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(54) Title: RADAR APPARATUS AND METHOD WITH INTERFERENCE DETECTION

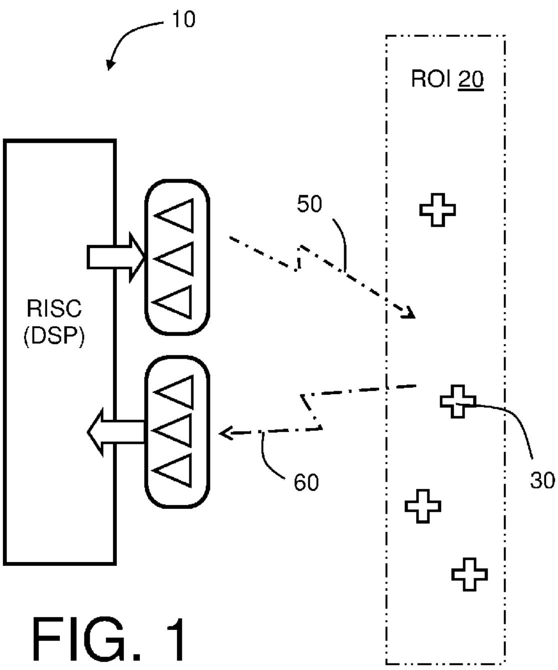

FIG. 1

(57) Abstract: A radar apparatus (10) includes an antenna arrangement for emitting interrogating radiation (50) to a region of interest (ROI, 20) and for receiving corresponding reflected radiation (60) from the region of interest (ROI, 20), and a signal processing arrangement (DSP) for generating signals for providing the interrogating radiation (50) and for processing received signals corresponding to the reflected radiation (60). Moreover, the radar apparatus (10) is operable to emit repetitively in the interrogating radiation (50) a sequence of test tones for interrogating the region of interest (ROI, 20) and the signal processing arrangement (DSP) is operable to process the reflected radiation (60) to determine from test tone information included in the reflected radiation (60) one or more objects in the region of interest (ROI, 20). In a listening period (80) between repetitive emission of the sequence of test tones, the radar apparatus (10) is operable to detect one or more interfering signals being emitted from the region of interest (ROI, 20), for distinguishing signal components arising from the one or more objects from the one or more interfering signals.

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RADAR APPARATUS AND METHOD WITH INTERFERENCE DETECTION

Technical Field

The present disclosure relates to radar apparatus, for example radar apparatus that is operable to emit and receive electromagnetic radiation at a frequency of substantially 77 GHz for interrogating a spatial region. Moreover, the present disclosure concerns methods of operating aforesaid radar apparatus, for example methods of operating aforesaid radar apparatus for enabling the radar apparatus to distinguish more effectively between desired and interfering signals. Furthermore, the present disclosure is concerned with computer program products comprising a non-transitory computer-readable storage medium having computer-readable instructions stored thereon, the computer-readable instructions being executable by a computerized device comprising processing hardware to execute aforesaid methods.

Background

In overview, radar apparatus is well known and includes an emitting arrangement for emitting electromagnetic radiation towards a region of interest (ROI) and a receiving arrangement for receiving a portion of the emitted electromagnetic radiation that is reflected back in operation from the region of interest. On account of the emitting arrangement and/or the receiving arrangement having polar characteristics having directions of greater gain, the radar apparatus is capable of mapping out the region of interest. Moreover, time-of-flight and Doppler frequency shift information included in the portion of the emitted electromagnetic radiation that is reflected back in operation from the region of interest enables one of more objects in the region of interest to be monitored, for example as in Doppler radar systems for selectively measuring speeds of road vehicles.

In a published United States patent application US2005/0035903A1 (inventor Bergkvist *et al.*; applicant: Saab AB), there is described a radar apparatus that is arranged to transmit electromagnetic energy in pulse repetition intervals and to receive reflections or echoes of the transmitted electromagnetic energy from objects in range gates intended for such purpose, wherein the range gates are provided with Doppler filters. The radar apparatus is arranged to approve ambiguous echoes that are desirable and to suppress ambiguous echoes that are of no interest or that interfere with a display function of the radar apparatus. The radar apparatus operates with a frequency of electromagnetic radiation, that is emitted therefrom and is received thereat, that varies according to a staggered or wobbling temporal pattern. The respective ambiguous echoes produce only one pulse in respective range gates concerned, within a predetermined number of periods. A respective Doppler filter concerned is arranged to work with an impulse function response that only consists of a small number of samples. The Doppler filter is also arranged, during the predetermined number of periods, to give rise to a plurality of independent samples from reflectors within the radar apparatus' unambiguous range. When the independent samples exceed a small number of samples, the radar apparatus approves the ambiguous echo; otherwise, it is suppressed. In such a manner, ambiguous echoes are prevented from interfering with reception at the radar apparatus, or display of the echoes on a display screen of the radar apparatus. The suppression of asynchronous interferences, for example pulses from other radar stations, can also be made easier in a simple way.

In a published Japanese patent application JP2002/174677A, there is described a radar apparatus that is capable of detecting continuously, for example for trapping and tracking a target in a military situation, even if interfering waves are transmitted from the target, when the target is a menace such as a enemy aircraft. The radar apparatus utilizes information regarding interfering electromagnetic radiation, for example its centre frequency and a bandwidth of its signal components, emitted from the target. In operation, an operating frequency of the radar apparatus is changed to avoid a frequency regime in which the interfering electromagnetic radiation from the target occurs.

In a published Canadian patent CA 2 762 762 A1 ("*Radar System and Method*"; inventor - Oswald *et al.*; applicant – Cambridge Consultants Ltd.), there is described a radar system for discriminating between sources of radar interference and targets of interest. The system includes a transmitter for transmitting radar signals into a region, a receiver for receiving return signals of the radar signals returned from within the region, and a processor for processing the return signals to discriminate between return signals returned from a first object and return signals returned from a second object, where the return signals from the second object comprise both zero and non-zero Doppler components and interfere with the return signals from the first object. The radar system is operable to discriminate between the return signals when the return signals are received at a distance from the second object that is less than a proximity limit based on the geometry of the object.

In a published European patent application EP2846167 A1 ("*Detection and ranging apparatus*"; inventor - Kazuo *et al.*; applicant – Fujitsu Ltd.), there is described a detection and ranging apparatus including a probe signal generating unit that generates a probe signal according to a first modulation method. There is also included a transmitting unit that transmits the generated probe signal, and a receiving unit that receives a signal including at least one of a reflection signal and an interference signal according to a second modulation method. Moreover, there is also included a demodulating unit that demodulates the reception signal according to a method corresponding to at least one of the first modulation method and the second modulation method. Furthermore, there is also provided an interference signal detecting unit that detects the interference signal from the demodulated signal, and an interference signal identifying unit that identifies specifications and a delay amount of the interference signal from the demodulated signal. Additionally, there is provided an interference signal removing unit that removes the interference signal within the reception signal by using the identified specifications and the identified delay amount of the interference signal.

In a published Japanese patent JP2000284045 ("*Radar System*"; inventor - Kazuo *et al.*; applicant – Mitsubishi Electric), there is described a system that comprises a main antenna for radiating a transmitting radio wave onto a target and receiving a reflected wave therefrom. There is also provided a target detector for detecting the target from the reflected wave received by the antenna, and disturbing wave detecting means for receiving a disturbing wave and detecting its incoming direction and its transmission frequency. There is also provided a frequency control circuit that is operable to switch the transmission frequency of a radio wave transmitted from the antenna from a first frequency that is incoherent to the disturbing wave to a second frequency that is incoherent to the disturbing wave. The radio wave transmitted from the antenna is used to identify the incoming direction of the disturbing wave, and returns the transmission frequency of the transmitted wave from the second frequency to the first frequency when the frequency of the transmitted wave is identified to be other than in the incoming direction.

In a published United States patent application US 2006/0036353 A1 ("*Method Of Suppressing Interferences In Systems For Detecting Objects*"; inventor - Markus Wintermantel), there is described a method of suppressing interferences while detecting objects in a target area, wherein a transmitter transmits a sequence of pulses into the target area, and a receiver detects the resulting reflection signal of the pulses reflected from the objects, within successive time windows that are referenced to a moment of transmitting an individual pulse and thus represent distance gates. The time spacing between the successive individual pulses is variable and randomized according to the pseudo-noise principle within predetermined limits, and the time windows are adapted accordingly. The received reflection signal may be sampled, digitized, digitally preprocessed and digitally filtered in the individual distance gates. A non-linear digital filter, optionally a sliding median filter, is used for filtering purposes to suppress transient disturbances. A median is determined from an odd number of consecutive sampled values of a reflection signal detected in operation within a distance gate.

In a published Chinese patent application CN101089653 A (*"Short-range frequency-modulation continuous wave FMCW radar anti-interference method"*; inventor – Mu Li; applicant – Xi An University of Technology), there is described an anti-interfering method for use in short-range FMCW radar apparatus, wherein the method includes designing a set of pseudo-random codes when using the radar apparatus, distributing different pseudo-random code to different radar apparatus operated at spatially different areas, applying different pseudo-random codes to modulate a frequency start-point of FM emission signal for a same given radar apparatus for each cycle, making a frequency-mixture for received echo signals by utilizing the FM emission signal, using a filter to remove an interference signal from the received echo signals to generate intermediate signals, and applying FM signal processing means to process the intermediate signals for obtaining a measure of object distance and speed information in high resolution.

From the foregoing, it will be appreciated that interference can occur in operation of a given radar system, for example various forms of deliberate or coincidental interference, for example from on-board vehicle radar systems in a congested traffic situation. When radar systems are employed to provide automated braking and/or automated steering of vehicles on highways, such interference can potentially cause hazardous situations to arise. There is therefore a need to improve radar apparatus to make it less susceptible to interference.

Summary

The present disclosure seeks to provide an improved radar apparatus that is more effectively capable of distinguishing signals arising from one or more interfering sources in a region of interest (ROI) in comparison to reflections of interrogating radiation from one or more objects within the region of interest (ROI).

Moreover, the present disclosure seeks to provide an improved method of operating a radar system for more effectively distinguishing signals arising from one or more interfering sources in a region of interest (ROI) in comparison to reflections of interrogating radiation from one or more objects within the region of interest (ROI).

According to a first aspect, there is provided radar apparatus including an antenna arrangement for emitting interrogating radiation to a region of interest (ROI) and for receiving corresponding reflected radiation from the region of interest (ROI), and a signal processing arrangement (DSP) for generating signals for providing the interrogating radiation and for processing received signals corresponding to the reflected radiation, characterized in that:

(i) the radar apparatus is operable to emit repetitively in the interrogating radiation a sequence of test tones for interrogating the region of interest (ROI);

(ii) the signal processing arrangement (DSP) is operable to process the reflected radiation to determine from test tone information included in the reflected radiation one or more objects in the region of interest (ROI); and

(iii) in a listening period between repetitive emission of the sequence of test tones, the radar apparatus is operable to detect one or more interfering signals being emitted from the region of interest (ROI), for distinguishing

signal components arising from the one or more objects from the one or more interfering signals.

The invention is of advantage in that the radar apparatus is susceptible to being operated for more effectively identifying the one or more sources of interrogating radiation by employing the sequence of test tones in combination with the listening period.

Optionally, the radar apparatus is operable to detect at least one spatial range of at least one source giving rise to the one or more interfering signals. More optionally, the radar apparatus is operable to compute the at least one spatial range by employing at least one triangulation measurement, and to apply a Kalman filter to measurement results of the at least one triangulation measurement. Yet more optionally, in the radar apparatus, the Kalman filter is operable to employ a motion estimation of motion of the at least one source.

Optionally, the radar apparatus is operable to generate the sequence of test tones to include one or more chirped tones.

Optionally, the radar apparatus is operable to generate the sequence of test tones in a pseudo-random manner.

Optionally, the radar apparatus is operable to vary at least one of:

(i) a duration of the listening period; and
(ii) a duration of a pulse train including the sequence of test tones.

More optionally, the radar apparatus is operable to process received signals during the listening period in a plurality of time periods, and to detect for signal components corresponding to the one or more interfering signals for each of the plurality of time periods.

Optionally, the radar apparatus is operable to emit to, and receiver radiation from, the region of interest (ROI) at an electromagnetic frequency range in a range of 30 GHz to 200 GHz, more optionally in a range of 50 GHz to 150 GHz, and yet more optionally substantially 77 GHz.

Optionally, the radar apparatus is arranged to interrogate the region of interest (ROI), wherein the region of interest (ROI) includes at least one of:

(a) a railway crossing;

(b) a region around a road vehicle onto which the radar apparatus is mounted in operation; and

(c) a region around a projectile onto which the radar apparatus is mounted in operation.

According to a second aspect, there is provided a method of using radar apparatus including an antenna arrangement for emitting interrogating radiation to a region of interest (ROI) and for receiving corresponding reflected radiation from the region of interest (ROI), and a signal processing arrangement (DSP) for generating signals for providing the interrogating radiation and for processing received signals corresponding to the reflected radiation, characterized in that the method includes:

(i) operating the radar apparatus to emit repetitively in the interrogating radiation a sequence of test tones for interrogating the region of interest (ROI);

(ii) operating the signal processing arrangement (DSP) to process the reflected radiation to determine from test tone information included in the reflected radiation one or more objects in the region of interest (ROI); and

(iii) in a listening period between repetitive emission of the sequence of test tones, the radar apparatus is operable to detect one or more interfering signals being emitted from the region of interest (ROI), for distinguishing signal components arising from the one or more objects from the one or more interfering signals.

Optionally, the method includes operating the radar apparatus to detect at least one spatial range of at least one source giving rise to the one or more interfering signals. More optionally, the method includes operating the radar apparatus to compute the at least one spatial range by employing at least one triangulation measurement, and to apply a Kalman filter to measurement results of the at least one triangulation measurement. Yet more optionally, the method includes using a Kalman filter that is operable to employ a motion estimation of motion of the at least one source.

Optionally, the method includes operating the radar apparatus to generate the sequence of test tones to include one or more chirped tones.

Optionally, the method includes operating the radar apparatus to generate the sequence of test tones in a pseudo-random manner.

Optionally, the method includes operating the radar apparatus to vary at least one of:

(i) a duration of the listening period; and
(ii) a duration of a pulse train including the sequence of test tones.

More optionally, the method includes operating the radar apparatus to process received signals during the listening period in a plurality of time periods, and to detect for signal components corresponding to the one or more interfering signals for each of the plurality of time periods.

Optionally, the method includes operating the radar apparatus to emit to, and receiver radiation from, the region of interest (ROI) at an electromagnetic frequency range in a range of 30 GHz to 200 GHz, more optionally in a range of 50 GHz to 150 GHz, and yet more optionally substantially 77 GHz.

Optionally, the method includes arranging tor the radar apparatus to interrogate the region of interest (ROI), wherein the region of interest (ROI) includes at least one of:

(a) a railway crossing;
(b) a region around a road vehicle onto which the radar apparatus is mounted in operation; and
(c) a region around a projectile onto which the radar apparatus is mounted in operation.

According to a third aspect, there is provided a computer program product comprising a non-transitory computer-readable storage medium having computer-readable instructions stored thereon, the computer-readable instructions being executable by a computerized device comprising processing hardware to execute a method pursuant to the second aspect.

It will be appreciated that features of the invention are susceptible to being combined in various combinations without departing from the scope of the invention as defined by the appended claims.

Description of the diagrams

Embodiments of the present disclosure will now be described, by way of example only, with reference to the following diagrams wherein:

FIG. 1 is a schematic illustration of a radar apparatus pursuant to the present disclosure for interrogating a region of interest (ROI);

FIG. 2 is a graph illustrating a regime of test frequencies, which are optionally chirped, with listening periods therebetween; and

FIG. 3 is a graph illustrating a frequency and amplitude distribution for test and interfering signals of the radar apparatus of FIG. 1 when in operation.

In the accompanying diagrams, an underlined number is employed to represent an item over which the underlined number is positioned or an item to which the underlined number is adjacent. A non-underlined number relates to an item identified by a line linking the non-underlined number to the item. When a number is non-underlined and accompanied by an associated arrow, the non-underlined number is used to identify a general item at which the arrow is pointing.

Description of embodiments

According to a first aspect, there is provided radar apparatus including an antenna arrangement for emitting interrogating radiation to a region of interest (ROI) and for receiving corresponding reflected radiation from the region of interest (ROI), and a signal processing arrangement (DSP) for generating signals for providing the interrogating radiation and for processing received signals corresponding to the reflected radiation, characterized in that:

(i) the radar apparatus is operable to emit repetitively in the interrogating radiation a sequence of test tones for interrogating the region of interest (ROI);

(ii) the signal processing arrangement (DSP) is operable to process the reflected radiation to determine from test tone information included in the reflected radiation one or more objects in the region of interest (ROI); and

(iii) in a listening period between repetitive emission of the sequence of test tones, the radar apparatus is operable to detect one or more interfering signals being emitted from the region of interest (ROI), for distinguishing signal components arising from the one or more objects from the one or more interfering signals.

In comparison to known radar apparatus, the radar apparatus pursuant to the first aspect is susceptible to being operated for more effectively identifying the one or more sources of interrogating radiation by employing the sequence of test tones in combination with the listening period.

Optionally, the radar apparatus is operable to detect at least one spatial range of at least one source giving rise to the one or more interfering signals. More optionally, the radar apparatus is operable to compute the at least one spatial range by employing at least one triangulation measurement, and to apply a Kalman filter to measurement results of the at least one triangulation measurement. Yet more optionally, in the radar apparatus, the Kalman filter is operable to employ a motion estimation of motion of the at least one source.

Optionally, the radar apparatus is operable to generate the sequence of test tones to include one or more chirped tones.

Optionally, the radar apparatus is operable to generate the sequence of test tones in a pseudo-random manner.

Optionally, the radar apparatus is operable to vary at least one of:

(i) a duration of the listening period; and
(ii) a duration of a pulse train including the sequence of test tones.

More optionally, the radar apparatus is operable to process received signals during the listening period in a plurality of time periods, and to detect for signal components corresponding to the one or more interfering signals for each of the plurality of time periods.

Optionally, the radar apparatus is operable to emit to, and receiver radiation from, the region of interest (ROI) at an electromagnetic frequency range in a range of 30 GHz to 200 GHz, more optionally in a range of 50 GHz to 150 GHz, and yet more optionally substantially 77 GHz.

Optionally, the radar apparatus is arranged to interrogate the region of interest (ROI), wherein the region of interest (ROI) includes at least one of:

(a) a railway crossing;

(b) a region around a road vehicle onto which the radar apparatus is mounted in operation; and

(c) a region around a projectile onto which the radar apparatus is mounted in operation.

According to a second aspect, there is provided a method of using radar apparatus including an antenna arrangement for emitting interrogating radiation to a region of interest (ROI) and for receiving corresponding reflected radiation from the region of interest (ROI), and a signal processing arrangement (DSP) for generating signals for providing the interrogating radiation and for processing received signals corresponding to the reflected radiation, characterized in that the method includes:

(i) operating the radar apparatus to emit repetitively in the interrogating radiation a sequence of test tones for interrogating the region of interest (ROI);

(ii) operating the signal processing arrangement (DSP) to process the reflected radiation to determine from test tone information included in the reflected radiation one or more objects in the region of interest (ROI); and

(iii) in a listening period between repetitive emission of the sequence of test tones, the radar apparatus is operable to detect one or more interfering signals being emitted from the region of interest (ROI), for distinguishing signal components arising from the one or more objects from the one or more interfering signals.

Optionally, the method includes operating the radar apparatus to detect at least one spatial range of at least one source giving rise to the one or more interfering signals. More optionally, the method includes operating the radar apparatus to compute the at least one spatial range by employing at least one triangulation measurement, and to apply a Kalman filter to measurement results of the at least one triangulation measurement. Yet more optionally, the method includes using a Kalman filter that is operable to employ a motion estimation of motion of the at least one source.

Optionally, the method includes operating the radar apparatus to generate the sequence of test tones to include one or more chirped tones.

Optionally, the method includes operating the radar apparatus to generate the 5 sequence of test tones in a pseudo-random manner.

Optionally, the method includes operating the radar apparatus to vary at least one of:

(i) a duration of the listening period; and
(ii) a duration of a pulse train including the sequence of test tones.

More optionally, the method includes operating the radar apparatus to process received signals during the listening period in a plurality of time periods, and to detect for signal components corresponding to the one or more interfering signals for each of the plurality of time periods.

Optionally, the method includes operating the radar apparatus to emit to, and receiver radiation from, the region of interest (ROI) at an electromagnetic frequency range in a range of 30 GHz to 200 GHz, more optionally in a range of 50 GHz to 150 GHz, and yet more optionally substantially 77 GHz.

Optionally, the method includes arranging tor the radar apparatus to interrogate the region of interest (ROI), wherein the region of interest (ROI) includes at least one of:

(a) a railway crossing;

(b) a region around a road vehicle onto which the radar apparatus is mounted in operation; and

(c) a region around a projectile onto which the radar apparatus is mounted in operation.

According to a third aspect, there is provided a computer program product comprising a non-transitory computer-readable storage medium having computer-readable instructions stored thereon, the computer-readable instructions being executable by a computerized device comprising processing hardware to execute a method pursuant to the second aspect.

In overview, referring to FIG. 1, embodiments of the present disclosure are concerned with radar apparatus, indicated by **10**. The radar apparatus **10** employs, when in operation, a method of detecting interferences in all spatial directions of operation of the radar apparatus **10**, via use of several continuous wave (CW) signals, for example by employing radar signals that have a principal frequency component in a range of 76.0 GHz to 76.5 GHz, that are relatively short in duration, for example less than 50 millisecond (ms); between periods of transmitting and correspondingly receiving radar signals, the radar apparatus **10** employs, temporally, a listening period in which interfering signals are detected by the radar apparatus **10**. Optionally, for example, in operation, a pulse train, for example a pulse train having a period in a range of 2 ms to 20 ms, for example substantially a pulse train having a duration of 5 ms, for transmitting and correspondingly receiving, radar signals is employed, wherein electromagnetic radar radiation is employed to interrogate a given spatial region of interest (ROI), with a listening period therebetween that is less than 2 ms, for example less than 1 ms, for listening for interfering signals originating from the region of interest (ROI) **20**. Optionally, the listening period is in a range of 2% to 30% of a total repetition period, wherein the total repetition period is a sum of the pulse train and the listening period.

By introducing a listening interval prior to using an actual waveform signal, namely a "*pulse train*", being emitted into the region of interest (ROI) **20** and corresponding reflected radiation being received, the radar apparatus **10** is operable to scan to determine a magnitude, frequency location and direction of one or more sources of disturbance and/or interference **30** present within the region of interest (ROI) **20**. Thus, using such information, the radar apparatus **10** is operable either to select suitable frequencies of its own transmitted radar energy or to employ interference suppression algorithms. In other words, the radar apparatus **10** is operable to detect the one or more sources of disturbance and/or interference **30**, and, as a result, modify, namely adapt, its operating parameters so that interference is reduced, thereby improving operation of the radar apparatus **10**.

The radar apparatus **10** is operable to estimate a range of a given interfering source of disturbance and/or interference **30**, giving rise to interfering signals in the listening period by employing a multiple range model, namely a hypothesis, that is based upon utilizing several listening interval measurements. Such an approach enables the source **30** to be identified with a greater degree of certainty, and its distance determined from temporal computations. Beneficially, the radar apparatus **10** is operable to employ triangulation, namely measurements performed at two or more spatial locations of the radar apparatus **10** relative the source **30**, for determining a pattern of motion of the source **30**. In order to determine an estimation of the range of the source **30** from the radar apparatus **10**, there is computed a probability, namely a likelihood, of a hypothesis of the source **30** being within a given assumed range from the radar apparatus **10**; such determination is, for example, usefully implemented using a Kalman filter or similar approach. By using a variable listening period, the radar apparatus **10** is also assisted to detect sources **30** that are operating with an intention to cause interference, but evading detection by intelligently becoming silent during the listening period of the radar apparatus **10**, for example when the sources **30** are malicious with an intention of confusing the radar apparatus **10**.

A Kalman filter, also known as a "*linear quadratic estimation*", is an algorithm that uses a series of temporal measurements, containing statistical noise, for example stochastic noise, and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone. Moreover, the Kalman filter algorithm functions in a two-step process including:

(i) a first prediction step, wherein the Kalman filter estimates a current state of one or more variables, together with their associated uncertainties; and

(ii) a second step of updating the estimates derived from the first predication step using a weighted average, with more weight being given to estimates of greater certainty,

wherein the first and second steps are performed recursively.

Optionally, the radar signals employed in the radar apparatus **10**, to provide corresponding electromagnetic radar radiation for interrogating the region of interest (ROI) **20** and to receive corresponding reflected electromagnetic radiation therefrom, is a chirped signal, namely a temporally frequency swept signal.

Referring to FIG. 2, there is shown a temporal graph of a signal employed by the radar apparatus **10** when in operation. The radar apparatus **10** is operable to employ the signal to generate interrogating radiation **50** to emit towards the region of interest (ROI) **20**, and to receive at the radar apparatus **10** corresponding reflected radiation **60** from the region of interest (ROI) **20**. The signal corresponds to a plurality of different frequency steps **70A**, **70B**, **70C**, **70D** and so forth, for example wherein a chirp frequency sweep is employed within each step, following by a listening period **80**, during which the radar apparatus **10** is operable to listen to potentially interfering signals generated within the region of interest (ROI) **20**. The frequency steps **70A**, **70B**, **70C**, **70D** and so forth optionally employ a sequence of operating frequencies that are repeated after each listening period; such a repeated form of signal is beneficially correlated with the reflected radiation from the region of interest (ROI) **20** during detection, to achieve an improved reliability of detection of one or more objects in the region of interest (ROI) **20**. Alternatively, the frequency steps **70A**, **70B**, **70C**, **70D** and so forth are optionally varied in a pseudo-random manner to prevent hostile interfering sources in the region of interest (ROI) **20** from recognizing the sequence of steps **70A**, **70B**, **70C**, **70D** and so forth and deliberately attempting to disrupt operation of the radar apparatus **10**; again, aforementioned correlation of the reflected radiation **60**, as a corresponding received signal in the radar apparatus **10**, with pseudo-random changes employed when generating the interrogating radiation **50**, is able to enable the radar apparatus **10** to detect more reliably one or more objects in the region of interest (ROI) **20**. Thus, embodiments of the present disclosure employ a special form of radar signal in the radar apparatus **10**, including a period for listening for interfering radar radiation from other sources in the region of interest (ROI) **20**.

In an example situation as illustrated in FIG. 3, wherein an abscissa axis **100** denotes increasing frequency from left to right, and an ordinate axis **110** denotes increasing amplitude from bottom to top, there is a 76.5 GHz jamming signal **120** emitted from the region of interest (ROI) **20**, for example from a source of noise or interfering radiation, so that the radar apparatus **10** pursuant to the present disclosure is operable to select a 76.0 GHz operation with a chirp to substantially 76.5 GHz, namely is operable to employ chirped signals at various CW test frequencies denoted by **130**; a 5 ms pulse train of chirp signals is emitted from the radar apparatus **10** as the interrogating radiation **50** to the region of interest (ROI) **20**, after which a 1 msec (ms) listening period is employed to listen for identifying interfering radiation being generated in the region of interest (ROI) **20**. Optionally, the duration of the pulse trains is varied, for example in a pre-determined or pseudo-random manner, to circumvent a situation that an interfering source present in the region of interest (ROI) **20** becomes aware of the manner of operation of the radar apparatus **10**, and synchronizes to be inactive during the listening period of the radar apparatus **10**, thereby attempting to avoid detection. Optionally, the radar apparatus **10** is operable to partition the listening period into a plurality of temporal portions, for example by using time-gates in the radar apparatus **10**, and to analyze signals generated by interfering sources in the region of interest (ROI) **20** for each of these temporal portions; such an approach is advantageously combined with making the pulse train period and/or the listening period temporally varying, for example in a pre-determined or pseudo-random manner; in such case, it is very difficult for an interfering source of radiation present in the region of interest (ROI) **20** to evade detection for any extensive period of time.

Frequency modulated continuous wave (FMCW) radar systems employ chirp bandwidths of several 100 MHz. For the radar system 10, chirped signals are emitted in operation as the interrogating radiation **50** to the region of interest (ROI) **20**, resulting in reflected radiation **60** being reflected therefrom. Upon receipt, the reflected radiation **60** is de-chirped with reference to a given signal employed to generate the interrogating radiation **50**, wherein such de-chirping demodulates the received reflected radiation **60** down to baseband signals for subsequent processing in the radar apparatus **10**, for example for time-gating and/or correlation algorithms. Optionally, in the radar apparatus **10**, there are employed a plurality of continuous wave (CW) tones covering an instantaneous bandwidth of the radar waveform employed; it is then feasible to process a signal corresponding to the reflected radiation **60** to determine a spatial location, frequency range and emitting power of one or more interfering sources within the region of interest **20**. Optionally, the frequency steps employed between the individual continuous wave (CW) frequencies corresponds to a baseband bandwidth of a receiver section of the radar apparatus **10** for processing a signal corresponding to the reflected radiation **60** from the region of interest (ROI) **20**. In other words, in the listening interval, employing a CW tone and a de-chirped baseband signal will comprise not only the return of the CW-tone, but also the interferences close to this CW tone, up to a maximum bandwidth of the baseband receiver section.

Optionally, the radar apparatus **10** employs an array of antenna elements for generating the interrogating radiation **50** for interrogating the region of interest (ROI) **20**, and also an array of antenna elements for receiving the reflected radiation **60** from the ROI. Optionally, a same array of antenna elements is employed both for emitting the interrogating radiation **50** and also receiving the reflected radiation **60**. Moreover, signal processing functions within the radar apparatus **10** are advantageously implemented using one or more fast processors to provide digital signal processing (DSP), for generating the interrogating radiation **50** and processing the received radiation **60**; for example, the one or more fast processors are advantageously implemented as one or more reduced instruction set computers (RISC), or an array of such RISC. The one or more fast processors are operable to execute one or more software products, including computer instructions.

The radar apparatus **10** is capable of being used in many fields of application, for example:

(i) for on-vehicle radar systems, for example for automatic vehicle braking systems and/or automatic vehicle steering systems, for example for use in autonomous self-steering vehicles;

(ii) for monitoring safety-critical areas, for example railway level-crossings;

(iii) for use in intruder alarm systems, for example for detecting unauthorized personnel;

(iv) for use in airborne projectile guidance, for example for guiding high-velocity guided mortars;

(v) for use in obstacle detection in automated agricultural equipment, for example for use in automated combine harvesters, ploughing equipment, automated fruit picking apparatus, and so forth;

(vi) for use on harbour ("*harbor*"; US English) facilities, for example for guiding automated equipment for handling ship containers;

and so forth.

Although use of embodiments of the present disclosure at electromagnetic radar radiation emission and reception frequencies in an order of 77 GHz is described in the foregoing, it will be appreciated that the radar apparatus **10** is optionally arranged to operate at radiation frequencies in a range of 30 GHz to 200 GHz, more optionally in a range of 50 GHz to 150 GHz, and yet more optionally in a range of 60GHz to 100 GHz.

The radar apparatus **10** is advantageously operable to avoid using test tones in the pulse train corresponding to a frequency of emission of the one or more interfering sources present in the region of interest (ROI, **20**) as determined by the radar apparatus **10** during the listening period **80**.

Modifications to embodiments of the invention described in the foregoing are possible without departing from the scope of the invention as defined by the accompanying claims. Expressions such as "including", "comprising", "incorporating", "consisting of", "have", "is" used to describe and claim the present invention are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural. Numerals included within parentheses in the accompanying claims are intended to assist understanding of the claims and should not be construed in any way to limit subject matter claimed by these claims.

CLAIMS

We claim:

1. A radar apparatus (10) including an antenna arrangement for emitting interrogating radiation (50) to a region of interest (ROI, 20) and for receiving corresponding reflected radiation (60) from the region of interest (ROI, 20), and a signal processing arrangement (DSP) for generating signals for providing the interrogating radiation (50) and for processing received signals corresponding to the reflected radiation (60), characterized in that

(i) the radar apparatus (10) is operable to emit repetitively in the interrogating radiation (50) a sequence of test tones for interrogating the region of interest (ROI, 20),

(ii) the signal processing arrangement (DSP) is operable to process the reflected radiation (60) to determine from test tone information included in the reflected radiation (60) one or more objects in the region of interest (ROI, 20), and in a listening period (80) between repetitive emission of the sequence of test tones; and

(iii) the radar apparatus (10) is operable to detect one or more interfering signals being emitted from the region of interest (ROI, 20), for distinguishing signal components arising from the one or more objects from the one or more interfering signals.

2. A radar apparatus (10) as claimed in claim 1, characterized in that the radar apparatus (10) is operable to detect at least one spatial range of at least one source (30) giving rise to the one or more interfering signals.

3. A radar apparatus (10) as claimed in claim 2, characterized in that the radar apparatus (10) is operable to compute the at least one spatial range by employing at least one triangulation measurement, and to apply a Kalman filter to measurement results of the at least one triangulation measurement.

4. A radar apparatus (10) as claimed in claim 3, characterized in that the Kalman filter is operable to employ a motion estimation of motion of the at least one source (30).

5. A radar apparatus (10) as claimed in claim 1, 2, 3 or 4, characterized in that the radar apparatus (10) is operable to generate the sequence of test tones to include one or more chirped tones.

6. A radar apparatus (10) as claimed in any one of claims 1 to 5, characterized in that the radar apparatus (10) is operable to generate the sequence of test tones in a pseudo-random manner.

7. A radar apparatus (10) as claimed in any one of claims 1 to 6, characterized in that the radar apparatus (10) is operable to vary at least one of:

(i) a duration of the listening period (80); and

(ii) a duration of a pulse train including the sequence of test tones.

8. A radar apparatus (10) as claimed in claim 7, characterized in that the radar apparatus (10) is operable to process received signals during the listening period (80) in a plurality of time periods, and to detect for signal components corresponding to the one or more interfering signals for each of the plurality of time periods.

9. A radar apparatus (10) as claimed in any one of the preceding claims, characterized in that the radar apparatus (10) is operable to emit to, and receiver radiation from, the region of interest (ROI, 20) at an electromagnetic frequency range in a range of 30 GHz to 200 GHz, more optionally in a range of 50 GHz to 150 GHz, and yet more optionally substantially 77 GHz.

10. A radar apparatus (10) as claimed in any one of the preceding claims, characterized in that the radar apparatus (10) is arranged to interrogate the region of interest (ROI, 20), wherein the region of interest (ROI, 20) includes at least one of:

(a) a railway crossing;

(b) a region around a road vehicle onto which the radar apparatus (10) is mounted in operation; and

(c) a region around a projectile onto which the radar apparatus (10) is mounted in operation.

11. A method of using radar apparatus (10) including an antenna arrangement for emitting interrogating radiation (50) to a region of interest (ROI, 20) and for receiving corresponding reflected radiation (60) from the region of interest (ROI, 20), and a signal processing arrangement (DSP) for generating signals for providing the interrogating radiation (50) and for processing received signals corresponding to the reflected radiation (60), characterized in that the method includes:

(i) operating the radar apparatus (10) to emit repetitively in the interrogating radiation (50) a sequence of test tones for interrogating the region of interest (ROI, 20);

(ii) operating the signal processing arrangement (DSP) to process the reflected radiation (60) to determine from test tone information included in the reflected radiation (60) one or more objects in the region of interest (ROI, 20); and

(iii) in a listening period (80) between repetitive emission of the sequence of test tones, the radar apparatus (10) is operable to detect one or more interfering signals being emitted from the region of interest (ROI, 20), for distinguishing signal components arising from the one or more objects from the one or more interfering signals.

12. A method as claimed in claim 11, characterized in that the method includes operating the radar apparatus (10) to detect at least one spatial range of at least one source (30) giving rise to the one or more interfering signals.

13. A method as claimed in claim 12, characterized in that the method includes operating the radar apparatus (10) to compute the at least one spatial range by employing at least one triangulation measurement, and to apply a Kalman filter to measurement results of the at least one triangulation measurement.

14. A method as claimed in claim 13, characterized in that the method includes using a Kalman filter that is operable to employ a motion estimation of motion of the at least one source (30).

15. A method as claimed in any one of claims 11 to 14, characterized in that the method includes operating the radar apparatus (10) to generate the sequence of test tones to include one or more chirped tones.

16. A method as claimed in any one of claims 11 to 15, characterized in that the method includes operating the radar apparatus (10) to generate the sequence of test tones in a pseudo-random manner.

17. A method as claimed in any one of claims 11 to 16, characterized in that the method includes operating the radar apparatus (10) to vary at least one of:

(i) a duration of the listening period (80); and

(ii) a duration of a pulse train including the sequence of test tones.

18. A method as claimed in claim 17, characterized in that the method includes operating the radar apparatus (10) to process received signals during the listening period (80) in a plurality of time periods, and to detect for signal components corresponding to the one or more interfering signals for each of the plurality of time periods.

19. A method as claimed in any one of claims 11 to 18, characterized in that the method includes operating the radar apparatus (10) to emit to, and receiver radiation from, the region of interest (ROI, 20) at an electromagnetic frequency range in a range of 30 GHz to 200 GHz, more optionally in a range of 50 GHz to 150 GHz, and yet more optionally substantially 77 GHz.

20. A method as claimed in any one of claims 11 to 19, characterized in that the method includes arranging tor the radar apparatus (10) to interrogate the region of interest (ROI, 20), wherein the region of interest (ROI, 20) includes at least one of:

(a) a railway crossing;

(b) a region around a road vehicle onto which the radar apparatus (10) is mounted in operation; and

(c) a region around a projectile onto which the radar apparatus (10) is mounted in operation.

21. A computer program product comprising a non-transitory computer-readable storage medium having computer-readable instructions stored thereon, the computer-readable instructions being executable by a computerized device comprising processing hardware to execute a method as claimed in any one of claims 11 to 20.

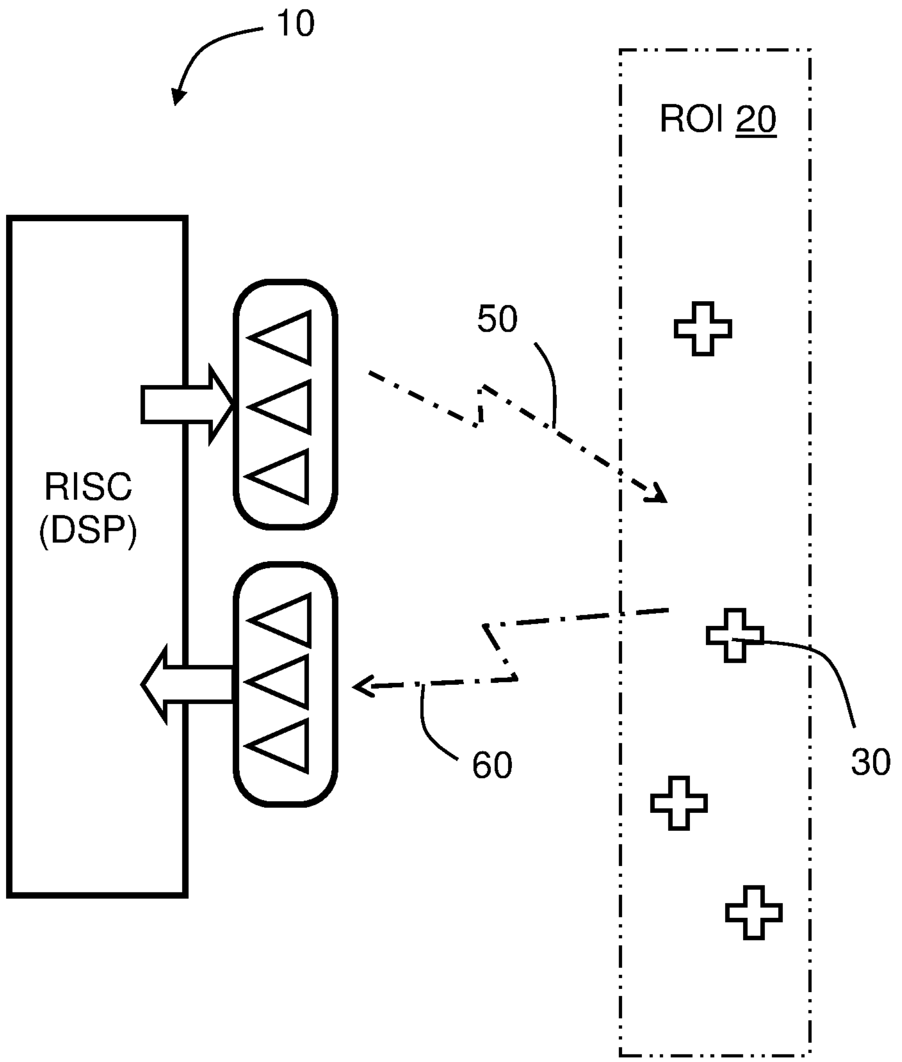


FIG. 1

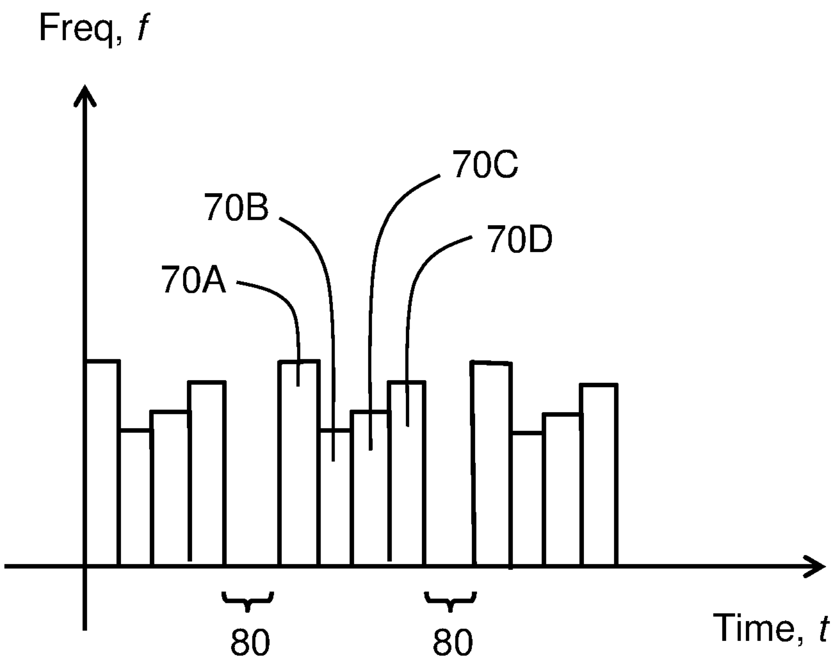
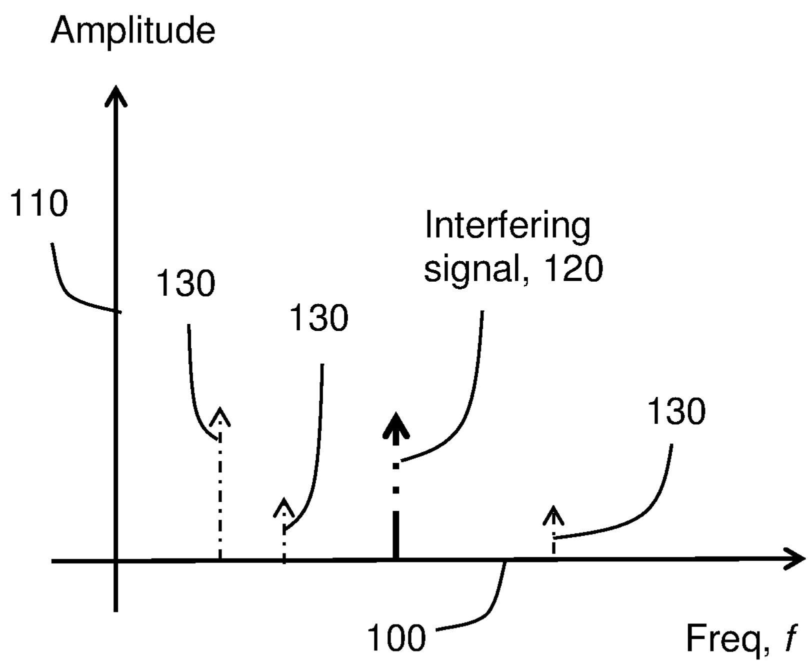


FIG. 2



Radar apparatus employs a cycle of various CW test frequencies during an active period, followed by a listening period for detecting interference, repeating the cycle as required.

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2016/050993

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S7/02 G01S13/93
ADD. G01S13/88 G01S13/91 G08G1/00 G01S13/22 G01S13/26
G01S13/34 G01S13/46

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S G08G

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/095269 A1 (UEHARA NAOHISA [JP] ET AL) 20 May 2004 (2004-05-20)	1,5, 7-11,15, 17-21
Y	paragraphs [0002], [0008] - [0009], [0024] - [0029], [0031], [0037] - [0046]; figures 1-3, 6	2-4,6, 12-14,16

X	EP 1 775 600 A1 (MITSUBISHI ELECTRIC CORP [JP]) 18 April 2007 (2007-04-18)	1,5-8, 10,11, 15-18, 20,21
Y	paragraphs [0016] - [0064], [0082] - [0088]; figures 1-7,11,12	6,16

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

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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

"L" document which may throw doubts on priority claim(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 in conflict with the application but cited to 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 with one or more other such documents, such combination being obvious to a person skilled in 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
16 January 2017	25/01/2017

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INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2016/050993

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 390 679 A1 (MITSUBISHI ELEC R&D CT EUROPE [GB]; MITSUBISHI ELECTRIC CORP [JP]) 30 November 2011 (2011-11-30) paragraphs [0001], [0018] - [0022], [0067] - [0080]; figures 2, 3a -----	1,5,7,8, 10,11, 15,17, 18,20,21
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/SE2016/050993

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		WO 2013045231 A1	04-04-2013