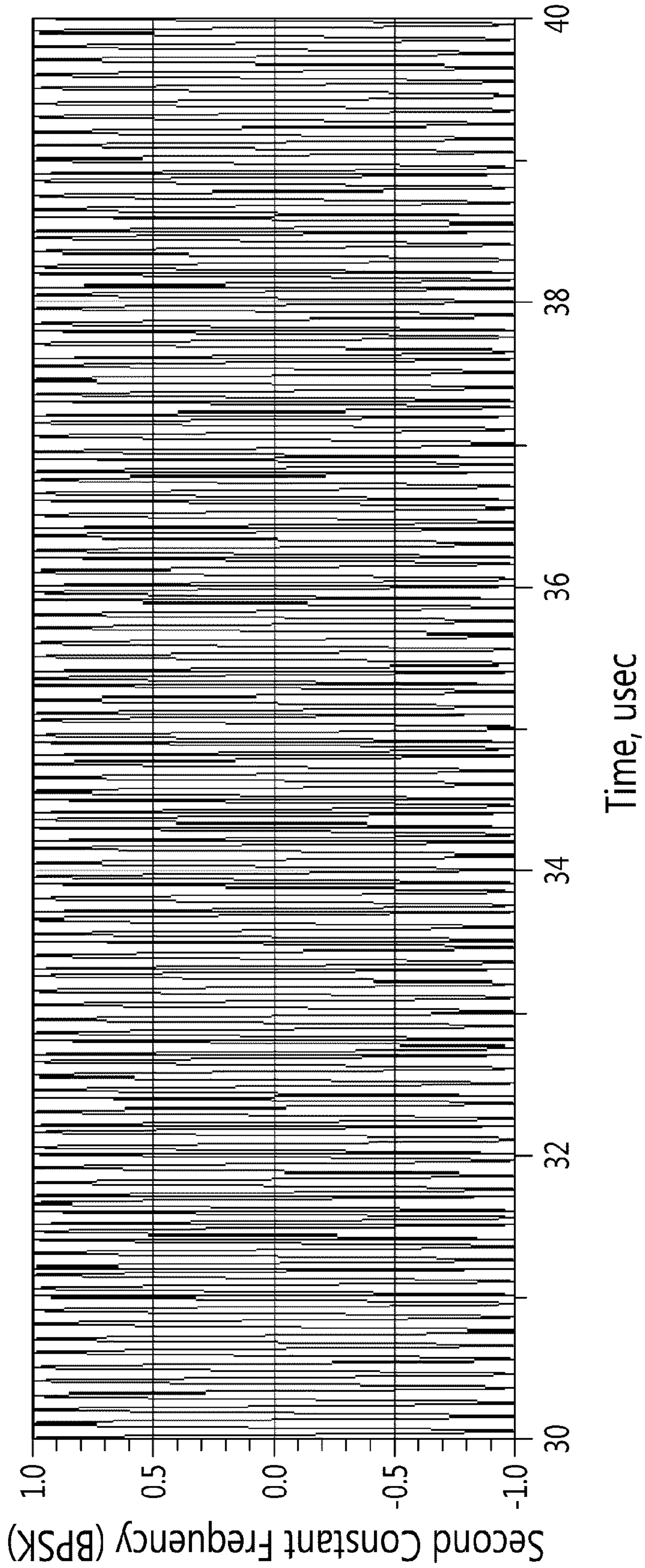
Second Constant Frequency (BPSK)
1.0
0.5
0.0
-0.5
-1.0
30
32
34
36
38
40
Time, usec

FIG - 7d

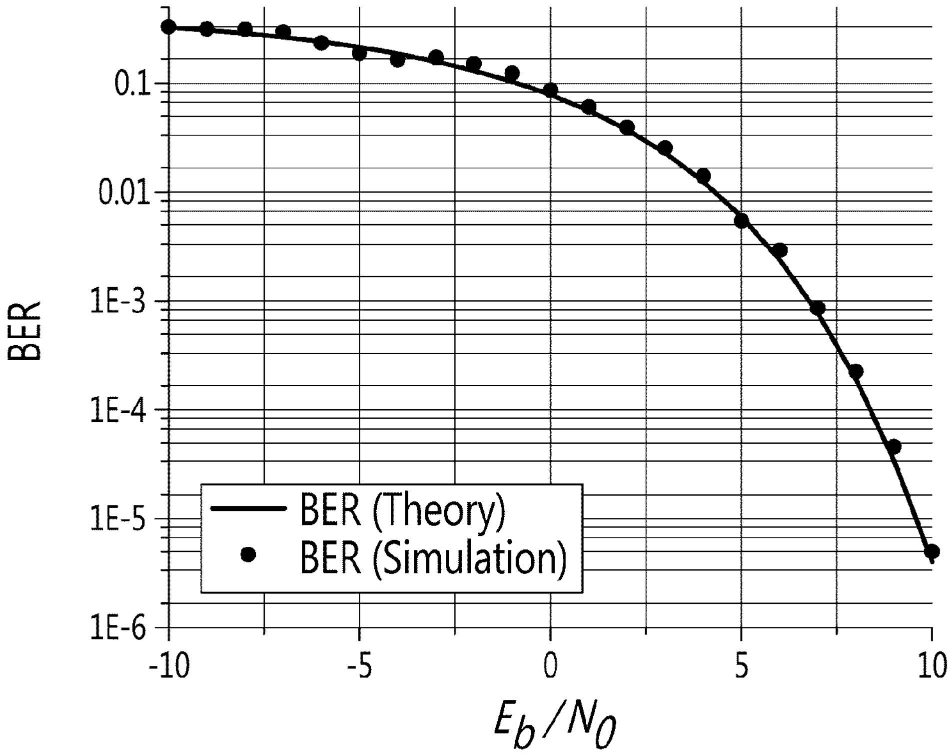
0.1
0.01
1E-3
1E-4
1E-5
1E-6
BER
-10
-5
0
5
10
E_b/N_0
BER (Theory)
BER (Simulation)

FIG. 8

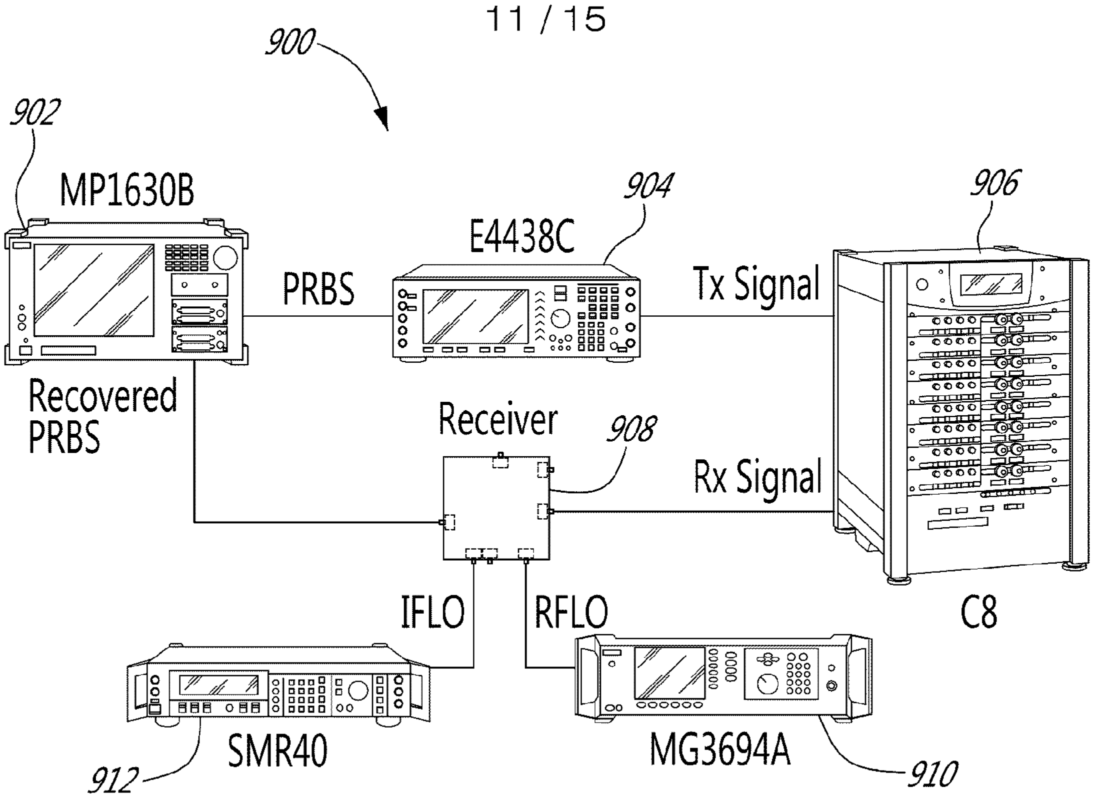
900
902
MP1630B
PRBS
E4438C
904
906
Tx Signal
Recovered
PRBS
Receiver
908
Rx Signal
IFLO
RFLO
C8
SMR40
MG3694A
912
910

FIG. 9

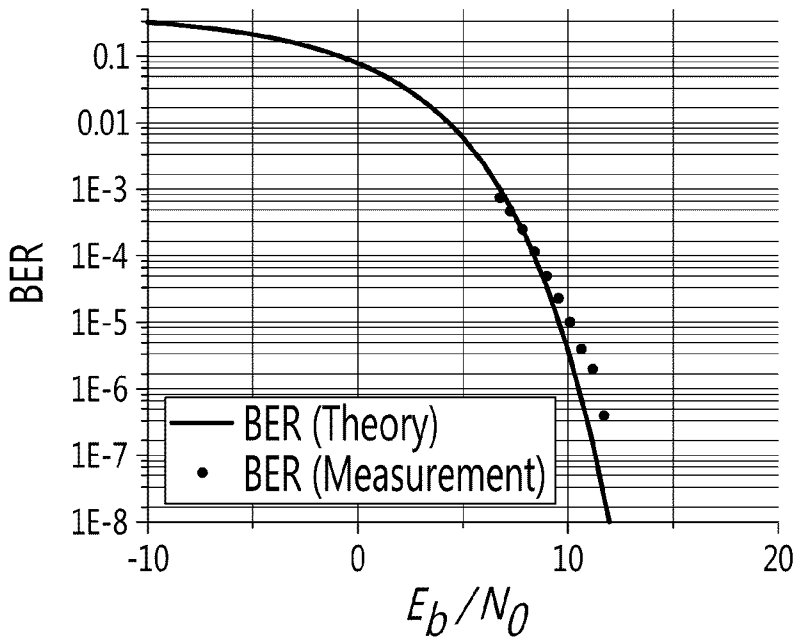
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
BER
BER (Theory)
BER (Measurement)
-10
0
10
20
E_b/N_0

FIG. 10

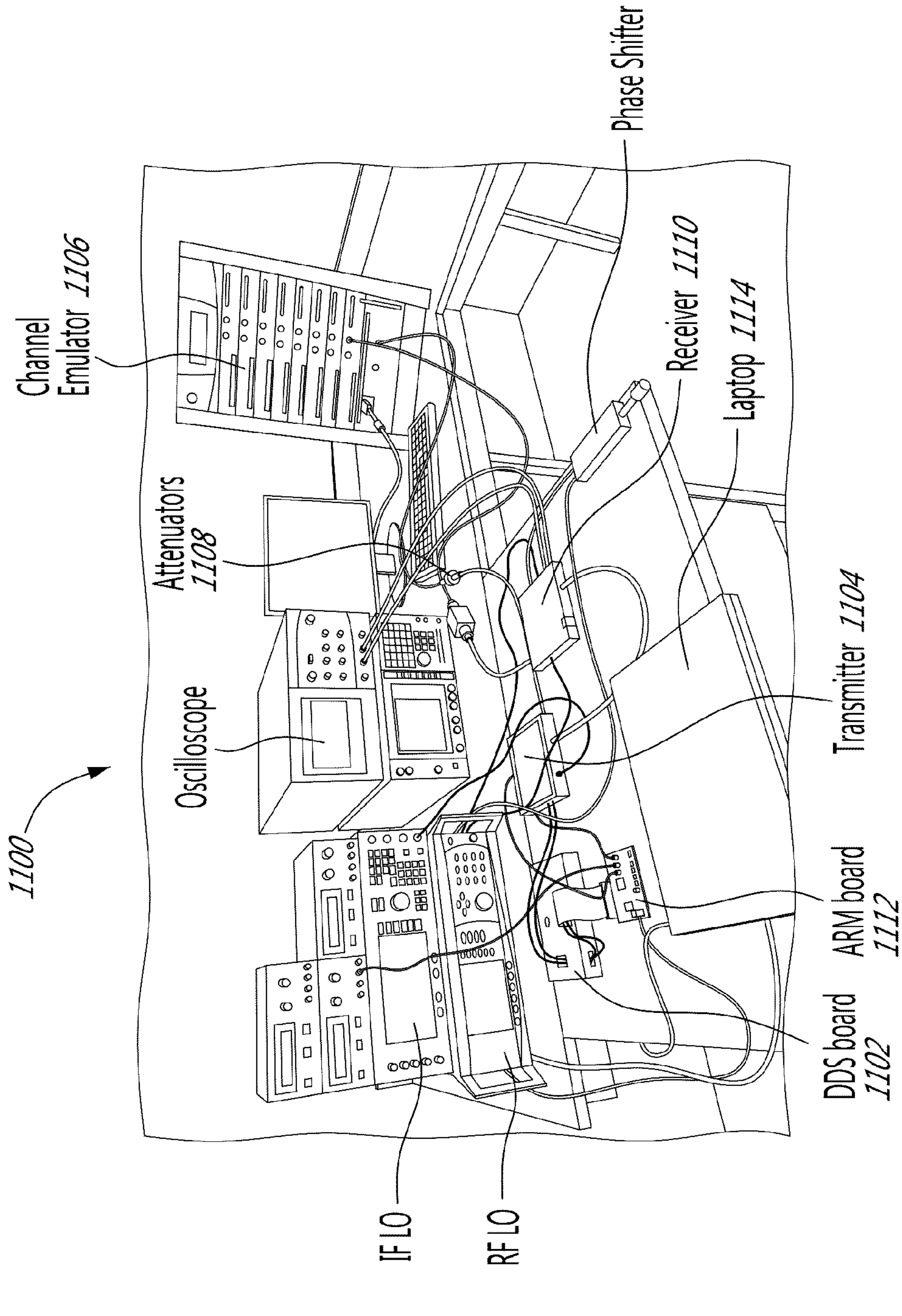
1100
Channel Emulator 1106
Attenuators 1108
Oscilloscope
Phase Shifter
Receiver 1110
Laptop 1114
Transmitter 1104
ARM board 1112
DDS board 1102
IF LO
RF LO

FIG - 11

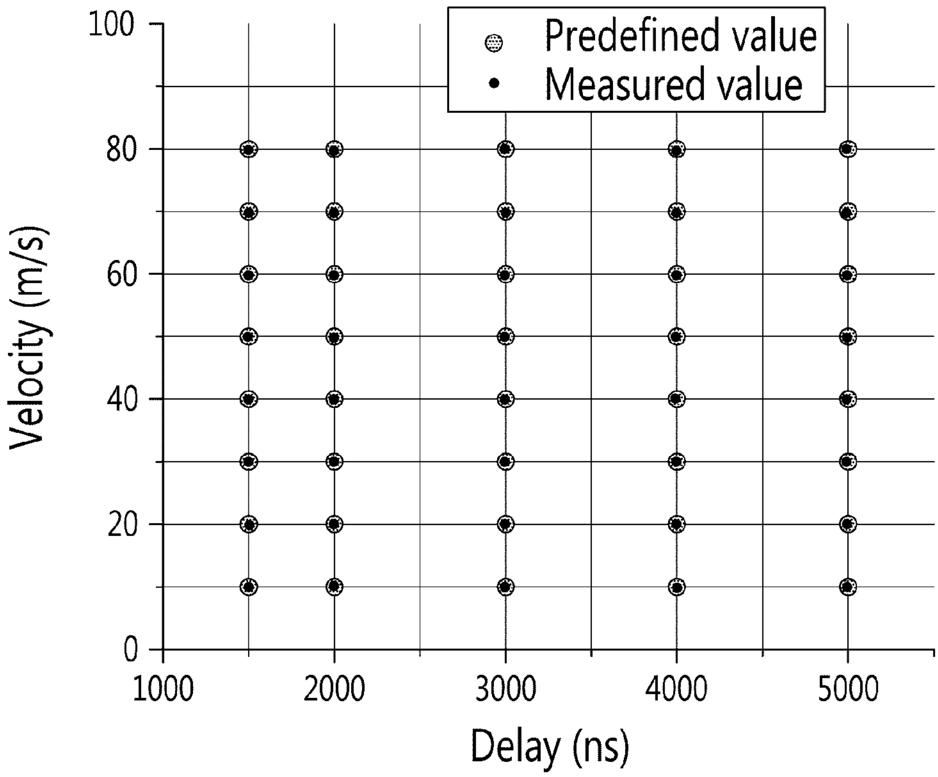
Predefined value
Measured value
Velocity (m/s)
100
80
60
40
20
0
1000
2000
3000
4000
5000
Delay (ns)

FIG. 12

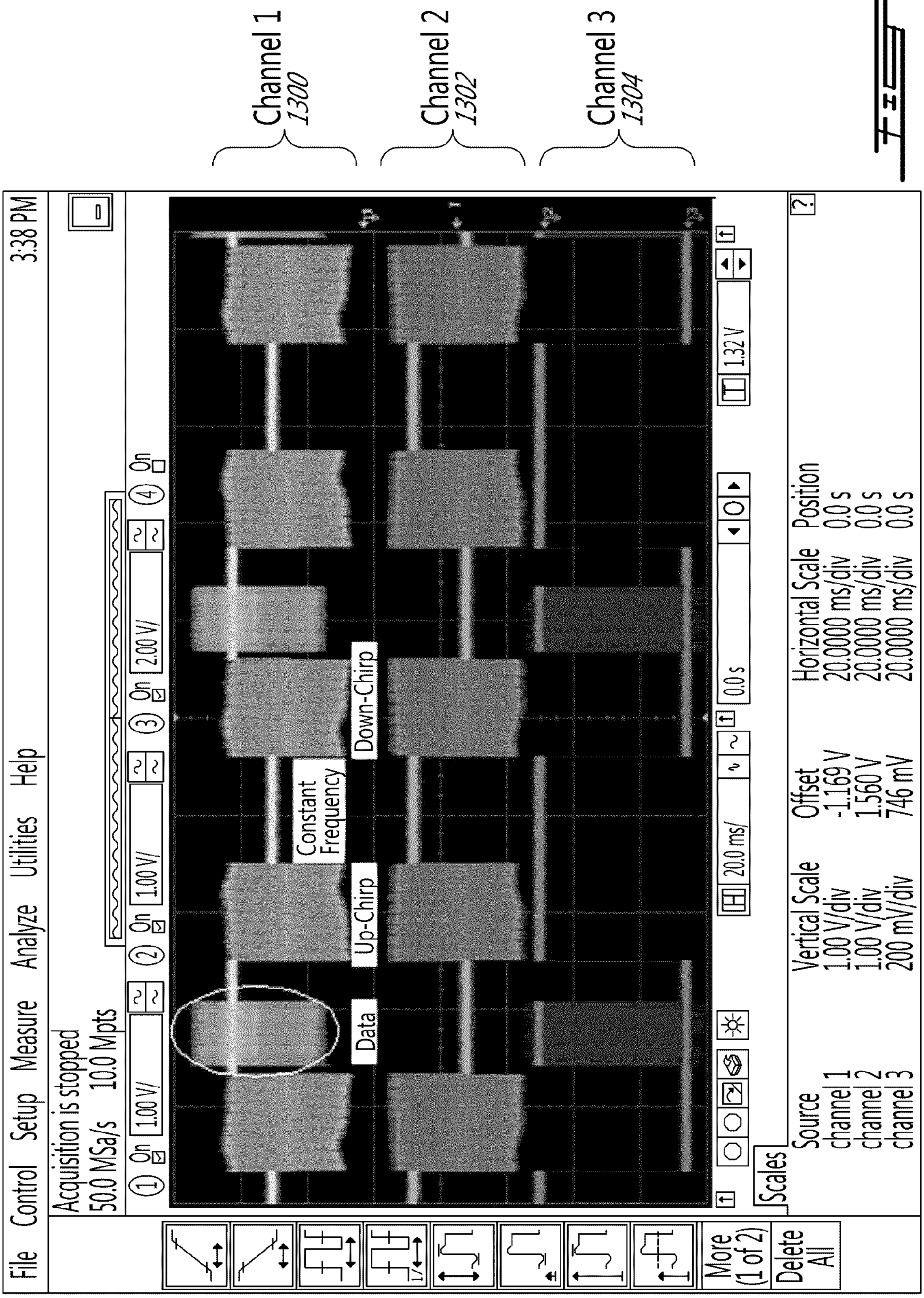
Channel 1
1300
Channel 2
1302
Channel 3
1304
File Control Setup Measure Analyze Utilities Help
3:38 PM
Acquisition is stopped
50.0 MSa/s 10.0 Mpts
1 On 1.00 V/
2 On 1.00 V/
3 On 2.00 V/
4 On
Data
Up-Chirp
Constant Frequency
Down-Chirp
20.0 ms/
0.0 s
1.32 V
More (1 of 2)
Delete All
Scales
Source
channel 1
channel 2
channel 3
Vertical Scale
1.00 V/div
1.00 V/div
200 mV/div
Offset
-1.169 V
1.560 V
746 mV
Horizontal Scale
20.0000 ms/div
20.0000 ms/div
20.0000 ms/div
Position
0.0 s
0.0 s
0.0 s

FIG-13

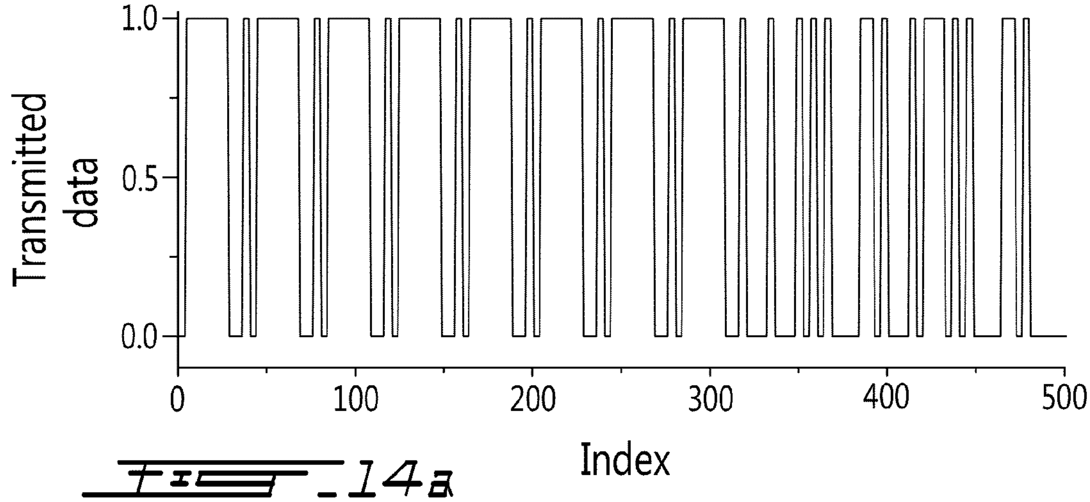

Fig. 14a

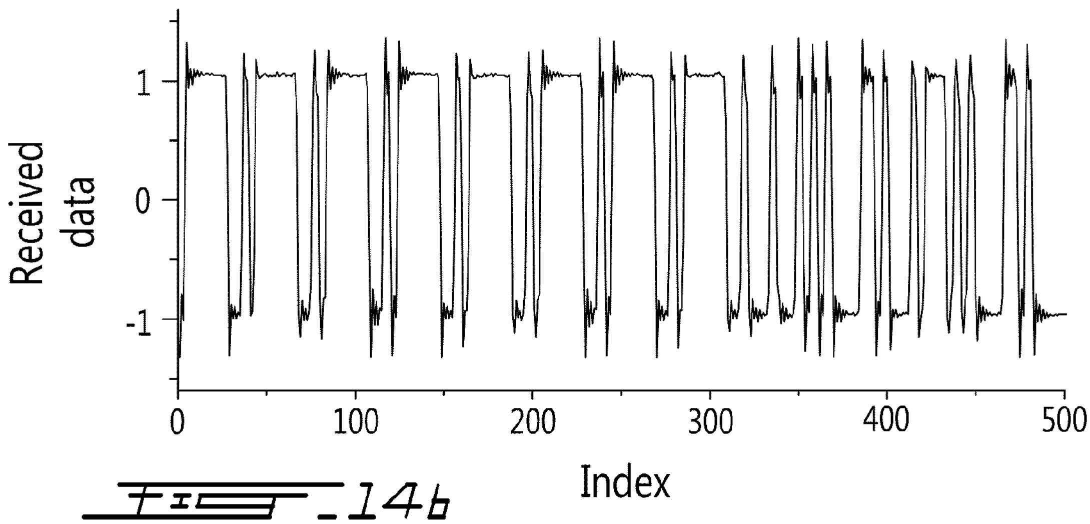

Fig. 14b

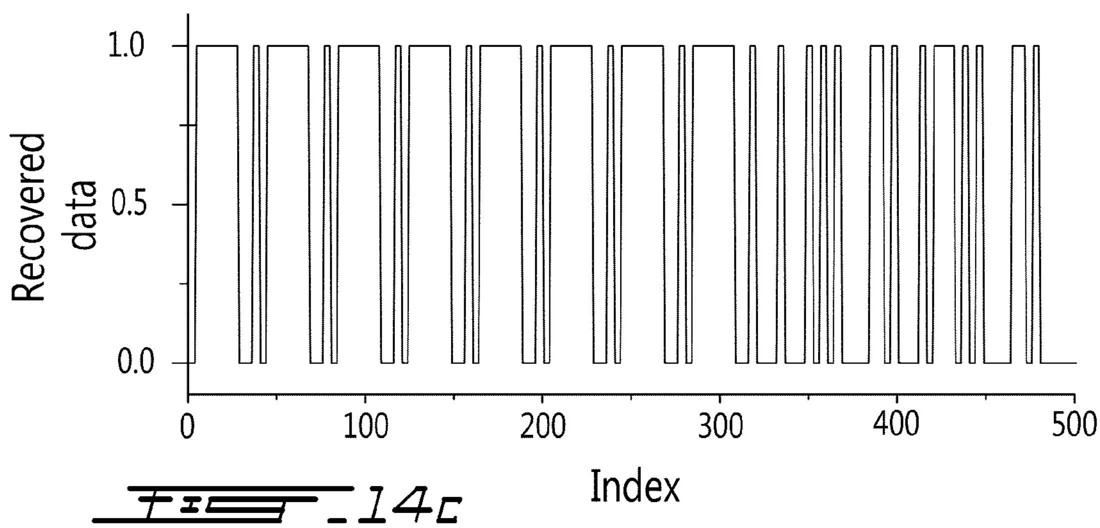

Fig. 14c

INTERNATIONAL SEARCH REPORT	International application No. PCT/CA20 11/050578

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***GOIS 13/86*** (2006.01) , ***G01S 13/58*** (2006.01) , ***G01S 7/282*** (2006.01) , ***G01S 7/285*** (2006.01) , ***H04B 7/26*** (2006.01) , ***H04L 27/34*** (2006.01) (more IPCs on the last page)

According to hiternational Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation seaixhed (classification system followed by classification symbols)

TPC: ***G01S**** (2006.01). ***H04B**** (2006.01). ***H04L**** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Canadian Patent Database, TotalPatent, TEEExplore, Google Patents, Google

Keywords: radar, radio, communication, transmit*, modulat*, waveform, frequency, data fusion, automobile, car, sensing, integrated

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category'*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Saddik, G.N.; Singh, R.S.; Brown, E.R., "Ultra-Wideband Multifunctional Communications/Radar System," Microwave Theory and Techniques, ΓEEE Transactions on , vol. 55, no. 7, pp. 1431-1437, July 2007 (07-2007) "entire document	1-20
A	Sarkas, I.: Laskin, E.: Hasch, J.: Chevalier, P.: Voinigescu, S.P., "Second generation transceivers for d-band radar and data communication applications," Microwave Symposium Digest (MTT), 2010 ΓEEE MTT-S hiternational, pp. 1328-1331, 23-28 May 2010 (28-05-2010) "entire document	1-20
P, X	Liang Han: Ke Wu, "Radar and radio data fusion platform for future intelligent transportation system," Radar Conference (EuRAD), 2010 European, pp. 65-68, Sept. 30 2010-Oct. 1 2010 (1-10-2010) "entire document	1-20

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority clami(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not m conflict with the application but citecTto understand the principle or theory underlying the invention

"X" document of particular relevance ; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined rath one or more other such documents, such combination being obvious to a person skilled m the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 December 2011 (08-12-2011)	26 January 2012 (26-01-2012)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatmeau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Authorized officer Jamie Hayami (819) 934-2670

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with mdication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	Sha Huan; Jianming Zhou; Nan He; Jian Zhang; Haoxiang Lai; Jianfei Yang, "Software-defined system integrated communications based on active phased array radar," Microwave Technology & Computational Electromagnetics (ICMTCE), 2011 IEEE hiternational Conference on , pp. 508-511, 22-25 May 2011 (25-05-2011) "entire document	1, 14, 19, 20

G01S 13/88 **(2006.01) , G01S 13/93 (2006.01)**