



(51) International Patent Classification:

G01S 7/02 (2006.01) *G01R* 23/15 (2006.01)
G01S 7/292 (2006.01)

(21) International Application Number:

PCT/GB2014/000067

(22) International Filing Date:

27 February 2014 (27.02.2014)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1303646.2 1 March 2013 (01.03.2013) GB

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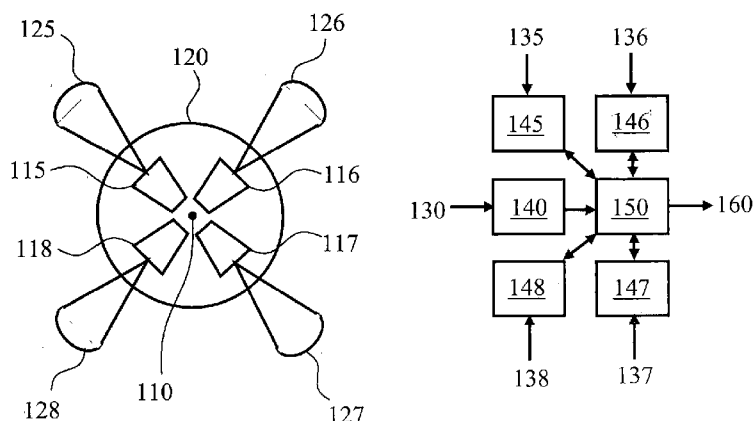
(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: A RADAR RECEIVER AND RADAR DETECTION METHOD

**Fig. 1**

(57) **Abstract:** There is provided a radar receiver, comprising a primary receiver (140) for connecting to a primary antenna (110), and a secondary receiver (145, 146, 147, 148) for connecting to a secondary antenna (115, 116, 117, 118). The primary receiver (140) has a greater sensitivity than the secondary receiver (145, 146, 147, 148). The primary receiver (140) is configured to detect a radar signal and to generate a trigger signal in response to detecting the radar signal, wherein the secondary receiver (145, 146, 147, 148) is configured to receive the trigger signal and to search for the radar signal, the search being based upon timing information carried by the trigger signal. There is further provided a method of detecting a radar signal at a secondary receiver, the detection being based upon a detection of the radar signal at a primary receiver having a greater sensitivity than the secondary radar receiver.

A RADAR RECEIVER AND RADAR DETECTION METHOD

Technical Field of the Invention

The invention relates to a radar receiver and a method of detecting a radar signal, for example for determining what radar systems are operating in the vicinity of the radar receiver.

Background to the Invention

Radar systems typically emit radar signals comprised of multiple radar pulses. The radar pulses are transmitted by the radar system transmitter, and then received by the radar system receiver at later times following reflection from various objects in the path of the transmitted radar pulses.

There is a desire to detect what radar systems are operating nearby, so that the characteristics of the radar systems can be determined, for example the direction of the radar system from a given location.

The document US 6,388,604 discloses a receiver for detecting radar signals from radar systems, the receiver having multiple channels of the same capability, each channel having its own antenna, frequency down-converter, and analogue-to-digital converter.

However, the amount of processing to be performed by such a receiver may make it prohibitively expensive to implement, particularly if the digital receiver is to monitor a large range of frequencies at high sensitivities, requiring the use of high-quality and low-noise components.

It is therefore an aim of the invention to improve upon the known art.

Summary of the Invention

According to a first aspect of the invention, there is provided a radar receiver, comprising a primary receiver for connecting to a primary antenna, and a secondary receiver for connecting to a secondary antenna. The primary receiver has a greater sensitivity than the

secondary receiver. The primary receiver is configured to detect a radar signal and to generate a trigger signal in response to detecting the radar signal. The secondary receiver is configured to receive the trigger signal and to search for the radar signal, the search being based upon timing information carried by the trigger signal.

Accordingly, a single sensitive receiver can be used in conjunction with a less sensitive receiver to gain further information on a received radar signal than could be determined by the sensitive receiver alone. The sensitive (primary) receiver is used to trigger the less sensitive (secondary) receiver to help compensate for the lower sensitivity of the secondary receiver, and means that the secondary receiver can be a lower-cost and/or wider bandwidth receiver than the primary receiver. For example, the primary receiver could use digital signal processing to increase sensitivity whilst the secondary receiver could be based upon Detector Log Video Amplifiers (DLVA's) to provide large dynamic range and bandwidth, as is known to those skilled in the art.

The sensitivity of a receiver is closely related to the bandwidth of the receiver, according to the well-known relation of noise power = Boltzmann's constant*Temperature*Bandwidth, meaning that the greater the bandwidth the lower the signal to noise ratio for a given signal will be, as will be apparent to those skilled in the art. Accordingly, the bandwidth of the secondary receiver may be greater than the bandwidth of the primary receiver to provide greater detection bandwidth at the secondary receiver, whilst providing greater sensitivity at the primary receiver than at the secondary receiver.

Alternatively, the bandwidths of the primary and secondary receiver could be the same but different sampling techniques used to generate a higher sensitivity primary receiver and a lower cost secondary receiver. For example, the primary receiver could oversample radar signals and the secondary receiver could undersample the radar signals.

The radar receiver may comprise a plurality of the secondary receivers, each of the secondary receivers configured to receive the trigger signal and to search for the radar signal, the search being based upon timing information carried by the trigger signal. Each of the secondary receivers may be connectable to a respective secondary antenna.

The radar receiver may further comprise a signal processor connected to each secondary receiver, the signal processor configured to receive an output signal of each secondary receiver to help determine a direction of a transmitter of the radar signal, for example by collating together output signals from a plurality of the secondary receivers and using amplitude, phase, frequency or time-of-arrival information with commonly known location algorithms, that will be apparent to those skilled in the art.

The signal processor may be connected to the primary receiver, and may collate an output signal of the primary receiver with output signal(s) from one or more secondary receivers to help determine a direction of a transmitter of the radar signal.

The signal processor may communicate the trigger signal from the primary receiver to the secondary receiver(s). Optionally, the signal processor may format the trigger signal from the primary receiver into a format that the secondary receiver(s) are configured to understand.

The primary receiver, secondary receiver(s), and signal processor may be formed as electronic circuitry of the radar receiver. The signal processor may be a DSP chip, or may be formed from multiple electronic components distributed throughout the radar receiver circuitry. The radar receiver may comprise an enclosure that houses the primary receiver, secondary receiver(s), and signal processor.

The determined direction is typically a direction from the secondary and/or primary antennas to the transmitter. The determined direction may for example be a particular geographical direction determined with reference to a known configuration of primary/secondary antennas, for example the determined direction may be expressed in terms of an angle of arrival relative a reference direction of the antenna configuration.

Alternatively, the determined direction may simply be provided in terms of the primary/secondary antennas, rather than in terms of any particular cartographic reference directions. For example if there are two secondary antennas then the determined direction may simply be information stating that the transmitter is closer to one secondary antenna than the other secondary antenna, such as when a stronger signal is received at the one secondary antenna than at the other secondary antenna, or when the one secondary antenna receives the radar signal before the other secondary antenna. As another example, if the secondary

antennas are directional, then the determined direction may simply be information stating that the transmitter is nearer the direction of a first one of the secondary antennas than the direction of a second one of the secondary antennas, such as when a stronger signal is received at the first secondary antenna than the second secondary antenna. The cartographic direction, for example North, East, South, or West, could be determined subsequently by the radar receiver, or by some other apparatus connected to the radar receiver that is aware of the positions/directions of the antennas.

Advantageously, the timing information carried by the trigger signal may comprise a repetition rate of radar pulses of the radar signal, and the repetition rate may be carried by the trigger signal by virtue of times when the trigger signal is sent to the receiver, or by virtue of a repetition rate indicated within data of the trigger signal. The trigger signal may for example be sent to the secondary receivers at regular intervals corresponding to the repetition rate of radar pulses of the radar signal, to inform the secondary receivers of the repetition rate. The secondary receivers may use the repetition rate to help search for the radar signal, for example by searching for radar pulses that occur at the repetition rate.

The timing information carried by the trigger signal may comprise a time of arrival of a radar pulse of the radar signal. The secondary receivers may use the time of arrival to help search for the radar pulses, for example each secondary receiver may be configured to search a part of an RF signal that was received at the time of arrival indicated by the trigger signal. The time of arrival may be specified to provide a resolution of less than 100ms, so that the radar pulses of the radar signal can be found at the secondary receiver without needing to check an excessive time span of an RF signal received at the secondary receiver.

The time of arrival may for example be the time when the primary antenna would have received the radar pulse, the time when the primary receiver received the radar pulse, or if the primary receiver has sufficient knowledge of the configuration of the secondary antennas and secondary receivers, the time when the primary receiver calculates the secondary antenna or the secondary receiver would have received the radar pulse.

Advantageously, the time of arrival of the radar pulse may be carried by the trigger signal by virtue of the time when the trigger signal is sent to the secondary receivers. Then, the trigger signal may be a single pulse which is sent to the secondary receivers each time that the

primary receiver determines that a radar pulse of the radar signal has been received. Alternatively, the trigger signal may comprise data that can be read by the secondary receivers, and the data may include a timestamp indicating when a radar pulse of the radar signal was received.

The trigger signal may be comprised of multiple signals that communicate timing information relating to the radar signal from the primary receiver to the secondary receivers.

Advantageously, the search performed by each secondary radar receiver may comprise defining multiple time segments of an RF signal received from a secondary antenna associated with the secondary radar receiver. The times of the multiple time segments are set according to the timing information carried by the trigger signal, so that it is known that a radar signal pulse exists within each one of the multiple time segments. The times of the time segments may for example comprise one or more of start times of the multiple time segments, end times of the multiple time segments, duration times of the multiple time segments.

Each secondary radar receiver may be configured to temporally overlay the multiple time segments of the RF signal received from the secondary antenna associated with the secondary radar receiver, based on the timing information, such that a radar pulse of the radar signal occurs in each one of the multiple time segments at substantially the same time. For example, the trigger signal may indicate that a radar pulse occurs at time T1, the time T1 being within a first time segment, that another radar pulse occurs at a later time T2, the time T2 being within a second time segment, and that still another radar pulse occurs at a still later time T3, the time T3 being within a third time segment. The temporal overlaying of the multiple time segments may be done such that the times T1, T2, and T3 all occur at a same time as one another, so that combining the temporally overlaid multiple time segments together has the effect of amplifying the radar signal pulses.

The temporally overlaid multiple time segments may be combined or integrated together to reconstruct a radar pulse of the radar signal. Continuing the example directly above, the radar pulse, the another radar pulse, and the still another radar pulse may be combined together to re-construct a radar pulse of the radar signal. Combining multiple pulses together in this way will help to amplify the radar signal above noise, increasing the effective sensitivity of the

secondary receiver. Clearly, the more time segments that are temporally overlaid with one another, the greater the improvement in sensitivity will be.

Advantageously, each secondary radar receiver may be configured to determine an intersection of the temporally overlaid multiple time segments to reconstruct a radar pulse of the radar signal, for example by calculating the product of the temporally overlaid multiple time segments at each moment of time covered by the temporally overlaid multiple time segments.

Calculating the intersection of the temporally overlaid multiple time segments with one another may enable the radar pulses received at the secondary antennas to be amplified above the noise floors of the secondary receivers, thereby enabling the secondary receivers to gather information upon the radar pulses that they would not have been able to gather had the more-sensitive primary receiver not received the radar pulses and sent the timing information to the less-sensitive secondary receivers. The gathered information may for example comprise times of arrival of the radar pulses at the various secondary antennas/receivers, and/or signal intensities of the radar pulses at the various secondary antennas/receivers, enabling the direction of the radar signal source to be determined.

The above temporal overlaying and intersection calculation of the multiple time segments is similar to performing a cross-correlation of the multiple time segments, but does not constitute a cross-correlation, since the intersection of the multiple time segments is only calculated when the relative temporal positions of the multiple time segments are set according to the timing information in the trigger signal, so that all the multiple time segments have a radar pulse at the same time. The intersection is not calculated at all possible relative temporal positions of the multiple time segments, thereby saving considerable processing time.

The above reconstruction of the radar pulse assumes that all the radar pulses of the radar signal have the same pulse shape as one another, as is often the case in radar systems currently in use. If the radar pulses of the radar signal have different pulse shapes to one another, then the reconstructed radar pulse will have an average pulse shape of the radar pulses of the radar signal, which should still provide useful information on the radar pulses.

Some direction finding techniques may only require the difference in received radar signal amplitudes between multiple receivers, without needing any information on the actual pulse shape. According, the multiple time segments may be combined together in another way without temporally overlaying them, for example by integrating or otherwise combining the multiple time segments to produce an output value, the magnitude of the output value indicating the strength of the radar signal.

The multiple time segments may comprise an initial time segment followed by subsequent time segments, and the start time of the initial time segment may be set according to the time of arrival carried by the trigger signal. The start times of the subsequent time segments may also be determined according to the timing information carried by the trigger signal. For example, the start times of the subsequent time segments may be determined according to the start time of the initial time segment, and according to a repetition rate carried by the trigger signal that enables the start times of the subsequent time segments relative to the start time of the initial time segment to be calculated.

The start times of the initial time segment may be set to be a fixed duration of time before the time of arrival carried by the trigger signal, such that the initial time segment fully contains the radar pulse that caused the generation of the trigger signal by the primary receiver. The start time of each subsequent radar segment may also be set to be a fixed duration of time before a subsequent radar pulse, either by receiving another trigger signal indicating that a subsequent radar pulse has been received, or by calculating when a subsequent pulse would have been received in the case where the trigger signal comprises data stating the pulse repetition rate. Then, temporally overlaying all of the multiple time segments without any temporal offsets between their start times should result in all of the radar pulses coinciding with one another, so that calculating the intersection of the temporally overlaid multiple time segments results in a reconstruction of the radar pulse.

Advantageously, the timing information carried by the trigger signal may comprise a pulse width of radar pulses of the radar signal, and a time duration of each one of the multiple time segments may be determined according to the pulse width. For example, the time durations of the multiple time segments may be set to be a multiple of the pulse width, the multiple being greater than 1, or the time durations may be set to be a fixed amount of time greater than the pulse width.

The trigger signal may further carry a frequency of the radar signal, and each secondary radar receiver may be configured to filter the RF signal received from the secondary antenna connected to the secondary radar receiver according to the frequency. The filtering may be done upon the RF signal, upon the multiple time segments, or upon the reconstructed radar pulse. Filtering out the frequencies of the RF signal that do not correspond to the radar signal may help to reduce the noise in the RF signal and/or reconstructed radar pulses.

According to a second aspect of the invention, there is provided a radar receiver system comprising the radar receiver described above, a primary antenna connected to the primary receiver, and a secondary antenna connected to the secondary receiver. The primary and secondary antennas may be located at the same location as one another, for example on the same structure as one another, such as on the same vehicle or ship, or on the same antenna tower.

A plurality of the secondary receivers and a plurality of respective secondary antennas may be comprised in the radar receiver system, to add to the accuracy of information on the radar signal that can be obtained by the radar receiver system.

The field of view of the secondary antenna(s) preferably fall within the field of view of the primary antenna, but the primary and secondary antenna(s) may have different directivities to one another. Both primary and secondary antenna(s) are capable of receiving the same signal of interest simultaneously, in the case of multiple secondary antennas at least one secondary antenna needs to be able to receive the same signal of interest as the primary antenna.

The primary antenna preferably has a wider field of view than the secondary antenna, enabling the primary antenna to monitor a wide range of directions for radar signals, and enabling the signal from the secondary antenna to provide useful directional information based upon the direction in which the secondary antenna is pointing.

Advantageously, the field of view of the secondary antenna may overlap the field of view of the primary antenna, to assist the secondary antenna in picking up radar signals that are received by the primary antenna, without needing to rotate the primary and secondary antennas.

Advantageously, the primary antenna may be an omnidirectional antenna, and the secondary antenna may be a directional antenna. In the case where a plurality of directional secondary antennas are connected to a plurality of respective secondary receivers comprised in the radar receiver, the plurality of secondary antennas may be directed in different directions to one another.

According to a third aspect of the invention, there is provided a method of detecting a radar signal at a secondary receiver, the detection being based upon a detection of the radar signal at a primary receiver having a greater sensitivity than the secondary radar receiver, the method comprising:

- detecting the radar signal at the primary receiver;
- generating a trigger signal in response to the detected radar signal, the trigger signal comprising timing information of the detected radar signal;
- receiving the trigger signal at a secondary receiver; and
- searching for the radar signal at the secondary receiver, the search being based upon the timing information received by the secondary receiver within the trigger signal.

The detection of the radar signal at the secondary radar receiver enables gathering of further information concerning the radar signal than could be obtained by the primary receiver alone, for example by virtue of the signal processing capabilities of the secondary receiver compared to the primary receiver, or by virtue of comparing the measurements taken by the primary and secondary radar receivers.

Advantageously, the primary receiver may receive the radar signal from a primary antenna, and the secondary receiver may receive the radar signal from a secondary antenna, the primary antenna and the secondary antenna potentially differing in positions, bandwidths and/or gains.

The method may further comprise any one or more of the actions described above in relation to the radar detector.

Brief Description of the Drawings

Embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Fig. 1 shows a plan schematic diagram of a radar receiver system comprising primary and secondary antennas connected to primary and secondary receivers according to an embodiment of the invention;

Fig. 2 shows a schematic diagram of one example of primary and secondary receivers suitable for use in the Fig. 1 embodiment;

Fig. 3 shows a schematic diagram of another example of primary and secondary receivers suitable for use in the Fig. 1 embodiment; and

Fig. 4 shows a flow diagram of a method according to an embodiment of the invention.

The drawings are for illustrative purposes only and are not to scale.

Detailed Description

An embodiment of the invention will now be described with reference to the schematic diagram of Fig. 1, which shows plan schematic diagram of a radar receiver system comprising primary 110 and secondary 115-118 antennas, primary 140 and secondary 145-148 receivers, and a signal processor 150.

The primary antenna 110 is an omnidirectional antenna and having a response illustrated by the curve 120. The secondary antennas 115 - 118 are directional antennas in the form of a horn antennas directed horizontally, and have directional responses illustrated by the curves 125- 128.

The primary antenna 110 is connected to the primary receiver 140 via a connection 130 (only partially shown in Fig. 1 for clarity), and the secondary antennas 115 - 118 are connected to respective ones of the secondary receivers 145 - 148 by respective connections 135 - 138 (only partially shown in Fig. 1 for clarity). The connections 135 - 138 are formed by co-axial cables connected between each secondary antenna and the respective secondary receiver.

The primary receiver 140 is a high sensitivity, narrowband receiver configured to detect radar signals and to generate a trigger signal in response to detecting a radar signal. The primary receiver 140 is connected to the signal processor 150, and is configured to send information upon the detected radar signal and a trigger signal to the signal processor 150.

The secondary receivers 145 – 148 are lower sensitivity, wideband receivers configured to search for the radar signal in response to receiving the trigger signal generated by the primary receiver 140. The search is based upon timing information carried by the trigger signal. The secondary receivers 145 - 148 are connected to the signal processor 150, and are configured to send information about the radar signal to the signal processor 150, and to receive the trigger signal from the primary receiver 140 via the signal processor 150.

The signal processor 150 gathers the information on the radar signal from the secondary receivers together, and determines a direction of a source of the radar signal based upon the differences in the radar signal reported by the secondary receivers. In particular, the signal processor may compare signal strengths of the radar signal at the various secondary receivers, in conjunction with the directions in which the secondary antennas point, in order to determine the direction of the radar source. The secondary receiver connected to the secondary antenna that is directed closest to the direction of the radar source, will clearly report the strongest signal strength. The direction of the radar source is output at output 160. The signal processor 150 may comprise electronic circuitry distributed between the primary and secondary receivers.

The bandwidth of the primary receiver is narrower than that of the secondary receivers, leading to the higher sensitivity of the primary receiver. For example, the primary receiver may have a bandwidth of 500MHz and the secondary receivers may each have a bandwidth of 16GHz.

One example of the primary and secondary receivers will now be described with reference to Fig. 2, which shows a primary receiver 240 and a secondary receiver 245. The primary receiver 240 receives an input signal 230 from a primary antenna such as the primary antenna 110, and the secondary receiver 245 receives an input signal 235 from a secondary antenna such as the secondary antenna 115.

The primary receiver comprises an RF front end 270, a radar signal detection unit 272, and a trigger pulse generator 274. The RF front end 270 receives an RF signal 230 from the primary antenna, and down-converts it in frequency for the radar signal detection unit 272. The radar signal detection unit 272 identifies a radar signal present within the RF signal from the primary antenna, and informs the trigger pulse generator 274 of the radar signal characteristics. The radar signal detection unit 272 also outputs the radar signal characteristics in a signal 273, for example to a signal processor such as the signal processor 150.

The trigger pulse generator 274 also receives the down-converted RF signal from the RF front end 270, and uses the radar signal characteristics received from the radar signal detection unit 272 to identify incoming radar signal pulses of the radar signal. Each time a radar signal pulse of the radar signal is received, the trigger pulse generator 274 outputs a trigger pulse as an output trigger signal 275. The trigger pulse is sent a predetermined length of time after the incoming radar signal pulse is received, so that the timing relationship between the incoming radar signal pulse within signal 230 and the trigger pulse within signal 275 is known. The trigger pulse is set to last for the same duration as the radar signal pulse.

The secondary receiver 245 comprises an RF front end 280, a delay stage 281, and an integrator 282. The RF front end 280 receives an RF signal 235 from the secondary antenna, and outputs it to the delay stage 281. After a time delay, the delay stage 281 outputs the signal from the RF front end 280 to the integrator 282, which integrates the signal. The integrator 282 also receives the trigger signal 275 that was generated by the primary receiver. The integration times of the integrator are controlled by the trigger pulses of the trigger signal 275. The trigger signal 275 may be received directly from the primary receiver, or via other circuitry, such as the signal processor 150.

The delay stage 281 delays the signal from the RF front end 280 by an amount corresponding to the predetermined delay introduced by the primary receiver between the incoming radar signal pulse within signal 230 and the trigger pulse within signal 275. Accordingly, when the integrator receives an incoming radar signal pulse from the delay stage 280, it also receives a trigger pulse within signal 275 that has the same timing and duration as the incoming radar signal pulse. The trigger pulse causes the integrator 282 to integrate the signal from the delay line for the duration of the radar signal pulse, and to cease integrating until another trigger

pulse corresponding to another incoming radar signal pulse is received, whereupon integration is performed again. Accordingly, the trigger pulses define multiple time segments of the received RF signal 235, each time segment comprising an incoming radar signal pulse. The repetition rate of the radar signal pulses is indicated by the repetition rate of the trigger pulses. The trigger pulses cause the integrator 282 to integrate (search) for the radar signal at the times when incoming pulses of the radar signal are known to be present.

After a set number of incoming radar pulses have been integrated, the output of the integrator is output in output signal 283, and the integrator is reset. The output signal 283 of the integrator 282 corresponds to the amplitude of the radar signal at the secondary receiver, and may be compared to the amplitudes recorded by other secondary receivers, and/or the primary receiver, for example within signal processor 150.

The integrator enables multiple incoming radar pulses to be combined together within the secondary receiver, realising a high processing gain that lifts the incoming radar signal pulses far enough above the noise floor of the secondary receiver, providing a useful indication of signal strength of the radar signal at the secondary antenna that is connected to the secondary receiver 245.

The number of radar pulses that are integrated can be determined in advance or dynamically determined in relation to a pre-specified signal-to-noise threshold target.

The secondary receiver may further comprise a radar signal detection unit (not shown in Figs) that is similar to the radar signal detection unit 272 of the primary receiver, but which may use the trigger signal 275 to assist in radar signal detection.

The above example primary and secondary receivers are relatively simple to implement, and use a straightforward trigger pulse as a trigger signal to indicate to the secondary receiver the times when it should be receiving the radar signal pulses of the radar signal detected by the primary receiver, so that a high processing gain can be realised to compensate for the lower sensitivity of the secondary receiver. The generation of a trigger pulse each time a radar signal pulse is received means the system can cope with jittered radar pulses that do not have fixed repetition intervals between them.

Another example of primary and secondary receivers suitable for use in the Fig. 1 system will now be described with reference to the schematic diagram of Fig. 3, which shows a primary receiver 340 and a secondary receiver 345. The primary receiver 340 receives an input signal 330 from a primary antenna such as the primary antenna 110, and the secondary receiver 345 receives an input signal 335 from a secondary antenna such as the secondary antenna 115.

The primary receiver comprises an RF front end 370, a radar signal detection unit 372, and a trigger signal generator 374. The RF front end 370 receives an RF signal 330 from the primary antenna, and down-converts it in frequency for the radar signal detection unit 372. The radar signal detection unit 372 identifies a radar signal present within the signal from the RF front end, and informs the trigger signal generator 374 of the radar signal characteristics. The radar signal detection unit 372 also outputs the radar signal characteristics in a signal 373, for example to a signal processor such as the signal processor 150.

The trigger signal generator 374 also receives the down-converted RF signal from the RF front end 370, and uses the radar signal characteristics received from the radar signal detection unit 372 to identify an incoming radar signal pulse of the radar signal. Once an incoming radar signal pulse is identified, the trigger signal generator 374 outputs a trigger signal 375. The trigger signal 375 includes data comprising a timestamp of the time of arrival of the radar signal pulse, a repetition rate of the radar signal pulses, a pulse width of the radar signal pulses, and an RF frequency of the radar signal pulses.

The secondary receiver 345 comprises an RF front end 380 connected to a buffer stage 381, and an intersection stage 382 connected to the buffer stage 381. The RF front end 380 receives an RF signal 335 from the secondary antenna, and the intersection stage 382 outputs a signal strength of the radar signal that is within the RF signal 335.

The secondary receiver further comprises a trigger signal interpreter 385, which receives the trigger signal 375 generated by the primary receiver 340, extracts the data within the trigger signal 375, and controls the RF front end 380 and the buffer stage 381 to search for the presence of the radar signal within the RF signal 335. The trigger signal 375 may be received by the secondary receiver 345 directly from the primary receiver 340, or via other circuitry, such as the signal processor 150.

The trigger signal interpreter 385 extracts the RF frequency of the radar signal pulses from the trigger signal 375, and sets filters and/or down-conversion local oscillator frequencies of the RF front end 380 to match the frequency of the radar signal pulses. The trigger signal interpreter 385 also extracts from the trigger signal 375 the timestamp, pulse repetition rate, and pulse width of the radar signal pulses for controlling the buffer stage 381.

In use, when the secondary receiver 345 receives the trigger signal 375 generated by the primary receiver 340, the RF front end 380 down-converts and filters the RF signal 335 from the secondary antenna according to the RF frequency carried by the trigger signal, and passes the down-converted and filtered signal to the buffer stage 381. The buffer stage 381 starts buffering this signal into a first row of the buffer stage at a start time indicated by the timestamp carried within the trigger signal 375, and for a duration according to the pulse width carried within the trigger signal 375. The data in the first row of the buffer stage constitutes an initial time segment of the RF signal received from the secondary antenna.

The buffer stage 381 then determines (or receives from the trigger signal interpreter 385) a start time of the next radar signal pulse of the radar signal, the start time of the next radar signal pulse being determined as the timestamp in the trigger signal data plus one radar signal pulse repetition interval, the radar signal pulse repetition interval determined from the repetition rate in the trigger signal data. At the start time of the next radar signal pulse, the buffer stage 381 starts buffering the signal from the RF front end 380 into a second row of the buffer stage, for a duration according to the pulse width carried within the trigger signal 375. The data in the second row of the buffer stage constitutes a subsequent time segment of the RF signal received from the secondary antenna.

This is repeated for subsequently received radar pulses, buffering each subsequently received radar pulse into a respective row of the buffer stage 381, to store a respective time segment. The buffering process temporally overlays the time segments by the data of the first row starting at the time of the timestamp, and the data of each subsequent row starting at the time of the timestamp plus an integer number of the pulse repetition interval, such that each column of the buffer stage 381 holds data corresponding to the same part of each received radar signal pulse.

Once a predetermined number of multiple time segments (radar signal pulses) are stored into buffer stage 381, the buffer stage 381 indicates to the intersection calculation stage 382 that the buffer stage 381 contains multiple time segments ready for intersection calculation. The predetermined number may be fixed, or the trigger signal may further comprise an indication of how many radar signal pulses are likely to be received following the timestamp, and the predetermined number may be set according to this indication. Since radar signal pulses are usually received in bursts, the trigger signal generator 374 preferably sends the trigger signal 375 in response receiving the first pulses(s) of a burst, so that there are several more radar signal pulses that will follow and will be collected within the buffer 381.

The intersection calculation stage 382 then calculates the intersection of the multiple time segments, to realise a processing gain that lifts the received radar signal pulses within the multiple time segments sufficiently above the noise floor to give an indication of the strength of the received radar signal, or to determine more accurately the rise and fall edges of the pulse for time of arrival measurements. The intersection may for example be calculated by adding up the data along the columns of the buffer stage 381 and dividing the added column values by the number of rows, to produce a composite time segment wherein the effects of noise are averaged-out.

Once the intersection has been calculated, the result is output as output signal 383, and the buffer stage 381 is reset pending receipt of another instruction from the trigger signal interpreter 385 that another trigger signal has been received. The output signal 383 indicates the signal strength of the radar signal at the secondary receiver 345, and may be compared to the amplitudes recorded by other secondary receivers, and/or the primary receiver, for example within signal processor 150.

To help ensure that the buffer stage 381 starts buffering the signal from the RF front end 380 at the time of the timestamp, the timestamp generated by the primary trigger signal may be a time at which the beginning of a next radar signal pulse is expected to be received, so that the buffer stage 381 receives the timestamp sufficiently quickly to start buffering at the time of the timestamp when that radar signal pulse is received. Or, the buffer stage 381 may include an initial delay stage, for example similar to the delay stage 281 of the secondary receiver 245. Or, the buffer stage 381 may treat the received timestamp as being the timestamp in the

trigger signal data plus one radar signal pulse repetition interval, the radar signal pulse repetition interval determined from the repetition rate in the trigger signal data.

The primary and secondary receivers 340 and 345 may for example be connected to a common clock to help ensure that the timestamp included in the trigger signal 375 at the primary receiver 340 is properly interpreted by the secondary receiver 345 without any significant timing offsets being introduced.

The secondary receiver 345 may further comprise a radar signal detection unit (not shown in Figs) that is similar to the radar signal detection unit 372 of the primary receiver, but which may use the trigger signal 375 to assist in radar signal detection.

Compared to the first example of Fig. 2, this example relies on a constant repetition rate of radar signal pulses so that the start times for the time segments can all be calculated based upon the timestamp and the radar pulse repetition rate. However, this example could be amended to make it applicable to jittered radar signal pulses if desired by including timestamps within the trigger signal for multiple radar signal pulses, instead of just a timestamp of a first radar signal pulse together with a repetition rate. Then, the multiple time segments could be defined with reference to the multiple timestamps.

The above example primary and secondary receivers 340 and 345 have less stringent timing requirements than the primary and secondary receivers 240 and 245, since the timing information of the trigger signal is carried as data within the trigger signal 375, rather than by the times at which trigger pulses of the trigger signal 275 arrive at the receiver.

Another embodiment uses different analogue-to-digital conversion techniques to provide a reduced complexity, multiple channel radar receiver system. The primary receiver uses an analogue-to-digital converter that oversamples an intermediate frequency signal from a tuning stage, the intermediate frequency signal containing the radar signal. An oversampling technique allows an optimum pulse detection method to be implemented and can result in high signal-to-noise ratios.

The secondary receiver(s) uses an analogue-to-digital converter that undersamples an intermediate frequency signal from a tuning stage, the intermediate frequency signal

containing the radar signal. Undersampling is simpler and more cost effective than the oversampling implemented in the primary receiver, but results in lower signal-to-noise ratios.

The difference in sensitivity between the oversampling primary receiver and the undersampling secondary receiver(s) is reduced by enabling the primary receiver to trigger the secondary receiver(s) when a radar signal is present and the secondary receiver(s) to integrate over multiple pulses in order to increase the signal-to-noise ratio of the secondary receiver(s) to a level that is comparable to the signal-to-noise ratio of the primary receiver.

A method according to an embodiment of the invention will now be described with reference to the flow diagram of Fig. 4. The method is a method of detecting a radar signal at a secondary receiver, the detection being based upon a detection of the radar signal at a primary receiver having a greater sensitivity than the secondary radar receiver. The primary receiver may for example be the primary receiver 240 or 340, and the secondary receiver may for example be the secondary receiver 245 or 345.

In a first step 410, the method comprises detecting a radar signal at the primary receiver. In a second step 420, the primary receiver generates a trigger signal in response to the detected radar signal, the trigger signal comprising timing information of the detected radar signal. Then, the trigger signal is sent from the primary receiver to the secondary receiver in a step 430, and in a step 440, the secondary receiver proceeds to search for the radar signal based upon the timing information received within the trigger signal.

Further embodiments falling within the scope of the appended claims will also be apparent to those skilled in the art.

CLAIMS

1. A radar receiver, comprising a primary receiver for connecting to a primary antenna, and a secondary receiver for connecting to a secondary antenna, wherein the primary receiver has a greater sensitivity than the secondary receiver, wherein the primary receiver is configured to detect a radar signal and to generate a trigger signal in response to detecting the radar signal, wherein the secondary receiver is configured to receive the trigger signal and to search for the radar signal, the search being based upon timing information carried by the trigger signal, and wherein, the secondary receiver is one of a plurality of secondary receivers comprised in the radar receiver, each of the plurality of secondary receivers being configured to receive the trigger signal and to search for the radar signal, the search being based upon timing information carried by the trigger signal, and wherein the radar receiver further comprises a signal processor connected to each of the plurality of secondary receivers, the signal processor configured to collate output signals of the secondary receivers to determine a direction of a transmitter of the radar signal.
2. The radar receiver of claim 1, wherein a bandwidth of the secondary receiver is greater than a bandwidth of the primary receiver.
3. The radar receiver of claim 1 or 2, wherein the primary receiver is configured to oversample the radar signal and wherein the secondary receiver is configured to undersample the radar signal.
4. The radar receiver of any preceding claim, wherein the timing information carried by the trigger signal comprises a repetition rate of radar pulses of the radar signal, and wherein the repetition rate is carried by the trigger signal by virtue of times when the trigger signal is sent to the secondary receiver, or by virtue of a repetition rate indicated within data of the trigger signal.
5. The radar receiver of any preceding claim, wherein the timing information carried by the trigger signal comprises a time of arrival of a radar pulse of the radar signal.

6. The radar receiver of any preceding claim, wherein the search performed by the secondary radar receiver comprises defining multiple time segments of an RF signal received from a secondary antenna, and wherein times of the multiple time segments are based upon the timing information carried by the trigger signal.
7. The radar receiver of claim 6, wherein the secondary radar receiver is configured to temporally overlay the multiple time segments with one another based on the timing information, such that a radar pulse of the radar signal occurs in each one of the multiple time segments at the same time.
8. The radar receiver of claim 7, wherein the secondary radar receiver is further configured to determine an intersection of the temporally overlaid multiple time segments to reconstruct a radar pulse of the radar signal.
9. The radar receiver of any one of claims 6 to 8, wherein the timing information carried by the trigger signal comprises a pulse width of radar pulses of the radar signal, and wherein a time duration of each one of the multiple time segments is determined according to the pulse width.
10. The radar receiver of any preceding claim, wherein the trigger signal further carries a frequency of the radar signal, and wherein the secondary radar receiver is configured to filter an RF signal received from a secondary antenna according to the frequency.
11. A radar receiver system, comprising the radar receiver of any preceding claim, a primary antenna connected to the primary receiver, and a secondary antenna connected to the secondary receiver.
12. The radar receiver system of claim 11, wherein the primary antenna has a wider field of view than the secondary antenna.
13. The radar receiver system of claim 11 or 12, wherein the field of view of the secondary antenna overlaps the field of view of the primary antenna.

14. A method of detecting a radar signal at a secondary receiver, the detection being based upon a detection of the radar signal at a primary receiver having a greater sensitivity than the secondary radar receiver, the method comprising:

- detecting the radar signal at the primary receiver;
- generating a trigger signal in response to the detected radar signal, the trigger signal comprising timing information of the detected radar signal;
- receiving the trigger signal at a secondary receiver; and
- searching for the radar signal at the secondary receiver, the search being based upon the timing information received by the secondary receiver within the trigger signal, wherein

the secondary receiver is one of a plurality of secondary receivers comprised in the radar receiver, each of the plurality of secondary receivers being configured to receive the trigger signal and to search for the radar signal, the search being based upon timing information carried by the trigger signal, and wherein the radar receiver further comprises a signal processor connected to each of the plurality of secondary receivers, the signal processor configured to collate output signals of the secondary receivers to determine a direction of a transmitter of the radar signal.

15. A radar receiver, comprising a primary receiver for connecting to a primary antenna, and a secondary receiver for connecting to a secondary antenna, wherein the primary receiver has a greater sensitivity than the secondary receiver, wherein the primary receiver is configured to detect a radar signal and to generate a trigger signal in response to detecting the radar signal, wherein the secondary receiver is configured to receive the trigger signal and to search for the radar signal, the search being based upon timing information carried by the trigger signal.

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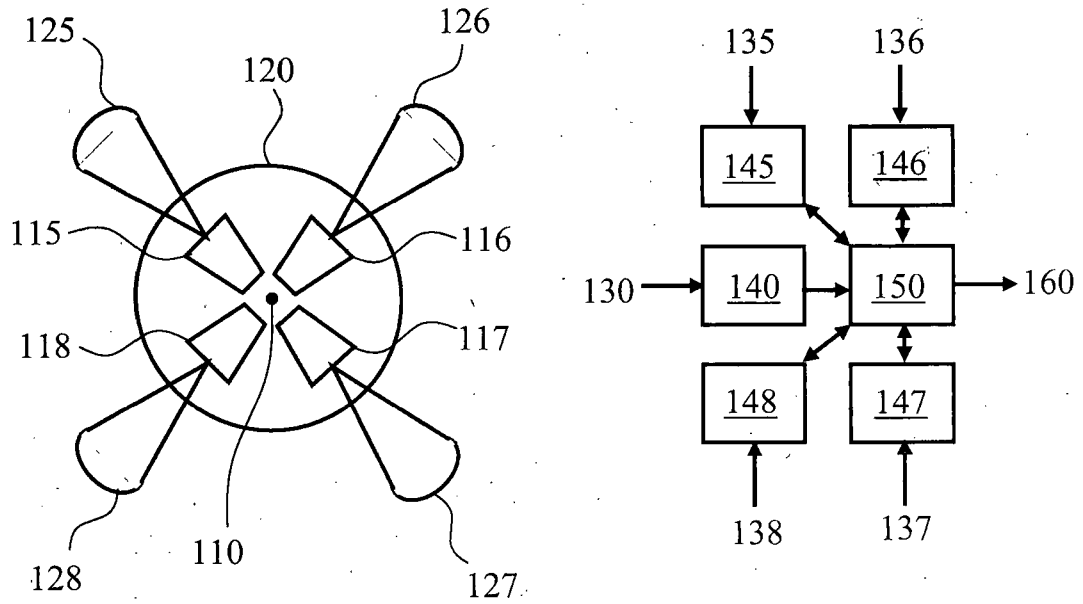


Fig. 1

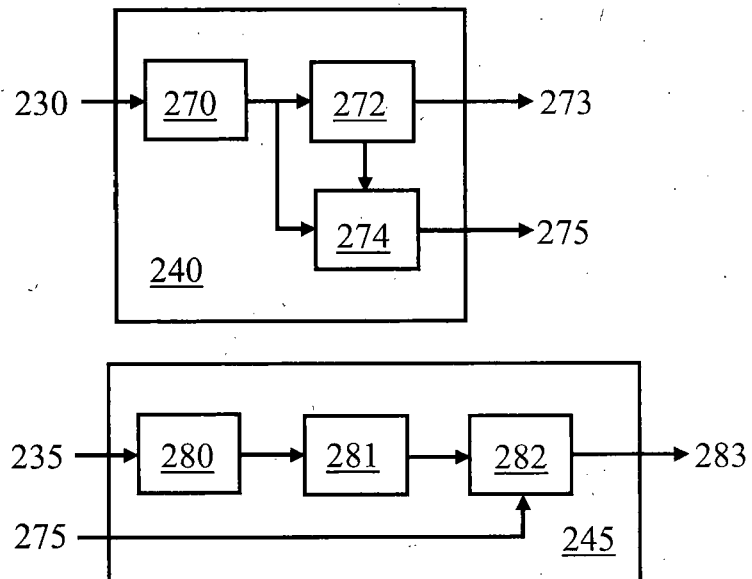
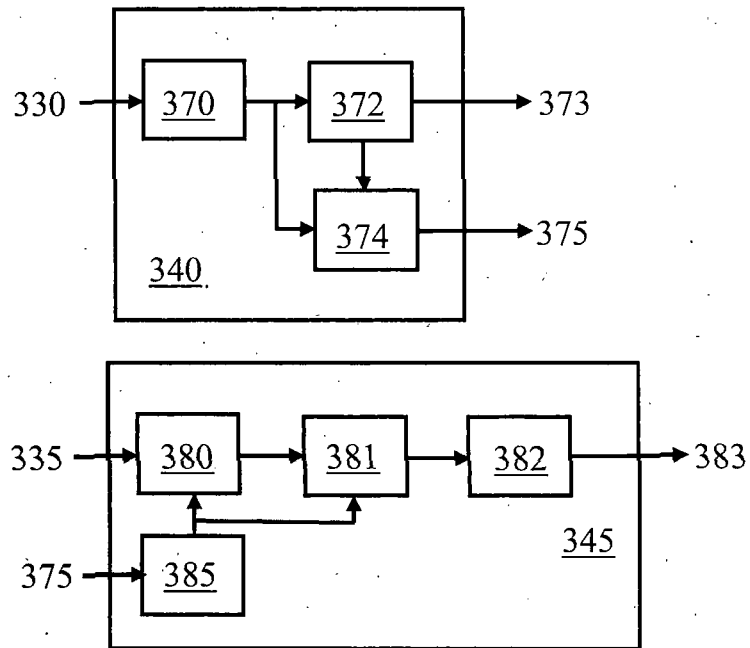
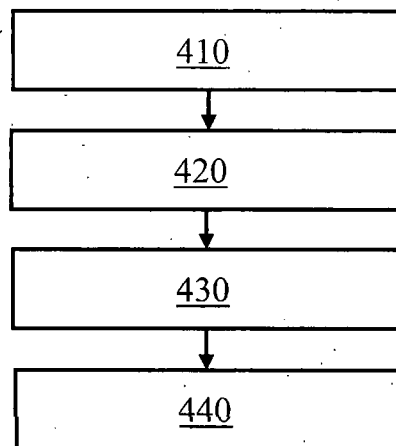


Fig. 2

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**Fig. 3****Fig. 4**

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2014/000067

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01S7/02 G01S7/292 G01S3/12 G01R23/15
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 G01R

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, 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 2 151 923 A1 (THALES SA [FR]) 10 February 2010 (2010-02-10) the whole document	1-15
A	US 4 644 267 A (TSUI JAMES B Y [US] ET AL) 17 February 1987 (1987-02-17) column 2, paragraph 6 - column 2, line 32; figure 1	1-15
A	US 2006/227050 A1 (VAUGHN DAVID A JR [US] VAUGHN JR DAVID A [US]) 12 October 2006 (2006-10-12) figure 1	1-15
A	US 6 727 840 B1 (SULLIVAN WILLIAM B [US]) 27 April 2004 (2004-04-27) figure 2	1-15
	-/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

19 May 2014

Date of mailing of the international search report

26/05/2014

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2014/000067

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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