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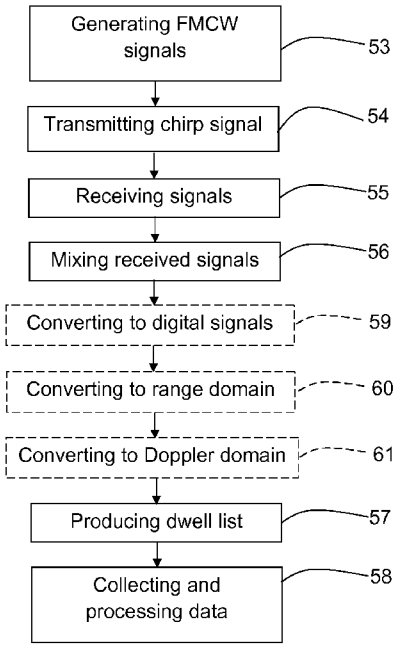


FIG. 10

(57) Abstract: The present disclosure relates to a vehicle radar system (3) comprising at least one transceiver arrangement (52) that is arranged to generate and transmit a least one FMCW chirp signal (4a, 4b). Each chirp signal (4a, 4b) comprises a corresponding plurality of frequency ramps (r_1, r_2). The vehicle radar system (3) is arranged to receive reflected signals (5a, 5b) and to mix the received signals (5a, 5b) with the respective transmitted chirp signal (4a, 4b) to obtain at least one IF signal (14). The vehicle radar system (3) is further arranged to produce a periodically updated dwell list (34), and to collect and process data in dependence of the present dwell list (34). The present dwell list (34) comprises information where the probability of presence of objects exceeds a certain threshold. The present disclosure also relates to a corresponding method.

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TITLE

A vehicle radar system

DESCRIPTION OF THE DISCLOSURE

The present disclosure relates to a vehicle radar system comprising at least one transceiver arrangement arranged to generate, transmit a least one FMCW (Frequency Modulated Continuous Wave) chirp signal, and to receive reflected signals.

Many vehicle radar systems comprise means for generating so-called chirp signals that are transmitted, reflected and received by means of appropriate antennas comprised in the radar system. A chirp signal is an FMCW (Frequency Modulated Continuous Wave) signal with a certain amplitude where the frequency is continuously ramped between two values, the chirp signal thus being in the form of a continuous sinusoid where the frequency varies from a first low frequency to a second high frequency over the course of the ramp. The change in frequency from start to finish, the bandwidth, may for example be of the order of 0.5% of the starting frequency.

The received signals, thus constituted by reflected radar echoes, are mixed with the transmitted chirp signal in order to convert the received signals to baseband signals. These baseband signals, or IF (Intermediate Frequency) signals, are amplified and transferred in a plurality of channels to an Analog Digital Converter (ADC) arrangement which is arranged to convert the received analog signals to digital signals. The digital signals are used for retrieving an azimuth angle of possible targets by simultaneously sampling and analyzing phase and amplitude of the received signals. The analysis is generally performed in one or more Digital Signal Processors (DSP:s) by means of Fast Fourier Transform (FFT) processing.

A vehicle radar system may be used for detecting other vehicles, fixed objects and pedestrians, where pedestrian protection will become of an increased importance. For detection of pedestrians, a radar system should be able to detect objects such as pedestrians at a sufficient distance and to classify detected objects as pedestrians if that is the case, being able to resolve a pedestrian from clutter.

It is possible to obtain object resolution with one or more of the three measurement categories:

1) The range resolution follows a function of Tx (transmit) frequency bandwidth (i.e. BW). Typically, the bandwidth is limited for regulatory reasons.

$$R_{res} = \frac{1}{2} \cdot C_0 / BW$$

2) The angular resolution can be estimated as a function of the effective antenna aperture (i.e. D_{eff}).

$$\Theta_{res} \approx \frac{1}{2} \cdot \pi \cdot \lambda / D_{eff}$$

3) The Doppler is calculated as a function of the so-called dwell time (i.e. Td). A radar dwells at a particular discrete range to search for the presence of objects at that range before indexing to the next in a sequence of discrete ranges.

$$V_{res} = \frac{1}{2} \cdot C_0 / (T_d \cdot F_0)$$

Since the transmitted chirp signals should be within a certain bandwidth, the resulting range resolution may not be satisfactory to differentiate between pedestrian and clutter in various scenarios.

Furthermore, a high azimuth angular resolution requires a large antenna dimension which is unattractive for an automotive radar sensor.

Regarding dwell time, the velocity resolution should preferably be at least 0.5km/h (or in other words 14ms dwell time @ 77GHz). However, the amount of data to be processed increases linearly with recording time, which has implications for both processor load and memory consumption.

It is thus a desire to provide a vehicle radar system where the need for memory and processor capacity is reduced, such that cost, complexity and heat generation is decreased.

The object of the present disclosure is thus to provide a vehicle radar system where the need for memory and processor capacity is reduced, such that cost, complexity and heat generation is decreased.

This object is obtained by means of a vehicle radar system comprising at least one transceiver arrangement that is arranged to generate and transmit a least one FMCW (Frequency Modulated Continuous Wave) chirp signal. Each chirp signal comprises a corresponding plurality of frequency ramps. The vehicle radar system is arranged to receive reflected signals and to mix the received signals with the respective transmitted chirp signal to obtain at least one IF (Intermediate Frequency) signal. The vehicle radar system is further arranged to produce a periodically updated dwell list, and to collect and process data in dependence of the present dwell list. Said dwell list comprises information where the probability of presence of objects exceeds a certain threshold.

This object is also obtained by means of a method for a vehicle radar system, where the method comprises:

- Generating at least one FMCW (Frequency Modulated Continuous Wave) chirp signal.
- Transmitting said at least one chirp signal, where each chirp signal comprises a corresponding plurality of frequency ramps.
- Receiving reflected signals.
- Mixing the received signals with the respective transmitted chirp signal to obtain at least one IF (Intermediate Frequency) signal.
- Producing a periodically updated dwell list.
- Collecting and processing data in dependence of the present dwell list. The dwell list comprises information where the probability of presence of objects exceeds a certain threshold.

According to an example, each of said at least one transceiver arrangement is arranged to

- convert said IF signals to digital signals,
- convert the digital signals to a range domain by means of a first FFT (Fast Fourier Transform), and to
- combine the results from successive chirp signal ramps into the Doppler domain by means of a second FFT,

such that a plurality of Range-Doppler matrices is obtained.

According to another example, the vehicle radar system is arranged to feed the two-dimensional spectrum of each Range-Doppler matrix into a first processing path and a second processing path. The first processing path is arranged to produce said dwell list, and the second processing path is arranged to collect and process data from each Range-Doppler matrix in dependence of said dwell list.

According to another example, each transceiver arrangement comprises a signal generator and is arranged to transmit a first chirp signal a second chirp signal. These chirp signals may for example be timed to be interleaved with each other.

According to another example, each chirp signal comprises a corresponding plurality of frequency ramps, where each pulse block has a duration of a block time with an idle time between two consecutive pulse blocks. Each pulse block comprises said chirp signal and during the idle time, there is no chirp signal.

According to another example, the radar system is arranged to combine pulse blocks by means of a Sequential Probability Ratio Test (SPRT) algorithm.

Other examples are disclosed in the dependent claims.

A number of advantages are obtained by means of the present disclosure. Mainly, cost, complexity and heat generation is decreased.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will now be described more in detail with reference to the appended drawings, where:

Figure 1 shows a schematic top view of a vehicle;

Figure 2 shows a simplified schematic of a vehicle radar system;

Figure 3a shows a first chirp signal;

Figure 3b shows a second chirp signal;

Figure 4 shows a graphical representation of a Range-Doppler matrix;

Figure 5 shows pulse blocks during a cycle;

Figure 6 shows details of a search module;

Figure 7 shows a Rayleigh distribution and a Gaussian distribution;

Figure 8 shows details of a dwell computation module;

Figure 9 shows details of a target detection module; and

Figure 10 shows a flowchart for a method according to the present disclosure.

DETAILED DESCRIPTION

Figure 1 schematically shows a top view of a vehicle 1 arranged to run on a road 2 in a direction D, where the vehicle 1 comprises a vehicle radar system 3 which is arranged to distinguish and/or resolve single targets from the surroundings by transmitting signals 4a, 4b and receiving reflected signals 5a, 5b and using a Doppler effect in a previously well-known manner. The vehicle radar system 3 is arranged to provide azimuth angles of possible objects 6, 7 by simultaneously sampling and analyzing phase and amplitude of the received signals 5a, 5b.

With reference to both Figure 1 and Figure 2, Figure 2 showing a simplified schematic of a vehicle radar system 3 according to a first example, the vehicle radar system 3 comprises transceiver arrangement 52 that in turn comprises a transmitter arrangement 8 which in turn comprises a signal generator 9 that is arranged to generate FMCW (Frequency Modulated Continuous Wave) chirp

signals of a previously known kind, a chirp signal being in the form of a continuous sinusoid where the frequency varies from a first low frequency to a second high frequency over the course of the ramp. The change in frequency from start to finish may for example be of the order of 0.5% of the starting frequency.

The transmitter arrangement 8 further comprises a first transmitter antenna arrangement 10a and a second transmitter antenna arrangement 10b, each transmitter antenna arrangement 10a, 10b either being constituted by one antenna element or by an array of antenna elements, and being arranged to transmit a corresponding first chirp signal 4a and second chirp signal 4b, the second chirp signal 4b being shown in Figure 3a with frequency on the Y-axis and time on the X-axis. The frequency varies from a first low frequency f_{start} to a second high frequency f_{stop} over the course of each ramp r (only three ramps indicated in Figure 3a for the sake of clarity).

The transceiver arrangement 52 further comprises a receiver arrangement 11, which receiver arrangement 11 in turn comprises a receiver mixer 12 and a receiver antenna array 13, where the receiver antenna array 13 comprises four receiver antenna arrangements 13a, 13b, 13c, 13d. In the same way as for the transmitter antenna arrangements, each receiver antenna arrangement 13a, 13b, 13c, 13d may be constituted by one antenna element or by an array of antenna elements.

The transmitted signals 4a, 4b are reflected at a first object 6, and the reflected signals 5a, 5b are received by the receiver arrangement 11 via the receiver antenna arrangements 13a, 13b, 13c, 13d. The reflected signals 5a, 5b each have corresponding wave fronts 21a, 21b, one wave front for each reflected signals 5a, 5b being schematically indicated in Figure 2. By detecting the phases of the received reflected signals 5a, 5b, the

inclination of the wave fronts 21a, 21b may be calculated, providing an azimuth bearing angle to the object 6, in other words a direction of arrival DOA.

The received signals 5a, 5b, thus constituted by reflected radar echoes, are mixed with the second chirp signal 4b in the receiver mixer 12, such that four corresponding IF (Intermediate Frequency) signals 14 are acquired. The difference frequency of the resulting IF signals relates to the target distance.

As shown in Figure 3a, the first chirp signal 4a comprises repeating cycles of a first plurality of frequency ramps r_1 and as shown in Figure 3b, the second chirp signal 4b comprises repeating cycles of a second plurality of frequency ramps r_2. As mentioned above, the frequency varies from a first frequency f_{start} to a second frequency f_{stop} over the course of each ramp r_1, r_2, where the magnitude of the first frequency f_{start} falls below the magnitude of the second frequency f_{stop}.

In this example, each ramp lasts a certain ramp time T_r, the ramp time T_r being the same for the first chirp signal 4a and the second chirp signal 4b. Between two consecutive ramps of the first chirp signal 4a as well as for the second chirp signal 4b there is also a ramp time t_r. The chirp signals 4a, 4b are timed such that between two consecutive ramps of the first chirp signal 4a there is ramp of the second chirp signal 4b and vice versa such that the chirp signals 4a, 4b are interleaved with each other.

In this way, improved angular accuracy and resolution is achieved since the number of Tx-Rx (transmit-receive) combinations is increased.

The transceiver arrangement 52 further comprises an Analog to Digital Converter (ADC) arrangement 16 and a sampling and timing arrangement 17. The four corresponding IF signals 14 are transmitted from the receiver to the ADC arrangement 16 where the IF signals 14 are sampled at a certain predetermined sampling frequency f_s and converted to digital signals 22, the sampling frequency f_s being provided in the form of a sampling and timing signal 19 produced by the sampling and timing arrangement 17.

The transceiver arrangement 52 further comprises a DSP (Digital Signal Processor) arrangement 18 that is adapted for radar signal processing by means of a first FFT (Fast Fourier Transform) to convert the digital signals 22 to a range domain, and a second FFT to combine the results from successive chirp signal ramps into the Doppler domain. This is shown in figure 4, where Doppler speed v in meter/second is shown on one axis, range R in meter on another axis with relative signal amplitude A in dB on a third axis.

Figure 4 thus schematically provides a graphical representation of a Range-Doppler matrix 35. Here, a Nyquist speed v_N and a Nyquist range R_N are indicated with corresponding dash-dotted lines 23, 24. The vehicle radar system 3 suitably comprises a main control unit 38, only schematically indicated in Figure 2, that controls the working of certain components in the vehicle radar system 3.

At a first range R_1 there is a first target indication 25 detected at a first speed v_1; at a second range R_2 there is a second target indication 26 detected at a second speed v_1 and a third target indication 27 detected at a third speed v_3; at a third range R_3 there is a fourth target indication 28 detected at a fourth speed v_4. The fourth target indication 28 is mirrored in the Nyquist range R_N line 24 such that a mirrored fourth target indication

28_m appears. The Range domain is the result of the first FFT, where targets further away appear at higher frequencies.

As a target increases in distance, it will start to alias, and appear as coming closer, which is undesirable. For example, if the fourth target indication 28 appears at an increasing frequency it would move towards a higher and higher range, towards and past the Nyquist range R_N line 24, while the mirrored fourth target indication 28_m would move towards a lower and lower range, towards and past the Nyquist range R_N line 24. Then the mirrored fourth target indication 28_m would be detected, constituting a false target indication.

A fifth target indication 29 appears at the third range R_3 at a fifth speed v_5 that exceeds the Nyquist speed v_N. Then, the fifth target indication 29 will appear as an imaginary fifth target indication 29_i at a lower sixth speed v_6 due to aliasing, constituting a false target indication.

The above false target indications will make identification of which target indication that is real more difficult. In order to counter-act this, the receiver arrangement comprises an anti-aliasing filter 7. The anti-aliasing filter 7 has a sufficient degree of suppression beyond the present Nyquist frequency. This has the effect of removing one of the two tones from the chirp signals 4a, 4b and allows the ADC arrangement 16 to work reliably.

According to the present disclosure, the two-dimensional spectrum of the Range-Doppler matrix 35 is fed into two parallel processing paths, a first processing path 30 and a second processing path 31. The first processing path 30 comprises a search module 32 and a dwell computation module 33, and is arranged to seek for useful signals, working independently from

the rest of the signal processing in the background, producing a periodically updated dwell list 34. Moreover, the first processing path 30 serves as a firewall which is arranged to suppress adverse signals such as interference or ambiguous signals.

The second processing path 31 is arranged to extract specific spectral lines from the Range-Doppler matrix 35 and store them in a buffer structure. In addition to the Range-Doppler matrix input, an access to information about supposed targets is needed. For this purpose, the dwell list 34 is accessed by a dwelling module 36 that is comprised in the second processing path 31 and is arranged to collect data from the Range-Doppler matrix 35 in dependence of the present dwell list 34. The second processing path 31 further comprises a target detection module 37.

By means of the dwell list 34, it is possible for the second processing path 31 to focus the processing efforts where there is an increased possibility for presence of objects.

An example of how these processing paths 30, 31 may work will be explained more in detail later.

With reference to Figure 3a, Figure 3b and Figure 5, each cycle has a duration of a cycle time t_C, where each cycle comprises a plurality of pulse blocks 4, and where each pulse block 4 has a duration of a block time t_B. Between two consecutive pulse blocks 4 there is a certain idle time t_i. Each pulse block 4 comprises the chirp signals 4a, 4b, and during the idle time t_i between two consecutive pulse blocks 4 there are no chirp signals. A Range-Doppler matrix 35 is prepared for each pulse block 4, one at a time.

In Figure 3a and Figure 3b, the first chirp signal 4a and the second chirp signal 4b are shown during one such a pulse block 4, block time t_B.

It should be noted that the Doppler resolution performance of a single pulse block 4 is lower compared to a continuous pulse sequence. Furthermore, the integration gain is proportional to the acquisition time which results in a lower signal to noise ratio for a single pulse block 4.

In the following, the workings of the processing paths 30, 31 will be described more in detail.

The search module 32 is arranged to find Range-Doppler (RD) matrix elements which most likely contain energy of radar targets. For this purpose, the consistency of the magnitudes of the Range-Doppler matrix 35 is evaluated one at a time. Since the individual pulses are not saved, it is necessary to sequentially work through the process and get the most important information in compressed form. This may for example be accomplished by combining the pulse blocks 4 of one or more processing cycles with the aim to restore both the detection probability and the resolution using a so-called sequential probability ratio test (SPRT) algorithm, where this algorithm in general is previously well-known and here is run by means of the main control unit 38. The ideal implementation of a sequential detection algorithm requires a decision to be made after every pulse block 4, where three decision outcomes are possible: No Target, Target Present, and No Decision. If the latter decision is made, then another pulse block 4 is evaluated.

With reference to Figure 6, the search module 32 comprises a noise estimation module 39, an LLF (Log Likelihood Function) matrix alignment module 40, a probability ratio computation

module 41 and LLF matrix updating module 42. The term LLF will be discussed in detail later in the description.

The noise estimation module 39 is arranged to estimate the noise floor for all ranges in the Doppler dimension within the Range-Doppler matrix 35 by means of a median function.

The LLF matrix alignment module 40 is arranged to alter the LLF matrix since it is the nature of the Range-Doppler matrix 35 that frequencies in the range dimension are changing as a function of time. The so-called range-rate of the energy within a certain RD matrix element can be derived from the matrix element index in the Doppler dimension.

The probability ratio computation module 41 is arranged to perform sequential detection using the SPRT algorithm. In order to adapt this algorithm to radar sensors, a calculated signal magnitude, m, is assumed as based on the on-going collection of noisy radar signal observations, so far comprising N such observations. The function $f_0(m)$ is a probability density function for the calculated signal magnitude m, when an object is actually present at some specified magnitude, and the function $f_1(m)$ is the probability density function for the calculated signal magnitude m, when no such object is actually present.

A probability density function describes the likelihood of observing particular values of a random variable. In particular, the probability of observing values contained within a certain interval is determined by integrating the probability density function over that interval. As such, the value of the probability density function at any particular value is proportional to the probability of observing the random variable within an infinitesimal interval centered on the value.

According to SPRT theory, the ratio, r, provides a measure of the relative probability r of the object being present or not:

$$r = \frac{f_0(m)}{f_1(m)} \qquad (1)$$

The calculation of the probability density functions, $f_0(m)$ and $f_1(m)$, is dependent on the nature of the observation noise. In particular, the noise on both the real and imaginary part of the Range-Doppler matrix 35 of a single pulse block 4 is modeled as independent normal variants having zero mean and equal variance. Under this assumption, the probability density function for the no-target case, $f_1(m)$, follows a Rayleigh distribution:

$$f1(m) = \frac{m}{\sigma^2} \cdot exp\left(- \frac{m^2}{2 \cdot \sigma^2} \right) \qquad (2)$$

The peak of a Rayleigh distribution occurs at the value of σ. Figure 7 illustrates a Rayleigh distribution for a σ equal to 10. The probability density function for the target-present case, $f_0(m)$, requires an assumed target magnitude. This magnitude has the interpretation that if a target is present with this magnitude, the specified probability of detection should be achieved. Thus, this magnitude is considered to be a threshold at which detection requirements will be satisfied.

Given the above-assumed signal noise characteristics, the probability density function for the target present case follows a Rice distribution. In practice, however, this can be approximated by the less complicated Gaussian distribution:

$$f0(m) = \frac{1}{\sigma \cdot \sqrt{(2 \cdot \pi)}} \cdot \exp\left(- \frac{(m - m_T)^2}{2 \cdot \sigma^2} \right) \qquad (3)$$

In the above equation, m_T is the detection threshold at which the performance requirements are to be satisfied. The Gaussian distribution is a good approximation to the Rice distribution as long as the threshold, m_T, is at least 1.5 times larger than the noise standard deviation, s.

In Figure 7, a Gaussian distribution 44 is illustrated for a noise standard deviation s equal to 10 and a detection threshold m_T equal to 40. Note that the peak of the Gaussian distribution 44 occurs at the value of m_T. The detection threshold m_T is determined as a multiple of the effective noise in a receiver channel, as described by the following equation:

$$m_T = D \cdot \sigma \qquad (4)$$

In the above equation, the parameter D represents the desired noise multiplier that for example may have a value somewhere between 2.5 and 32. This corresponds to a threshold ranging from 8dB to 30dB above noise (i.e. 12dB = 20 $\log_{10}(4)$).

The ratio r of equation (1) may be transformed to a logarithmic form. The resulting expression is called the log-likelihood function (LLF), mentioned previously. In the following, the linear ratio of the functions $f_0(m)$ vs. $f_1(m)$ is illustrated:

$$r(m,\sigma) = \frac{\frac{1}{\sigma\cdot\sqrt{(2\cdot\pi)}}\cdot exp\left(-\frac{(m-D\cdot\sigma)^2}{2\cdot\sigma^2}\right)}{\frac{m}{\sigma^2}\cdot exp\left(-\frac{m^2}{2\cdot\sigma^2}\right)} = \frac{\sqrt{2}\cdot\sigma\cdot e^{D\cdot m/\sigma - D^2/2}}{2\cdot\sqrt{\pi\cdot m}} \qquad (5)$$

The log-likelihood function is obtained by applying of the natural logarithm:

$$ln(r(m,\sigma)) = ln\left(\frac{\sigma}{m}\right) - \frac{ln(2\cdot\pi)}{2} - \frac{D^2}{2} + \frac{D\cdot m}{\sigma} \qquad (6)$$

The LLF matrix updating module 42 is arranged for actual target signal detection. A target is decided to be present when the following inequality is satisfied for a first threshold A:

$$r > A \qquad (7)$$

A target is decided to not be present when the following inequality is satisfied for a second threshold B:

$$r < B \qquad (8)$$

If neither inequality is satisfied, it is not possible to make a decision another observation has to be collected. The first thresholds A and second threshold B can be based on a probability of detection (i.e., 1 – a) and false alarm (i.e., b) requirements. In particular, the following approximations may be used:

$$A \approx \frac{1-\beta}{\alpha} \qquad (9)$$

$$B \approx \frac{\beta}{1-\alpha} \qquad (10)$$

Here, α denotes missed detection probability, e.g. 5% => 0.05; and β denotes false-alarm probability, e.g. 1% => 0.01.

For the incoherent version of the SPRT target detection each matrix element of the LLF matrix is summed up with the LLF value of the corresponding RD spectral line. This process is executed until either a noise decision is made, or until a target decision can be done. This relationship can be expressed by the following inequality:

$$B < \sum_{i=1}^{N} \left(LN\left(\frac{\sigma_i}{m_i}\right) - \frac{LN(2\cdot\pi)}{2} - \frac{D^2}{2} + \frac{D\cdot m_i}{\sigma_i} \right) < A \qquad (11)$$

With renewed reference to Figure 2, the dwell computation module 33 is arranged to be executed at the end of every RSP (Radar Signal processing) cycle, and is arranged to select range-velocity combinations that most likely contain energy of radar targets. In addition the dwell buffer is initialized and the dwell list 34 is rewritten as preparation for the next RSP cycle.

With reference to Figure 8, the dwell computation module 33 comprises a RD matrix element identification module 45 and a dwell position calculation module 46.

The RD matrix element identification module 45 is arranged to investigated whether the matrix elements contents of the latest LLF matrix exceeds the designated first threshold A.

In order to illustrate the dwell position calculation module 46, it is assumes that a proper cell is found in the LLF matrix having a range index of i_R and a Doppler index of i_D. The corresponding dwell position i_{pR}/i_{pD} is calculated as follows. Since the basic approach of an SAD (Search And Dwell) algorithm assumes a constant velocity, the Dwell index, i.e. position of Range-Doppler (RD) matrix elements of interest for dwelling, can be taken over from the LLF matrix:

$$i_{pD} = i_D \qquad (12)$$

In order to lose as little energy as possible during the dwelling process, it is desired to put the measuring point at the optimum position. The calculation is basically the prediction of the target position using the current position, i.e. i_R, dwell duration, i.e. T_C, and the target speed represented by the Doppler index, i.e. i_D. The best projection time point t would be when the dwell-period is progressed halfway; which may be expressed as $t = 0.5 \cdot N_R \cdot T_R$, where N_R is the number of ramps r_1, r_2 in one pulse block 4.

$$ip_R = i_R + \frac{N_R \cdot T_R \cdot V_{RES} \cdot f_D(i_D)}{2 \cdot R_{RFS}} \qquad (13)$$

The function $f_D(i_D)$ represents the interpretation of the Doppler index i_D. Since the RD spectrum has a limited Doppler Nyquist speed $v_N = v_{RES} \cdot N_R$, where v_{RES} is the Doppler resolution, it is necessary to define the operation range of the target velocities. This function $f_D(i_D)$ returns an integer value which is a multiplier for the Doppler resolution in order to obtain the velocity represented by the Doppler index i_D. The simplest

example is to center the velocity range of values on zero. One implementation of such function might be:

$$f_D(i_D) = \begin{cases} \text{if } i_D < N_R/2: & i_D - 1 \\ \text{else:} & i_D - N_R - 1 \end{cases} \quad (14)$$

There are of course alternative ways to compensate for the coherency losses caused by range rate of the radar targets. For example, it is conceivable that the Range-Doppler matrix 35 is aligned by frequency multiplication with respect to change in position prior to the actual transformation. This is however only an additional example, and will not be discussed further here.

With renewed reference to Figure 2, the dwelling module 36 that is comprised in the second processing path 31 is arranged to collect data from the Range-Doppler matrix 35 in dependence of the present dwell list 34. This list is cyclically created from the search module 32. The number N_{DP} of values to be stored depends on the size of the dwell buffer. The length N_{SP} of the buffer may have limitations such as the RSP cycle time.

The second processing path 31 further comprises the target detection module 37 that is arranged to evaluate the stored data in the dwell buffer. With reference to Figure 9, the target detection module 37 comprises a dwell data transformation module 47, a peak detection module 48 and a parameter estimation module 49.

The dwell data transformation module 47 is arranged to apply a proper window function to each dwell signal. Moreover, all dwell

signals have to be transferred into the frequency domain; actually the third dimension of a spectral cube.

Here, each dwell signal is considered to constitute an independent Doppler signal with following properties:

- The Doppler resolution of a dwell probe, V_{RES_DP}:

$$V_{RES_DP} = \frac{C_0}{N_{SP} \cdot T_{SP} \cdot (F_U + F_L)} \qquad (15)$$

- The Doppler Nyquist of a dwell probe, V_{N_DP}:

$$V_{N_DP} = V_{RES_DP} \cdot N_{SP} \qquad (16)$$

The peak detection module 48 comprises a detection algorithm where a magnitude signal is created from the complex FFT output. Then, the noise floor is estimated for each signal. After this a detection threshold is calculated. In the last step, all local maxima above the threshold are declared as targets.

The parameter estimation module 49 is arranged to calculate all parameters, i.e. range, Doppler and bearing. For this purpose, it is necessary to consider the orthogonal neighboring matrix elements in the three-dimensional signal space of every target peak. With the magnitudes of the neighbors, a 3-point interpolation may be applied, and the target distance can be calculated using the equation

$$R_{RES} = \frac{N_S - 1}{N_S} \cdot \frac{C_0}{2 \cdot BW} \qquad (17)$$

where R_{res} is the range resolution, N_s is the number of samples per Tx ramp r_1, r_2, BW is the Tx frequency bandwidth and C_0 is the speed of light in vacuum. With R_{RES} and the spectral peak position, the target distance may be calculated.

The determination of the target speed requires the Doppler calculation from the RD matrix 35 of one pulse block 4 according to

$$V_{RES} = \frac{N_R - 1}{N_R} \cdot \frac{C_0}{(t_B - T_R) \cdot (f_{start} - f_{stop})} \qquad (18)$$

or simplified,

$$V_{RES} = \frac{C_0}{N_R \cdot T_R \cdot (f_{start} - f_{stop})} \qquad (19)$$

in combination with the calculation of the Dwell signal according to equation (15) (and (16) above.

Although the Dwell signal provides a accurate Doppler estimation it has a relatively low Nyquist speed. By combining the Doppler calculation and the calculation of the Dwell signal an enhanced accuracy can be achieved.

This is possible if a Nyquist hypothesis is determined by using the result of the rough calculation. It should be noted this technique assumes that the accuracy of the coarse method is higher than the Nyquist speed of the fine calculation. Regarding the term Nyquist hypothesis, an FFT has a limited range of values, a Nyquist range. If it also is desired to measure targets outside of this range, it is required to know both the peak

position and the number of ambiguity wraps within the FFT. Here, one wrap is one Nyquist hypothesis.

The main advantage of the SPRT algorithm is that the memory for the IF signal 14 can be released after every processing step, i.e. after every pulse block 4.

This approach results in a plurality of advantages, for example:

- Reduced memory requirements.
- Flexible observation time.
- Negligible signal smear at higher velocity.
- Resolvability of Doppler ambiguities. This can be achieved by analyzing the frequency shift over time in the range dimension.
- Slower Tx ramps possible, which would lead to a lower sampling rate.

The essence of the present disclosure is that the two-dimensional spectrum of the Range-Doppler matrix 35 is fed into a first processing path 30 and a second processing path 31. The first processing path 30 is arranged to produce a periodically updated dwell list 34, and the second processing path 31 is arranged to collect and process data from the Range-Doppler matrix 35 in dependence of the present dwell list 34. By means of the dwell list 34, it is possible for the second processing path 31 to focus the processing efforts for true target detection where there is an increased possibility for presence of objects. The dwell list comprises information where the probability of presence of objects exceeds a certain threshold.

Exactly how this is accomplished may vary, the example disclosed above is only an example, and the processing may be performed in the main control unit 38 which in turn may be comprised by one or more separate or integrated control units. There may be one

main control unit 38 for each transceiver arrangement 52, or one main control unit 38 for the vehicle radar system 3.

With reference to Figure 10, the present disclosure also relates to a method for a vehicle radar system (3), where the method comprises:

53: Generating at least one FMCW (Frequency Modulated Continuous Wave) chirp signal 4a, 4b.

54: Transmitting said at least one chirp signal 4a, 4b, where each chirp signal 4a, 4b comprises a corresponding plurality of frequency ramps r_1, r_2.

55: Receiving reflected signals 5a, 5b.

56: Mixing the received signals 5a, 5b with the respective transmitted chirp signal 4a, 4b to obtain at least one IF (Intermediate Frequency) signal 14.

57: Producing a periodically updated dwell list 34.

58: Collecting and processing data in dependence of the present dwell list 34, where said dwell list 34 comprises information where the probability of presence of objects exceeds a certain threshold.

According to an example, the method further comprises:

59: Converting said IF signals 14 to digital signals 22.

60: Converting the digital signals 22 to a range domain by means of a first FFT (Fast Fourier Transform.

61: Combining the results from successive chirp signal ramps into the Doppler domain by means of a second FFT, such that a plurality of Range-Doppler matrices 35 is obtained.

As indicated in Figure 1, the vehicle 1 comprises a safety control unit 50 and safety means 51, for example an emergency braking system and/or an alarm signal device. The safety control unit 50 is arranged to control the safety means 51 in dependence

of input from the radar system 3. Such input may be input via the main control unit 38.

The present disclosure is not limited to the examples above, but may vary freely within the scope of the appended claims. For example, ramp time T_r does not have to be the same for the first chirp signal 4a and the second chirp signal 4b; and the times between consecutive ramps r_1, r_2 not have to be the same for the first chirp signal 4a and the second chirp signal 4b as well. The first chirp signal 4a and the second chirp signal 4b do not have to be interleaved, but may run at the same time or independently of each other during each block 4. Furthermore, the chirp signals 4a, 4b may be transmitted in any kind of cycles; the pulse blocks 4 described is only an example. When the chirp signals 4a, 4b are interleaved with each other, they may be interleaved in each pulse block 4.

All times mentioned are of course only mentioned by way of example, any suitable times and timing schedules are clearly possible in a radar system according to the above. The ramp may similarly be configured as an up-ramp as described, or a down-ramp, or some combination of both. The magnitude of the first frequency f_{start} may thus exceed the magnitude of the second frequency f_{stop}.

Furthermore, there may be any number of transmitter antenna arrangements 10a, 10b and receiver antenna arrangements 13a, 13b, 13c, 13d, but there is at least one transmitter antenna arrangement and at least one receiver antenna arrangement. There may thus be one or more FMCW chirp signals, having any suitable cycle constitution.

Each antenna arrangement 10a, 10b; 13a, 13b, 13c, 13d may for example comprise on or more antennas, and each antenna may be

constituted by one antenna element or by an array of antenna elements.

If the chirp signals 4a, 4b are interleaved, a ramp in the first chirp signal 4a does thus not have to start exactly when a preceding ramp in the second chirp signal 4b ends, but the start may be either after or before the end of the second chirp signal 4b, and vice versa.

The radar system may be implemented in any type of vehicle such as cars, trucks and buses as well as boats and aircraft.

The schematics of vehicle radar systems are simplified, only showing parts that are considered relevant for an adequate description of the present disclosure. It is understood that the general design of radar systems of this kind is well-known in the art. For example, no devices that are arranged to use the acquired target information is shown, but many different such devices are of course conceivable; for example a warning and/or collision avoidance system.

The number of antenna arrangements, antennas within each antenna arrangement and IF signals may vary.

The ADC arrangement and the DSP arrangement should each one be interpreted as having a corresponding ADC or DSP functionality, and may each be constituted by a plurality of separate components. Alternatively, each ADC arrangement may be comprised in one ADC chip, and each DSP arrangement may be comprised in one DSP chip.

In the example shown, there has only been one receiver channel. Of course, a receiver in this context may be arranged for a plurality of channels.

Generally, the hardware used to generate the radar signal may be active only for part of the cycle period and powered down for the rest of the cycle, i.e. when it is not needed.

The vehicle radar system 3 has been shown having one transceiver arrangement 52; of course the vehicle radar system 3 may comprise two or more transceiver arrangement having the same or different structures, comprising similar or different components. Each transceiver arrangement 52 may comprise control units.

Each chirp signal 4a, 4b may comprise at least one cycle of a corresponding plurality of frequency ramps r_1, r_2. Each chirp signal 4a, 4b may alternatively comprise a corresponding plurality of continuously running frequency ramps r_1, r_2.

Generally, the present disclosure relates to a vehicle radar system 3 comprising at least one transceiver arrangement 52, each of said at least one transceiver arrangement 52 being arranged to generate and transmit a least one FMCW (Frequency Modulated Continuous Wave) chirp signal 4a, 4b, where each chirp signal 4a, 4b comprises a corresponding plurality of frequency ramps r_1, r_2, where the vehicle radar system 3 is arranged to receive reflected signals 5a, 5b and to mix the received signals 5a, 5b with the respective transmitted chirp signal 4a, 4b to obtain at least one IF, Intermediate Frequency, signal 14, wherein the vehicle radar system 3 further is arranged to produce a periodically updated dwell list 34, and to collect and process data in dependence of the present dwell list 34, where said dwell list 34 comprises information where the probability of presence of objects exceeds a certain threshold.

According to an example, each of said at least one transceiver arrangement 52 is arranged to:

- convert said IF signals 14 to digital signals 22,
- convert the digital signals 22 to a range domain by means of a first FFT (Fast Fourier Transform) and to
- combine the results from successive chirp signal ramps into the Doppler domain by means of a second FFT,

such that a plurality of Range-Doppler matrices 35 is obtained.

According to an example, the vehicle radar system 3 is arranged to feed the two-dimensional spectrum of each Range-Doppler matrix 35 into a first processing path 30 and a second processing path 31, where the first processing path 30 is arranged to produce said dwell list 34, and where the second processing path 31 is arranged to collect and process data from each Range-Doppler matrix 35 in dependence of said dwell list 34.

According to an example, each transceiver arrangement 52 comprises a signal generator 9 and is arranged to transmit a first chirp signal 4a and a second chirp signal 4b.

According to an example, the chirp signals 4a, 4b are timed such that between two consecutive ramps of the first chirp signal 4a there is ramp of the second chirp signal 4b and vice versa such that the chirp signals 4a, 4b are interleaved with each other.

According to an example, each chirp signal 4a, 4b comprises a corresponding plurality of frequency ramps r_1, r_2 formed in pulse blocks 4, where each pulse block 4 has a duration of a block time t_B with an idle time t_i between two consecutive pulse blocks 4, where furthermore each pulse block 4 comprises said chirp signal 4a, 4b and where there is no chirp signal during the idle time t_i.

According to an example, the radar system 3 is arranged to combine pulse blocks 4 by means of a Sequential Probability Ratio Test (SPRT) algorithm.

According to an example, the radar system 3 is arranged to provide input to a safety control unit 35 that in turn is arranged to control safety means 36, where the radar system 3, the safety control unit 35 and the safety means 36 are comprised in a vehicle 1.

Generally, the present disclosure also relates to a method for a vehicle radar system 3, where the method comprises:

53: generating at least one FMCW (Frequency Modulated Continuous Wave) chirp signal 4a, 4b;

54: transmitting said at least one chirp signal 4a, 4b, where each chirp signal 4a, 4b comprises a corresponding plurality of frequency ramps r_1, r_2;

55: receiving reflected signals 5a, 5b; and

56: mixing the received signals 5a, 5b with the respective transmitted chirp signal 4a, 4b to obtain at least one IF, Intermediate Frequency, signal 14;

wherein the method further comprises:

57: producing a periodically updated dwell list 34; and

58: collecting and processing data in dependence of the present dwell list 34, where said dwell list 34 comprises information where the probability of presence of objects exceeds a certain threshold.

According to an example, the method comprises:

59: converting said IF signals 14 to digital signals 22;

60: converting the digital signals 22 to a range domain by means of a first FFT (Fast Fourier Transform) and

61: combining the results from successive chirp signal ramps into the Doppler domain by means of a second FFT;
such that a plurality of Range-Doppler matrices 35 is obtained.

According to an example, the method comprises feeding the two-dimensional spectrum of each Range-Doppler matrix 35 into a first processing path 30 and a second processing path 31, where the first processing path 30 is used for producing said dwell list 34, and where the second processing path 31 is used for collecting and processing data from each Range-Doppler matrix 35 in dependence of said dwell list 34.

According to an example, there is a first chirp signal 4a and a second chirp signal 4b, where the chirp signals 4a, 4b are timed such that between two consecutive ramps of the first chirp signal 4a there is ramp of the second chirp signal 4b and vice versa such that the chirp signals 4a, 4b are interleaved with each other.

According to an example, each chirp signal 4a, 4b has a corresponding plurality of frequency ramps r_1, r_2 formed in pulse blocks 4, where each pulse block 4 has a duration of a block time t_B with an idle time t_i between two consecutive pulse blocks 4, where furthermore each pulse block 4 comprises said chirp signal 4a, 4b and where there is no chirp signal during the idle time t_i.

According to an example, the method further comprises combining pulse blocks 4 using a Sequential Probability Ratio Test (SPRT) algorithm.

CLAIMS

1. A vehicle radar system (3) comprising at least one transceiver arrangement (52), each of said at least one transceiver arrangement (52) being arranged to generate and transmit a least one FMCW, Frequency Modulated Continuous Wave, chirp signal (4a, 4b), where each chirp signal (4a, 4b) comprises a corresponding plurality of frequency ramps (r_1, r_2), where the vehicle radar system (3) is arranged to receive reflected signals (5a, 5b) and to mix the received signals (5a, 5b) with the respective transmitted chirp signal (4a, 4b) to obtain at least one IF, Intermediate Frequency, signal (14), **characterized in** that the vehicle radar system (3) further is arranged to produce a periodically updated dwell list (34), and to collect and process data in dependence of the present dwell list (34), where said dwell list (34) comprises information where the probability of presence of objects exceeds a certain threshold.

2. A vehicle radar system (3) according to claim 1, **characterized in** that each of said at least one transceiver arrangement (52) is arranged to:

- convert said IF signals (14) to digital signals (22),
- convert the digital signals (22) to a range domain by means of a first FFT, Fast Fourier Transform, and to
- combine the results from successive chirp signal ramps into the Doppler domain by means of a second FFT,

such that a plurality of Range-Doppler matrices (35) is obtained.

3. A vehicle radar system (3) according to claim 2, **characterized in** that the vehicle radar system (3) is arranged to feed the two-dimensional spectrum of each Range-Doppler matrix (35) into a first processing path (30) and a second processing path (31), where the first processing path (30) is arranged to produce said dwell list (34), and where the second

processing path (31) is arranged to collect and process data from each Range-Doppler matrix (35) in dependence of said dwell list (34).

4. A vehicle radar system (3) according to any one of the preceding claims, **characterized in** that each transceiver arrangement (52) comprises a signal generator (9) and is arranged to transmit a first chirp signal (4a) and a second chirp signal (4b).

5. A vehicle radar system (3) according to claim 4, **characterized in** that the chirp signals (4a, 4b) are timed such that between two consecutive ramps of the first chirp signal (4a) there is ramp of the second chirp signal (4b) and vice versa such that the chirp signals (4a, 4b) are interleaved with each other.

6. A vehicle radar system (3) according to any one of the preceding claims, **characterized in** that each chirp signal (4a, 4b) comprises a corresponding plurality of frequency ramps (r_1, r_2) formed in pulse blocks (4), where each pulse block (4) has a duration of a block time (t_B) with an idle time (t_i) between two consecutive pulse blocks (4), where furthermore each pulse block (4) comprises said chirp signal (4a, 4b) and where there is no chirp signal during the idle time (t_i).

7. A vehicle radar system (3) according to claim 6, **characterized in** that the radar system (3) is arranged to combine pulse blocks (4) by means of a Sequential Probability Ratio Test, SPRT, algorithm.

8. A vehicle radar system (3) according to any one of the preceding claims, **characterized in** that the radar system (3) is arranged to provide input to a safety control unit (35) that in

turn is arranged to control safety means (36), where the radar system (3), the safety control unit (35) and the safety means (36) are comprised in a vehicle (1).

9. A method for a vehicle radar system (3), where the method comprises:

(53) generating at least one FMCW, Frequency Modulated Continuous Wave, chirp signal (4a, 4b);

(54) transmitting said at least one chirp signal (4a, 4b), where each chirp signal (4a, 4b) comprises a corresponding plurality of frequency ramps (r_1, r_2);

(55) receiving reflected signals (5a, 5b); and

(56) mixing the received signals (5a, 5b) with the respective transmitted chirp signal (4a, 4b) to obtain at least one IF, Intermediate Frequency, signal (14);

characterized in that the method further comprises:

(57) producing a periodically updated dwell list (34); and

(58) collecting and processing data in dependence of the present dwell list (34), where said dwell list (34) comprises information where the probability of presence of objects exceeds a certain threshold.

10. A method according to claim 9, **characterized in** that the method comprises:

(59) converting said IF signals (14) to digital signals (22);

(60) converting the digital signals (22) to a range domain by means of a first FFT, Fast Fourier Transform; and

(61) combining the results from successive chirp signal ramps into the Doppler domain by means of a second FFT;

such that a plurality of Range-Doppler matrices (35) is obtained.

11. A method according to claim 10, **characterized in** that the method comprises feeding the two-dimensional spectrum of each Range-Doppler matrix (35) into a first processing path (30) and a second processing path (31), where the first processing path (30) is used for producing said dwell list (34), and where the second processing path (31) is used for collecting and processing data from each Range-Doppler matrix (35) in dependence of said dwell list (34).

12. A method according to any one of the claims 9-11, **characterized in** that there is a first chirp signal (4a) and a second chirp signal (4b), where the chirp signals (4a, 4b) are timed such that between two consecutive ramps of the first chirp signal (4a) there is ramp of the second chirp signal (4b) and vice versa such that the chirp signals (4a, 4b) are interleaved with each other.

13. A method according to any one of the claims 9-12, **characterized in** that each chirp signal (4a, 4b) has a corresponding plurality of frequency ramps (r_1, r_2) formed in pulse blocks (4), where each pulse block (4) has a duration of a block time (t_B) with an idle time (t_i) between two consecutive pulse blocks (4), where furthermore each pulse block (4) comprises said chirp signal (4a, 4b) and where there is no chirp signal during the idle time (t_i).

14. A method according to claim 13, **characterized in** that the method further comprises combining pulse blocks (4) using a Sequential Probability Ratio Test, SPRT, algorithm.

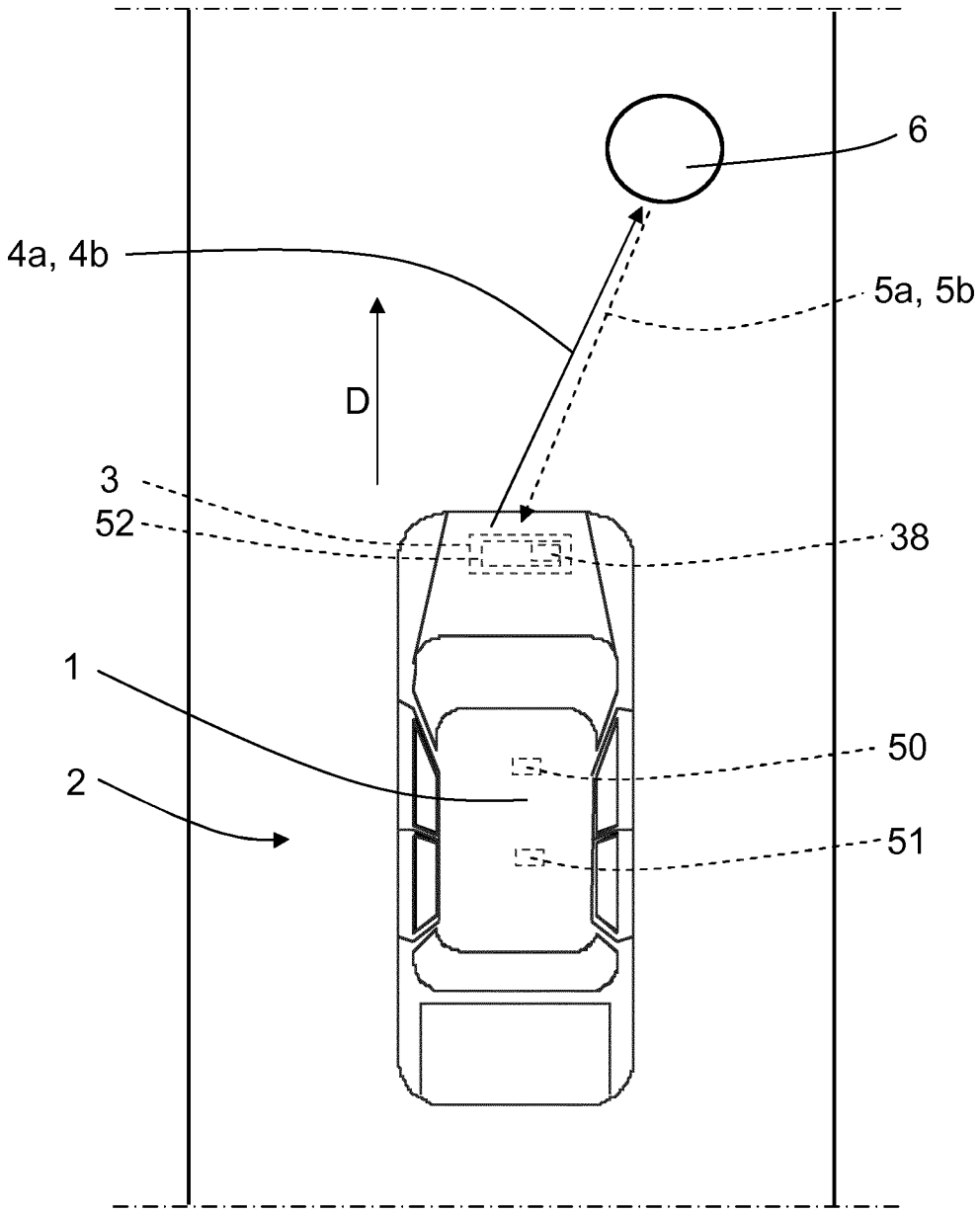


FIG. 1

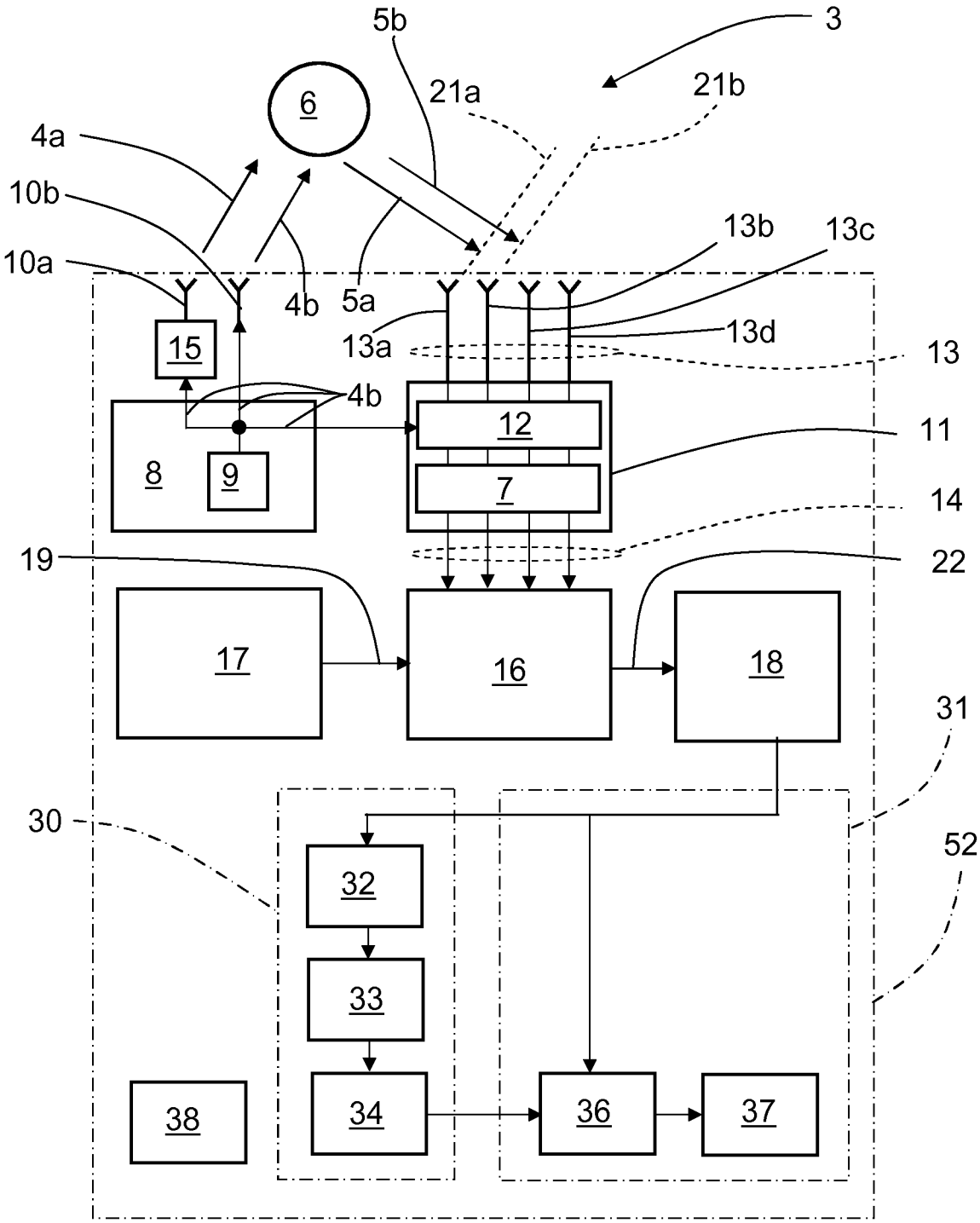

5b
3
6
21a
21b
4a
10b
10a
13b
13c
4b
5a
13a
13d
13
15
4b
12
11
8
9
7
14
19
22
17
16
18
31
30
52
32
33
38
34
36
37

FIG. 2

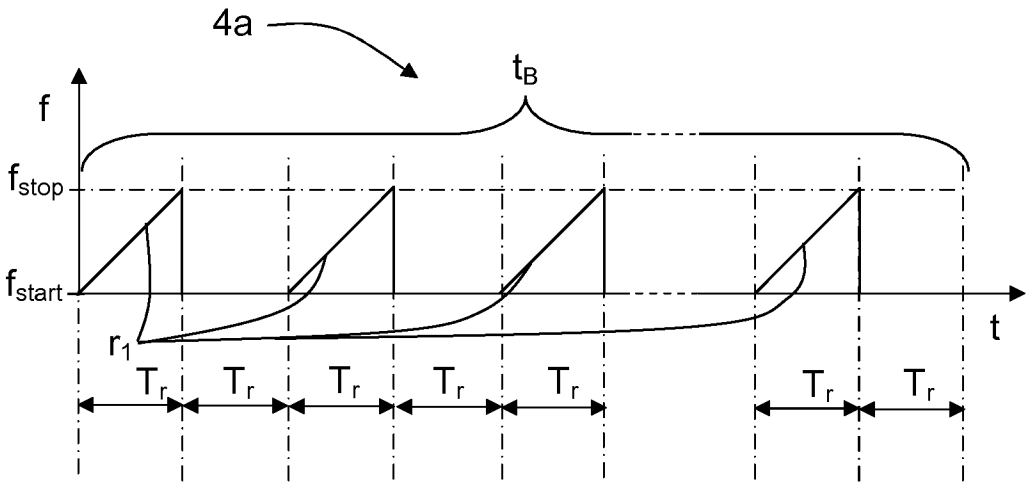

4a
t_B
f
f_{stop}
f_{start}
r_1
t
T_r
T_r
T_r
T_r
T_r
T_r
T_r

FIG. 3a

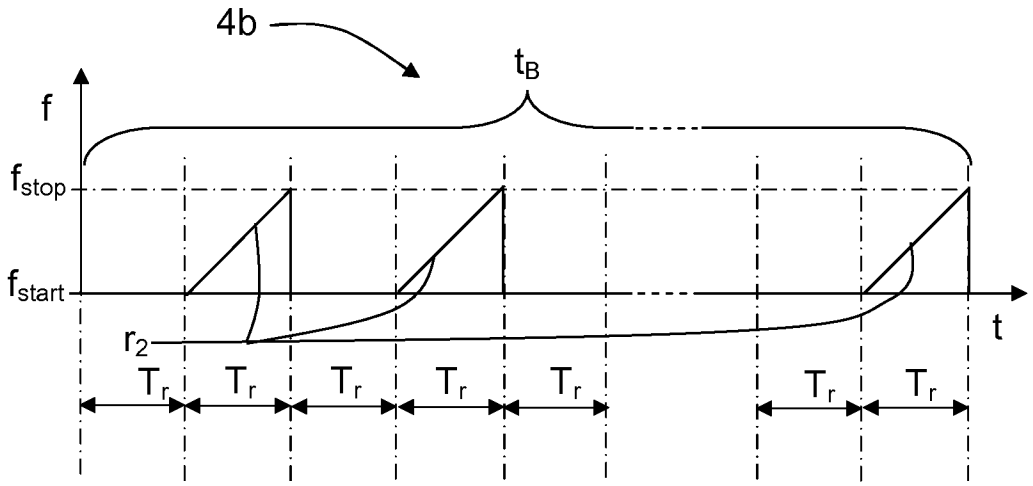

4b
t_B
f
f_{stop}
f_{start}
r_2
t
T_r
T_r
T_r
T_r
T_r
T_r
T_r

FIG. 3b

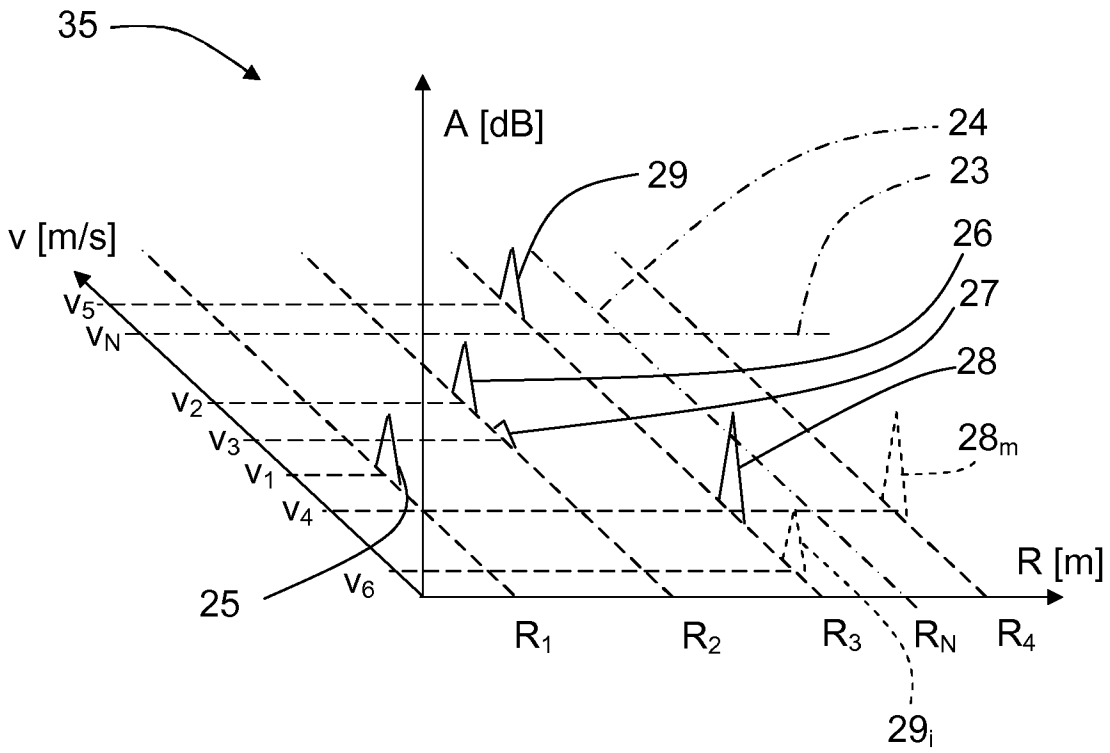

35
A [dB]
24
29
23
v [m/s]
26
27
v_5
v_N
28
v_2
v_3
28_m
v_1
v_4
R [m]
v_6
25
R_1
R_2
R_3
R_N
R_4
29_i

FIG. 4

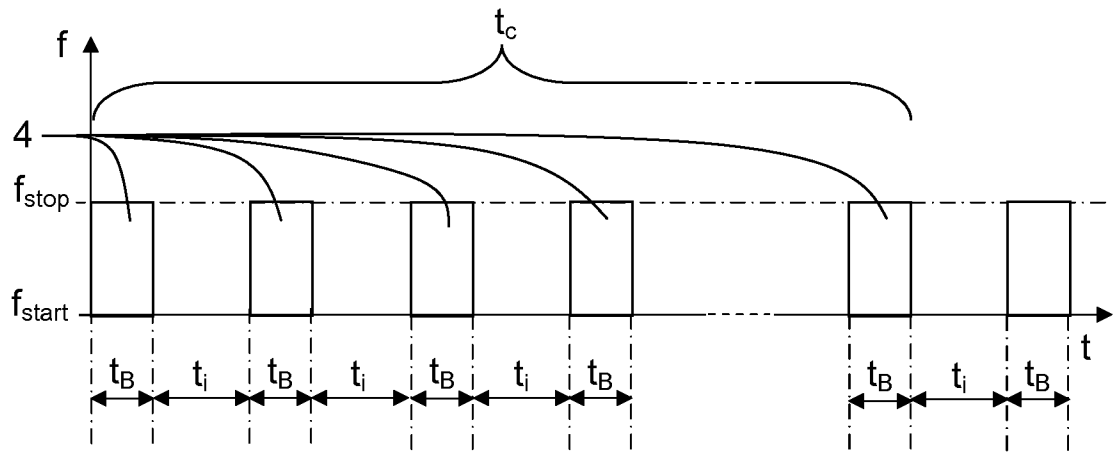

f
t_c
4
f_{stop}
f_{start}
t
t_B
t_i
t_B
t_i
t_B
t_i
t_B
t_B
t_i
t_B

FIG. 5

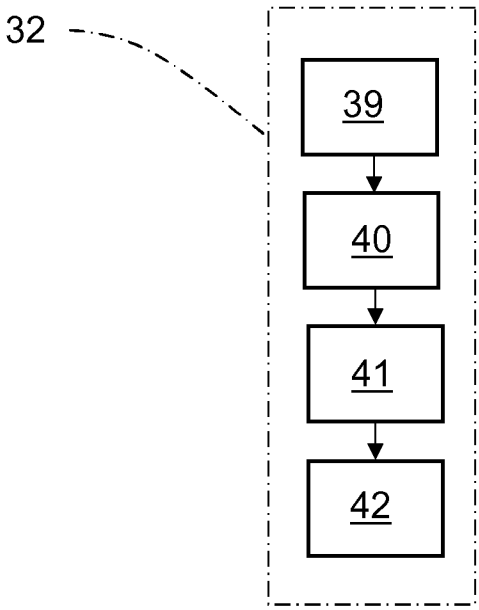

32
39
40
41
42

FIG. 6

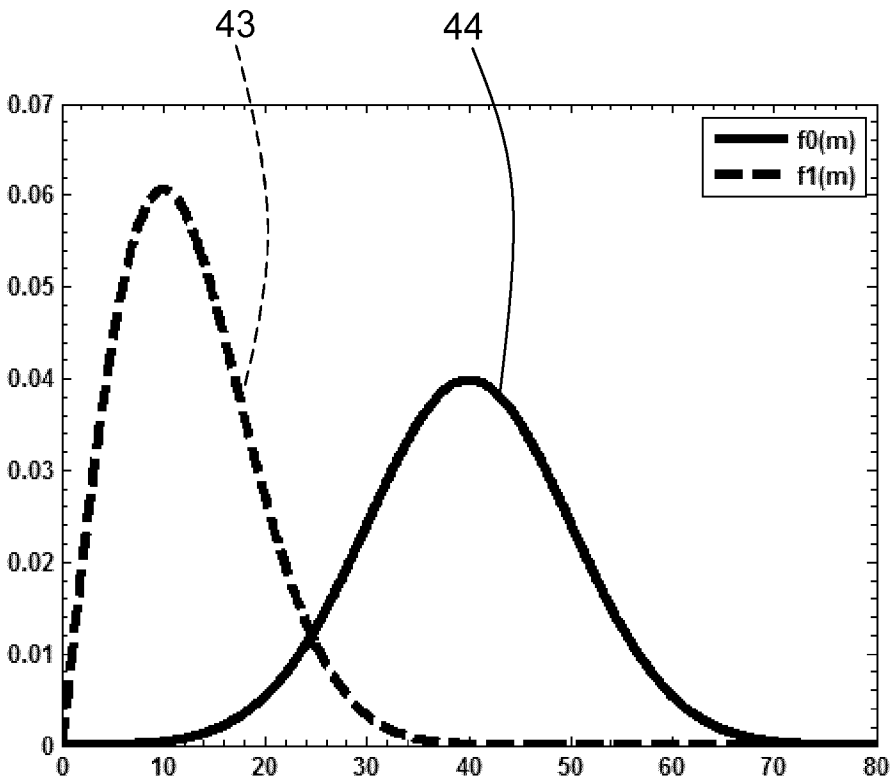

43
44
f0(m)
f1(m)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
10
20
30
40
50
60
70
80

FIG. 7

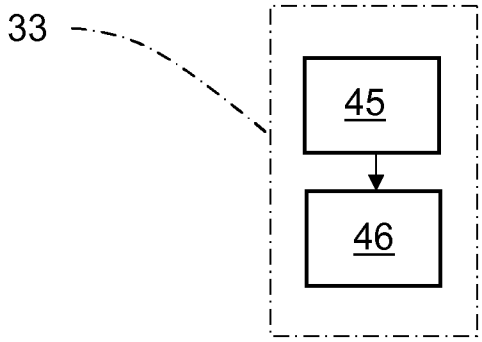


FIG. 8

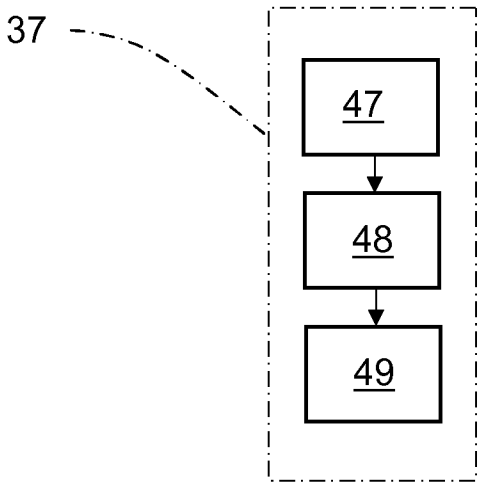


FIG. 9

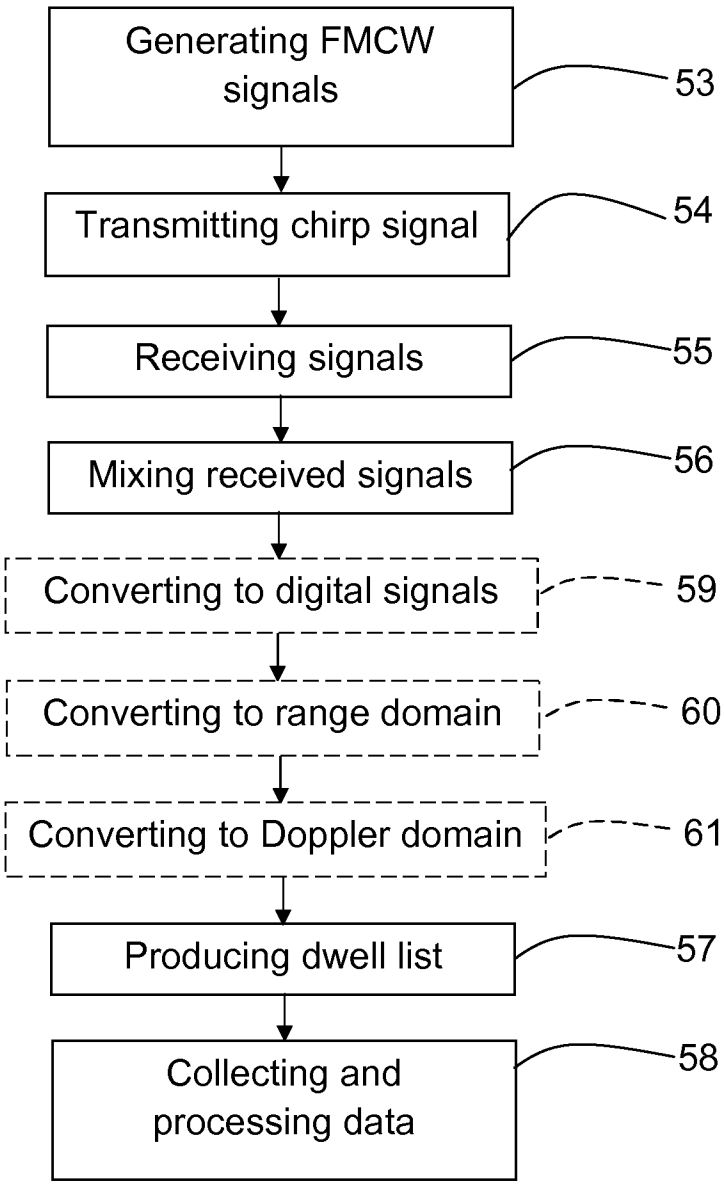

Generating FMCW signals
53
Transmitting chirp signal
54
Receiving signals
55
Mixing received signals
56
Converting to digital signals
59
Converting to range domain
60
Converting to Doppler domain
61
Producing dwell list
57
Collecting and processing data
58

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/061412

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S13/34 G01S13/58 G01S13/72 G01S13/93 G01S7/35
ADD.

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

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, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 045 877 A1 (DELPHI TECH INC [US]) 8 April 2009 (2009-04-08)	1-6,8-13
Y	column 3, line 45 - column 4, line 21 column 5, line 39 - column 6, line 36 column 7, line 6 - column 8, line 21 column 9, line 5 - line 22 figures 1-8	7,14

Y	US 2006/152405 A1 (EGRI ROBERT G [US] ET AL) 13 July 2006 (2006-07-13) paragraph [0006] - paragraph [0050] figures 1-7	7,14

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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 :

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"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
13 July 2016	20/07/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Köppe, Maro

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/061412

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 416 488 A (GROVER RICHARD K [AZ] ET AL) 16 May 1995 (1995-05-16) column 1, line 5 - line 10 column 3, line 9 - column 4, line 7 column 5, line 3 - column 7, line 10 figures 1-7	1-14
A	US 2011/025546 A1 (COOK CARL D [US] ET AL) 3 February 2011 (2011-02-03) paragraph [0029] - paragraph [0039] figures 3-13, 15	1-14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/061412

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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