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(71) Applicant: **THE SECRETARY OF STATE FOR DEFENCE** [GB/GB]; DSTL, Porton Down, Salisbury, Wiltshire, SP4 0JQ (GB).

(72) Inventor: **RICHES, James, Peter**; DSTL IP Group, G01-B Building 005, DSTL Porton Down, Salisbury, Wiltshire SP4 OJQ. (GB).

(74) Agent: **FARNSWORTH, Alastair, Graham**; DIPR Formalities Section, Poplar 2#2214, MOD Abbey Wood (South), Bristol, BS34 8JH (GB).

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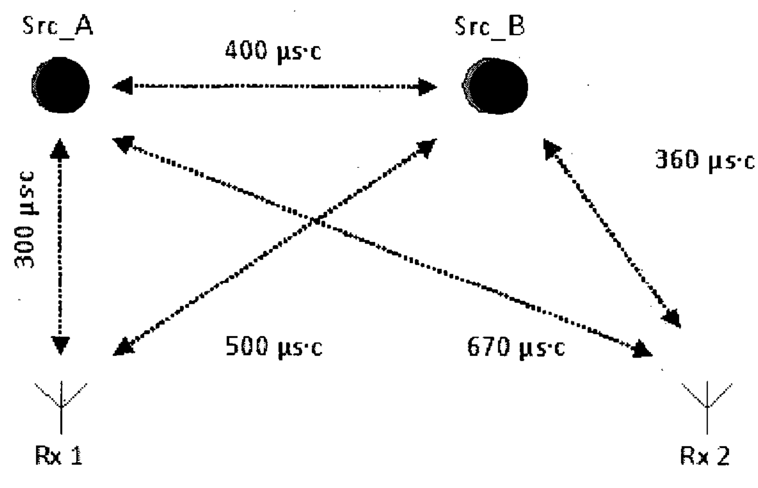

Fig. 1

(57) Abstract: There is provided a method of separating an unknown radar signal (Src_A) out from multiple unknown radar signals (SRC_A, Src_B) and a radio signal separator (10) configured to perform the method. The method comprises receiving the multiple unknown radar signals at spatially different antennas (RX1, RX2T RX3), and separating the unknown radar signal out from the multiple unknown radar signals based upon the time difference of arrival (TDOA) of the unknown radar signal at the spatially different antennas

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SEPARATING AN UNKNOWN RADAR SIGNAL OUT FROM MULTIPLE UNKNOWN RADAR SIGNALS

Technical Field of the Invention

The invention relates to a method and a radar signal separator for separating an unknown radar signal out from multiple unknown radar signals.

Background to the Invention

There is a desire to separate unknown radar signals out from one another, so that the unknown radar signals can be individually analysed and identified. In dense radar environments with multiple radar transmitters, it can be difficult to separate different radar signals out from one another.

A radar signal typically comprises a train of pulses that are transmitted by a radar transmitter. The identification of which pulses relate to which radar transmitters, so that the radar signal of any particular radar transmitter can be reconstructed by selecting just the pulses relating to that particular radar transmitter, is a first step in identifying unknown radar transmitters.

Since the radar signals are unknown, it is not possible to separate a given radar signal out from other radar signals by searching for known characteristics of the given radar signal, for example in a manner similar to that done for separating known GPS system signals out from one another.

A known technique for separating unknown radar signals out from one another comprises separating radar pulses according to their radio frequency. However, maritime navigation radars may make up the majority of signals and these typically operate on very similar radio frequencies. Other known techniques include separating radar pulses based upon the pulse width and/or bearing if available. Other approaches have been to use artificial intelligence techniques and graph theory.

Another known technique comprises the use of Pulse Repetition Interval (PRI) to separate radar signals from one another, by assuming that radar pulses which occur at fixed time intervals are likely to belong to the same radar signal, or at least to belong to a smaller group of radar signals than all of the radar signals that are present. However, the radar pulses of a radar signal are sometimes jittered in time, which can make detection of the jittered radar signal more difficult.

US Patent No 5, 583,505 discloses a receiver that uses PRI techniques and which is designed to cope with jittered pulses, however when many different radar signals are present, separation of individual radar signals even when using these techniques becomes difficult, particularly when different radar signals have similar PRIs.

It is therefore an aim of the invention to provide an improved way of separating unknown radar signals from one another.

Summary of the Invention

The Time Of Arrival (TOA) for a radar signal at an antenna is a function of the relative distance from the radar transmitter to the antenna. Therefore a radar signal from a particular radar transmitter will arrive at spatially different antennas at different times. The time difference between a radar signal arriving at one antenna and the same radar signal arriving at another antenna is referred to herein as a Time Difference Of Arrival (TDOA).

When radar signals are sent from different radar transmitters that have different positions to one another, the radar signals normally have different TDOA's from one another, due to the differing radar transmitter positions. Therefore, it is possible to distinguish different radar signals from one another based upon the TDOA of the radar signals at spatially different antennas.

Therefore, according to a first aspect of the invention, there is provided a method for separating an unknown radar signal out from multiple unknown radar signals. The method comprises receiving the multiple unknown radar signals at spatially different antennas, and separating the unknown radar signal out from the multiple unknown radar signals based upon the time difference of arrival (TDOA) of the unknown radar signal at the spatially different antennas.

Preferably, the signals received from the spatially different antennas are compared to one another by performing a cross-correlation between them to determine a correlation peak. The correlation peak designates the TDOA of radar pulses within the received signals, the radar pulses responsible for producing the correlation peak. The parts of the received signals that correlate with one another at this correlation peak may then be extracted to construct the radar signal that produced the radar pulses.

The cross-correlation may produce multiple correlation peaks, and each peak may be reviewed for constructing a radar signal from the parts of the received signals that correlate with one another at the correlation peak. Since signals transmitted from different transmitters will have different TDOA's at the spatially different antennas, each correlation peak should correspond to a particular transmitter, and therefore a particular signal, such as a radar signal.

Since radar signals generated from spatially different sources are separated from one another based upon the fact that they have different TDOAs, rather than that they have any particular values of TDOA, the received signals recorded at the spatially different antennas do not need to be time-synchronised with one another. This is because time offsets affect all of the TDOAs, and do not typically cause one TDOA to match another TDOA when the TDOAs would not have matched one another had the received signals been all recorded at exactly the same time. Accordingly, the method can be easily implemented without any requirement for complex and/or expensive time synchronisation methods between the received signals.

Advantageously, the receiving of the multiple unknown radar signals at spatially different antennas may comprises receiving a first RF time segment taken from a first antenna of the spatially different antennas; and receiving a second RF time segment taken from a second antenna of the spatially different antennas. The first RF time segment is a recording of the RF signal received at the first antenna during a first time segment, and the second RF time segment is a recording of the RF signal received at the second antenna during a second time segment.

Hence, only two spatially different antennas are required to separate an unknown radar signal out from multiple unknown radar signals. Whilst two different radar transmitters could theoretically produce the same TDOA at the two antennas if the two different transmitters were both located in positions producing the same TDOA, the vast majority of transmitter positions will produce different TDOA's, and so this is considered unlikely to occur in practice. Even if this does occur, a particular signal that is identified as having a particular TDOA, will normally comprise many less radar signals to be separated than all the radar signals in the first and second RF time segments. In such a case, the method may further comprise additional processing steps to separate the unknown radar signal out from the particular signal, such that the separation of the unknown radar signal from the multiple unknown radar signals is based upon the known techniques, as well as being based upon the TDOA of the unknown radar signal at the first and second antennas.

The calculation of the TDOA may comprise calculating a cross-correlation between the first RF time segment and the second RF time segment; and identifying a peak in the calculated cross-correlation, the peak designating the TDOA of the unknown radar signal at the first and second antennas.

The first and second time segments preferably overlap one another in time so that the cross-correlation can identify a true TDOA between the first and second segments rather than just an aliased TDOA, which may occur when later radar pulses of a radar signal correlate to earlier radar pulses of the radar signal, if there is very little variation between the radar pulses of the radar signal.

If every individual pulse emitted from the radar transmitter is unique, for example if the radar signal contains jittered pulses, then there are unlikely to be any significant peaks in the correlation that correspond to aliased TDOAs, improving the efficacy of the method.

The TDOA of the unknown radar signal at the first and second antennas may be a timeshift of the second RF time segment from the first RF time segment at which the first RF time segment and the second RF time segment correlate with one another. The separating the unknown radar signal out from the multiple unknown radar signals may further comprise calculating an intersection of the first RF time segment and the second RF time segment when the second RF time segment is shifted from the first RF time segment by the timeshift; and outputting the calculated intersection as the unknown radar signal.

The intersection operation outputs the signal parts that are present in both the first RF time segment and the second RF time segment when the second RF time segment is shifted from the first RF time segment by the timeshift, and may for example be calculated by multiplying the first RF time segment and the second RF time segment when the second RF time segment is shifted from the first RF time segment by the timeshift.

The second antenna is sufficiently remote from the first antenna to give measurable differences between the time of arrival of a pulse at the first antenna and the time of arrival of the pulse at the second antenna. Whether a time difference is measurable or not, and therefore how remote the first and second antennas need to be, will clearly depend upon the sampling rates of the first and second RF time segments. For example, the higher the sampling rate, the closer together the first and second antennas could be positioned.

To help avoid non-radar transmitters from generating correlation peaks, the frequency range of each of the first and second RF time segments may be restricted to cover expected radar signal frequencies, prior to the step of calculating a cross-correlation between the first RF time segment and the second RF time segment. Then, there will be less correlation peaks that need to be reviewed.

Advantageously, the receiving the multiple unknown radar signals at spatially different antennas may comprise receiving a third RF time segment taken from a third antenna of the spatially different antennas. Then, the calculating a cross-correlation between the first RF time segment and the second RF time segment comprises calculating the cross-correction between the first RF time segment, the second RF time segment and the third RF time segment. Therefore, a correlation peak on the three dimensional surface resulting from the cross-correlation will designate a TDOA of the unknown radar signal at the first and third antennas, in addition to the TDOA between the first and second antennas. The TDOA between the first and second antennas may also be determined.

The TDOA of the unknown radar signal at the first and third antennas may be a timeshift of the third RF time segment from the first RF time segment at which the third RF time segment correlates with the first and second RF time segments, the second RF time segment being shifted from the first RF segment by the timeshift of the second RF time segment from the first RF time segment.

The step of calculating an intersection may comprise calculating the intersection of the first RF time segment, the second RF time segment, and the third RF time segment, when the second RF time segment is shifted from the first RF time segment by the timeshift of the second RF time segment from the first RF time segment, and the third RF time segment is shifted from the first RF time segment by the timeshift of the third RF time segment from the first RF time segment.

Using three RF time segments from three spatially different antennas helps to separate radar signals that have the same TDOA to both the first and second antennas, for example when two different radar signal transmitters both lie on a hyperboloid surface that has its foci at the first and second antennas, as will be apparent to those skilled in the art.

Advantageously, a position from which the unknown radar signal originates may be determined based upon the timeshift of the second RF time segment from the first RF time segment, the timeshift of the third RF time segment from the first RF time segment, the relative times at which the first, second, and third RF time segments were taken from the first, second, and third antennas respectively, and the positions of the first, second, and third antennas.

The relative times at which the RF time segments were taken from the antennas may be determined according to respective timestamps associated with each one of the RF time segments, or the antennas may all be configured to begin recording at exactly the same time as one another, for example by receiving a start command from a transmitter that is equidistant from all of the antennas.

The method may further comprise identifying a further peak in the calculated cross-correlation, the further peak designating a TDOA of a further unknown radar signal at the first and second antennas. A further intersection may be calculated to separate the further unknown radar signal from the received signals.

According to a second aspect of the invention, there is provided a radar signal separator for separating an unknown radar signal out from multiple unknown radar signals. The radar signal separator is configured to receive the multiple unknown radar signals from spatially different antennas; and separate the unknown radar signal out from the multiple unknown radar signals based upon the time difference of arrival (TDOA) of the unknown radar signal at the spatially different antennas.

The radar signal separator may be configured to receive the multiple unknown radar signals from spatially different antennas by receiving a first RF time segment taken from a first antenna; and receiving a second RF time segment taken from a second antenna that is remote from the first antenna, and may be further configured to separate the unknown radar signal out from the multiple unknown radar signals based upon the TDOA of the unknown radar signal at the spatially different antennas by:

- calculating a cross-correlation between the first RF time segment and the second RF time segment;
- identifying a peak in the calculated cross-correlation, the peak designating a timeshift of the second RF time segment from the first RF time segment at which the first RF time segment and the second RF time segment correlate with one another;
- calculating an intersection of the first RF time segment and the second RF time segment when the second RF time segment is shifted from the first RF time segment by the timeshift; and
- outputing the calculated intersection as the unknown radar signal.

The radar signal separator may be configured to perform the methods discussed in relation to the first aspect. The phrase "spatially different antennas" refers to antennas that are at different positions to one another.

Preferably the computational burden of the method is reduced by converting the radar signals (or more typically the RF segments of interest) from a detailed waveform (e.g. a raw waveform or an envelope, which may include sampling at or near to radar frequencies of interest) to a simplified representation. The simplified representation preferably contains information on the timing of radar pulses. This typically includes the leading and/or trailing edges of the (each) waveform, and may substantially comprise a list of the leading and/or trailing edges of pulses in the (each) waveform. Optionally the leading edges are used, optionally the trailing edges are used, and preferably both are used. Alternatively or additionally it may include information on the mid-point of the radar pulses, or any other representative timing indicator (fourth rising edge of each pulse, three-quarter point of each pulse etc). It should not matter if a consistent offset is included and so the simplified representation may include the timings of each radar pulse plus a constant (E.g. 1ms) although in practice there should be no particular benefit in doing so.

Performing the cross-correlation on the simplified representation enables a reduction in the computational burden of the operation, as compared to performing the cross-correlation on a raw waveform. This may enable the processing method to omit the step of recording a raw waveform in the first place. Due to the high frequencies used in radar transmissions, recording raw waveforms is technically challenging, and cross correlating the raw waveforms quickly (e.g. in real time) requires considerable processing power which is expensive, so the use of a simplified representation may reduce the cost, and perhaps also the power requirement of an associated computer processor.

When the cross correlation is performed on a simplified representation, a peak in the identified output is used to identify a TDOA of one of the signals, and this is used to identify leading edges and/or trailing edges of pulses in the signals (or RF segments of interest) which have a TDOA that match the identified TDOA, and to construct one of the original signals (i.e. in this case a simplified representation thereof including information on the leading and/or trailing edges of pulses in the radar signal) which can be used to identify the type of radar transmitter and/or the status of the radar transmitter. Techniques for identifying the type of radar transmitter and/or its status are known in the art and are outside the scope of this document, however as an example a pulse repetition interval, or indeed a whole pattern known to be included in certain types of radars, or radars in certain operating modes may be identified in the reconstructed radar signal.

Therefore advantageously in the method of the first aspect the first and second RF time segments may each comprise a simplified representation of respectively associated radio frequency waveform time segments, each simplified representation including summary information including the timings of radar pulses of the respectively associated radio frequency waveform time segments (the timings being at least relative timings – i.e. relative to other pulses in the same RF time segment). More specifically the first and second RF time segments may each include information on the timings (typically the relative timings) of radar pulses of (i.e. that were derived from) respectively associated radio frequency waveforms, and substantially exclude such associated radio frequency waveforms (i.e. omitting waveform sampling data at or near the wavelength of the carrier frequency of the radar signals). Optionally this is preceded by the step of extracting information on the timings of radar pulses of a radio frequency waveform of the first and second RF time segments, or alternatively the simplified representation is received and accordingly processed.

Brief Description of the Drawings

Illustrative 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 schematic diagram of two unknown radar transmitters and two spatially different antennas according to first and second illustrative embodiments of the invention;

Fig. 2 shows a timing diagram of a first radar signal emitted from a first one of the unknown radar transmitters of Fig. 1;

Fig. 3 shows a timing diagram of a second radar signal emitted from a second one of the unknown radar transmitters of Fig. 1;

Fig. 4 shows a timing diagram of the radar signals received at a first one of the spatially different antennas of Fig. 1;

Fig. 5 shows a timing diagram of the radar signals received at a second one of the spatially different antennas of Fig. 1;

Fig. 6 shows a diagram of a cross-correlation between the radar signals received at the first one of the spatially different antennas and the radar signals received at the second one of the spatially different antennas;

Fig. 7 shows a diagram of the calculation of the intersection between the radar signals received at the first one of the spatially different antennas and the radar signals received at the second one of the spatially different antennas when shifted according to a first correlation peak corresponding to the first radar signal;

Fig. 8 shows a diagram of the calculation of the intersection between the radar signals received at the first one of the spatially different antennas and the radar signals received at the second one of the spatially different antennas when shifted according to a second correlation peak corresponding to the second radar signal;

Fig. 9 shows a timing diagram of a first jittered radar signal emitted from the first one of the unknown radar transmitters of Fig. 1;

Fig. 10 shows a timing diagram of a second jittered radar signal emitted from the second one of the unknown radar transmitters of Fig. 1;

Fig. 11 shows a diagram of a cross-correlation between the jittered radar signals received at the first one of the spatially different antennas and the jittered radar signals received at the second one of the spatially different antennas;

Fig. 12 shows a schematic diagram of an unknown radar transmitter and three spatially different antennas according to a third illustrative embodiment of the invention; and

Fig. 13 shows a schematic diagram of a radar signal separator system according to the third illustrative embodiment.

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

Detailed Description

A first illustrative embodiment of the invention will now be described with reference to Figs. 1 - 8. Fig. 1 shows a schematic diagram of first and second unknown radar transmitters Scr_A and Src_B respectively, and first and second spatially different antennas Rx1 and Rx2 respectively.

As shown in Fig. 1, the first and second unknown radar transmitters, and the first and second spatially different antennas, are all located at different positions to one another.

Since the antennas RX1 and RX2 are at different positions to one another, a radar signal from the first unknown radar transmitter takes differing amounts of time to reach the antennas RX1 and RX2. Specifically, the Scr_A radar signal takes 300μs to reach the antenna RX1 and takes 670μs to reach the antenna RX2. The Time Difference Of Arrival (TDOA) of the Scr_A radar signal between the first and second antennas is therefore 370μs.

Furthermore, since the first and second unknown radar transmitters are also at different positions to one another, the Scr_B radar signal takes 500μs to reach the antenna RX1 and takes 360μs to reach the antenna RX2. The Time Difference Of Arrival (TDOA) of the Scr_B radar signal between the first and second antennas is therefore -140μs.

Since the radar signals travel at the speed of light c, the antenna RX1 is a distance of 300μs.c from the first unknown radar transmitter Scr_A, and 500μs.c from the second unknown radar transmitter Scr_B. The antenna RX2 is a distance of 670μs.c from the first unknown radar transmitter Scr_A and 360μs.c from the second unknown radar transmitter Scr_B.

The timing diagram of Fig. 2 shows the Src_A radar signal as comprising multiple pulses RP_A. The pulses RP_A are 20μs in width, and are repeated at a pulse repetition interval (PRI) of 450μs. The timing diagram of Fig. 3 shows the Src_B radar signal as comprising multiple pulses RP_B. The pulses RP_B are also 20μs in width, but are repeated at a pulse repetition interval (PRI) of 633μs. The first radar pulses RP_A and RP_B are both emitted from the radar transmitters Src_A and Scr_B at a time T = 0.

The timing diagram of Fig. 4 shows a first RF time segment taken from the antenna RX1, the first RF time segment running from the time T = 0μs to T = 10000μs. Since the antenna RX1 is 300μs.c from the radar transmitter Scr_A, the first pulse RP_A arrives at T = 300μs, and since the antenna RX1 is 500μs.c from the radar transmitter Scr_B, the first pulse RP_B arrives at T = 500μs. Throughout the first RF time segment The pulses RP_A are received every 450μs, and the pulses RP_B are received every 633μs.

The timing diagram of Fig. 5 shows a second RF time segment taken from the antenna RX2, the second RF time segment also running from the time T = 0μs to T = 10000μs. Since the antenna RX2 is 670μs.c from the radar transmitter Scr_A, the first pulse RP_A arrives at T = 670μs, and since the antenna RX2 is 360μs.c from the radar transmitter Scr_B, the first pulse RP_B arrives at T = 360μs. Throughout the second RF time segment, the pulses RP_A are received every 450μs, and the pulses RP_B are received every 633μs.

Next, the first and second RF time segments are cross-correlated with one another to identify correlation peaks that may correspond to radar signals being received at the first and second antennas at different times to one another. The result of the cross-correlation is shown in Fig.

6. The cross-correlation runs from -2500µs to +2500µs, as the second RF time segment is slid past the first RF time segment from -2500µs relative to the first RF time segment to +2500µs relative to the first RF time segment.

The large correlation peak CP_A at -370µs indicates that the first RF time segment and the second RF time segment correlate well with one another when the second time segment has a time shift of -370µs from the first RF time segment. This corresponds to the TDOA of the Scr_A radar signal, the radar transmitter Scr_A being 370µs.c closer to the first antenna RX1 than the second antenna RX2.

The correlation peaks at -820µs, -80µs, and 530µs correspond to aliased TDOA's of the Scr_A radar signal, when earlier pulses RP_A correlate well to later pulses RP_A of the Scr_A radar signal. The correlation peaks of -820µs, -370µs, -80µs, and 530µs, occur at intervals matching the pulse repetition interval of 450µs of the Src_A radar signal.

The large correlation peak CP_B at 140µs indicates that the first RF time segment and the second RF time segment correlate well with one another when the second time segment has a time shift of 140µs from the first RF time segment. This corresponds to the TDOA of the Scr_B radar signal, the radar transmitter Scr_B being 140µs.c further from the first antenna RX1 than the second antenna RX2.

The correlation peaks at -493µs, and 773µs correspond to aliased TDOA's of the Scr_B radar signal, when earlier pulses RP_B correlate well to later pulses RP_B of the Scr_B radar signal. The correlation peaks of -493µs, 140µs, and 773µs, occur at intervals matching the pulse repetition interval of 633µs of the Src_B radar signal.

The correlation peaks relating to the pulses RP_A are higher than the correlation peaks relating to the pulses RP_B due to the higher pulse repetition rate, and therefore the greater the number of pulses that correlate between the RF time segments, of the Src_A radar signal.

Once the cross-correlation has been calculated, a correlation peak is chosen for reconstructing the signal that is responsible for the correlation peak. Typically, the highest correlation peak is chosen first. The signal is reconstructed by performing an intersection between the first and second RF time segments when shifted according to the correlation peak.

The diagram of Fig. 7 shows the calculation of an intersection INT1 between the first and second RF time segments when the correlation peak at -370μs is chosen. Specifically, the second RF time segment is shifted -370μs relative to the first RF time segment, and the first and second RF time segments are multiplied together to produce the intersection INT1, which corresponds to the radar signal from the unknown radar transmitter Src_A. The dashed lines on Fig. 7 show how the pulses RP_A are aligned with one another at the timeshift of -370μs, and therefore result in the pulses RP_A being reconstructed in the intersection INT1.

Once the Src_A radar signal has been reconstructed, and identified as having a pulse repetition interval of 450μs, the correlation peaks that appear in the Fig. 6 cross-correlation at intervals of 450μs can be discounted as aliases. Had a different one of the -820μs, -370μs, -80μs, and 530μs correlation peaks been chosen first, then the Src_A radar signal would still have been reconstructed, albeit with earlier-transmitted pulses multiplied with later-transmitted pulses to yield the reconstructed radar signal. This should not lead to a significantly different result; if the earlier-transmitted pulses were significantly different to the later-transmitted pulses, then the correlation peak would not have been produced in the first place.

The diagram of Fig. 8 shows the calculation of an intersection INT2 between the first and second RF time segments when the next correlation peak at 140μs is chosen. Specifically, the second RF time segment is shifted 140μs relative to the first RF time segment, and the first and second RF time segments are multiplied together to produce the intersection INT2, which corresponds to the radar signal from the unknown radar transmitter Src_B. The dashed lines on Fig. 7 show how the pulses RP_B are aligned with one another at the timeshift of 140μs, and therefore result in the pulses RP_B being reconstructed in the intersection INT2.

Once the Src_B radar signal has been reconstructed, and identified as having a pulse repetition interval of 633μs, the correlation peaks that appear in the Fig. 6 cross-correlation at intervals of 633μs can be discounted as aliases. Had a different one of the -493μs, 140μs, and 773μs correlation peaks been chosen first, then the Src_B radar signal would still have been reconstructed, albeit with earlier-transmitted pulses multiplied with later-transmitted pulses to yield the reconstructed radar signal. This should not lead to a significantly different result; if the earlier-transmitted pulses were significantly different to the later-transmitted pulses, then the correlation peak would not have been produced in the first place.

The reconstructed radar signals INT1 and INT2 can then be passed to any subsequent processing stages to further characterise them if necessary. Although in this embodiment the first and second RF time segments were both synchronised to start at time T = 0, a difference between the starts of the first and second RF time segments would simply be reflected by a difference in the timing of the correlation peak, and would not therefore have any significant effect upon the reconstructed signal.

A second illustrative embodiment of the invention will now be described with reference to Figs. 1 and 9 – 11. The second embodiment uses the same configuration of first and second unknown radar transmitters and first and second antennas as the first embodiment, however the radar signals that are transmitted differ from those of the first embodiment.

The timing diagram of Fig. 9 shows a jittered radar signal Src_AJ that is transmitted from the first unknown radar transmitter Src_A. The jittered radar signal Src_AJ comprises multiple pulses that have a nominal pulse repetition interval of 450µs, but which are jittered by plus or minus 50µs.

The timing diagram of Fig. 10 shows a jittered radar signal Src_BJ that is transmitted from the second unknown radar transmitter Src_B. The jittered radar signal Src_BJ comprises multiple pulses that have a nominal pulse repetition interval of 633µs, but which are jittered by plus or minus 50µs.

The jittered radar signals Src_AJ and Src_BJ are received at the first and second antennas RX1 and RX2, and first and second RF time segments are taken therefrom. Fig. 11 shows a cross-correlation of these first and second RF time segments, and it can be seen that the cross-correlation only produces two peaks, one peak CP_AJ corresponding to the radar signal Src_AJ at a TDOA of -370µs, and one peak CP_BJ corresponding to the radar signal Src_BJ at a TDOA of 140µs. The aliased correlation peaks that were present in Fig.6 have all disappeared due to the jittering of the pulses, and the number of radar signals can be directly counted according to the number of correlation peaks.

A third embodiment of the invention will now be described with reference to Figs. 12 and 13.

Fig. 12 shows a schematic diagram of an unknown radar transmitter Scr_C, and first, second, and third spatially different antennas RXA and RXB, and RXC. The three antennas each receive a radar signal from the unknown radar transmitter Src_C. The three antennas also receive radar signals from other unknown radar transmitters (not shown in Figs).

Fig. 13 shows a schematic diagram of a radar signal separator system which comprises the three antennas RXA and RXB, and RXC, a radar signal separator 10, and a radar signal analyser 20. The three antennas RXA and RXB, and RXC are connected to the radar signal separator 10 at three respective inputs I_RXA, I_RXB, and I_RXC.

In use, the radar signal separator 10 records three RF time segments from the antennas RXA and RXB, and RXC. The connections between the antennas and the radar signal separator are of different lengths, and the radio signal separator 10 automatically offsets the recorded RF time segments from one another according to the differences between the lengths of the connections, such that the recorded RF time segments are all synchronised with one another in time.

The radar signal separator 10 calculates the cross-correction between the first RF time segment, the second RF time segment, and the third RF time segment, and a correlation peak designates a TDOA of the Scr_C radar signal between the first and second antennas RXA and RXB, and a TDOA of the Scr_C radar signal between the first and third antennas RXA and RXC.

The radar signal separator 10 then calculates the intersection between the first RF time segment, the second RF time segment, and the third RF time segment when the RF time segments are aligned according to the correlation peak, which yields the reconstructed Scr_C radar signal. The reconstructed Scr_C radar signal is output at an output OP to the radar signal analyser 20 for analysis.

Since three antennas are present rather than only two, the TDOA's can be used to determine the position of the unknown radar transmitter Scr_C by multi-lateration. Specifically, the TDOA of the Scr_C radar signal between the first and second antennas RXA and RXB defines a first hyperbola HYP1 along which the unknown radar transmitter Scr_C must lie, and the TDOA of the Scr_C radar signal between the first and third antennas RXA and RXC defines a second hyperbola HYP2 along which the unknown radar transmitter Scr_C must lie. The intersection of the first and second hyperbolas gives the location of the unknown radar transmitter Scr_C.

As an alternative to synchronising the first, second, and third RF time segments in time according to the lengths of the connections between the first, second, and third antennas and the radio signal separator 10, the RF signals may be recorded at the locations of the first, second, and third antennas, and be sent to the radio signal separator 10 together with timestamps indicating at which times the RF time segments were recorded.

Note that figures 2 to 10 predominantly depict an embodiment where instead of the method involving the recording or processing of the raw RF waveform, the method is applied to a simplified representation of the RF waveform, including information on the (at least relative) timing of the pulses arriving at each receiver. Figures 2 to 10 are described above specifically recording the timing of leading and trailing edges, and this being embodied in an envelope waveform representation, however it will be apparent that any timing measurement relevant to the pulses can be used if used consistently, such as the midpoint of each pulse, and it will be apparent that the calculation of performing the cross correlation need not involve a graphical representation, nor even an envelope waveform data file, and instead a list of the timings may be sufficient.

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

CLAIMS

1. A method of receiving multiple unknown radar signals at spatially different antennas, the multiple unknown radar signals being from different radar transmitters that have different positions to one another such that the radar signals have different time difference of arrival (TDOA) from one another with respect to the spatially different antennas, and separating and extracting an unknown radar signal out from the multiple unknown radar signals, the method comprising:

receiving the multiple unknown radar signals at spatially different antennas, including receiving a first RF time segment taken from a first antenna of the spatially different antennas and receiving a second RF time segment taken from a second antenna of the spatially different antennas, and

separating the unknown radar signal out from the multiple unknown radar signals based upon the time difference of arrival (TDOA) of the unknown radar signal at the spatially different antennas, including:

calculating a cross-correlation between the first RF time segment and the second RF time segment, and

identifying a peak in the calculated cross-correlation, the peak designating a TDOA of the unknown radar signal at the first and second antennas,

and,

extracting the parts of the received signals that correlate with one another at the identified correlation peak to construct a radar signal,

wherein, the first and second RF time segments each comprise a simplified representation of respectively associated radio frequency waveform time segments, each simplified representation including summary information including timings of radar pulses of the respectively associated radio frequency waveform time segments.

2. The method of claim 1, wherein the TDOA of the unknown radar signal at the first and second antennas is a timeshift of the second RF time segment from the first RF time segment at which the first RF time segment and the second RF time segment correlate with one another, and wherein the separating the unknown radar signal out from the multiple unknown radar signals further comprises:

- calculating an intersection of the first RF time segment and the second RF time segment when the second RF time segment is shifted from the first RF time segment by the timeshift; and

- outputting the calculated intersection as the unknown radar signal.

3. The method of claim 2, wherein the calculating an intersection of the first RF time segment and the second RF time segment comprises calculating the product of the first RF time segment and the second RF time segment.

4. The method of claim 1,2 or 3 further comprising restricting a frequency range of each of the first and second RF time segments to cover expected radar signal frequencies, prior to the step of calculating a cross-correlation between the first RF time segment and the second RF time segment.

5. The method of claim 1, 2, 3 or 4 wherein:

- the receiving the multiple unknown radar signals at spatially different antennas comprises receiving a third RF time segment taken from a third antenna of the spatially different antennas;

- the calculating a cross-correlation between the first RF time segment and the second RF time segment comprises calculating the cross-correction between the first RF time segment, the second RF time segment and the third RF time segment; and

- the peak additionally designates a TDOA of the unknown radar signal at the first and third antennas.

6. The method of claim 5, wherein the TDOA of the unknown radar signal at the first and third antennas is a timeshift of the third RF time segment from the first RF time segment at which the third RF time segment correlates with the first and second RF time segments.

7. The method of claim 6, further comprising determining a position from which the unknown radar signal originates based upon the timeshift of the second RF time segment from the first RF time segment, the timeshift of the third RF time segment from the first RF time segment, the relative times at which the first, second, and third RF time segments were taken from the first, second, and third antennas respectively, and the positions of the first, second, and third antennas.

8. The method of claim 7, wherein the relative times at which the RF time segments were taken from the antennas are determined according to respective timestamps associated with each one of the RF time segments.

9. The method of claim 5, 6, 7 or 8 wherein the step of calculating an intersection comprises calculating the intersection of the first RF time segment, the second RF time segment, and the third RF time segment, when the second RF time segment is shifted from the first RF time segment by the timeshift of the second RF time segment from the first RF time segment, and the third RF time segment is shifted from the first RF time segment by the timeshift of the third RF time segment from the first RF time segment.

10. The method of any one of claims 1 - 9, further comprising identifying a further peak in the calculated cross-correlation, the further peak designating a TDOA of a further unknown radar signal at the first and second antennas.

11. The method of claim 10, further comprising repeating the steps of any one of claims 2 – 9 for the further peak to output the further unknown radar signal.

12. A radar signal separator for separating an unknown radar signal out from multiple unknown radar signals, the radar signal separator configured to:

- receive the multiple unknown radar signals from spatially different antennas; and
- separate the unknown radar signal out from the multiple unknown radar signals based upon the time difference of arrival (TDOA) of the unknown radar signal at the spatially different antennas.

13. The radar signal separator of claim 12, wherein the radar signal separator is configured to receive the multiple unknown radar signals from spatially different antennas by:

- receiving a first RF time segment taken from a first antenna; and
-receiving a second RF time segment taken from a second antenna that is remote from the first antenna, and

wherein the radar signal separator is configured to separate the unknown radar signal out from the multiple unknown radar signals based upon the TDOA of the unknown radar signal at the spatially different antennas by:

- calculating a cross-correlation between the first RF time segment and the second RF time segment;

- identifying a peak in the calculated cross-correlation, the peak designating a timeshift of the second RF time segment from the first RF time segment at which the first RF time segment and the second RF time segment correlate with one another;

- calculating an intersection of the first RF time segment and the second RF time segment when the second RF time segment is shifted from the first RF time segment by the timeshift; and

- outputing the calculated intersection as the unknown radar signal.

14. A method of separating an unknown radar signal out from multiple unknown radar signals, comprising receiving the multiple unknown radar signals at spatially different antennas, and separating the unknown radar signal out from the multiple unknown radar signals based upon the time difference of arrival (TDOA) of the unknown radar signal at the spatially different antennas.

15. A method of receiving multiple unknown radar signals at spatially different antennas, the multiple unknown radar signals being from different radar transmitters that have different positions to one another such that the radar signals have different time difference of arrival (TDOA) from one another with respect to the spatially different antennas, and separating and extracting an unknown radar signal out from the multiple unknown radar signals, the method comprising:

receiving the multiple unknown radar signals at spatially different antennas, including receiving a first RF time segment taken from a first antenna of the spatially different antennas and receiving a second RF time segment taken from a second antenna of the spatially different antennas, and

separating the unknown radar signal out from the multiple unknown radar signals based upon the time difference of arrival (TDOA) of the unknown radar signal at the spatially different antennas, including:

calculating a cross-correlation between the first RF time segment and the second RF time segment, and identifying a peak in the calculated cross-correlation, the peak designating a TDOA of the unknown radar signal at the first and second antennas,

and,

extracting the parts of the received signals that correlate with one another at the identified correlation peak to construct a radar signal.

1/5

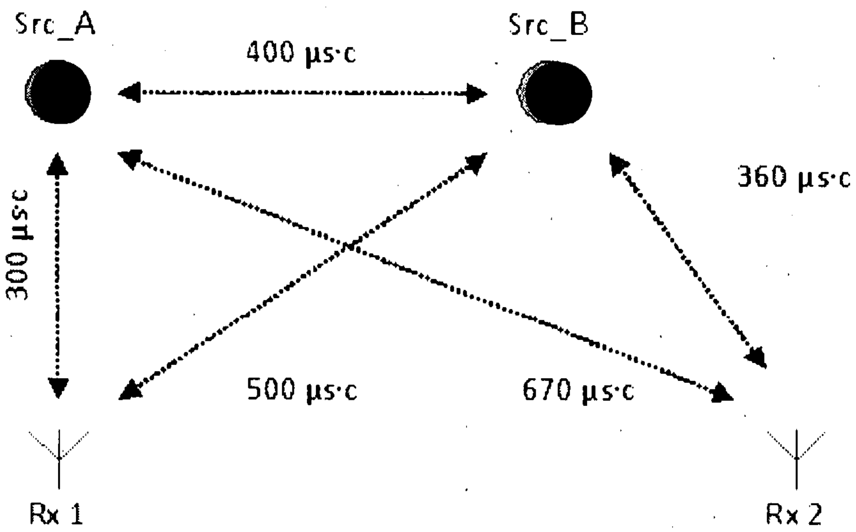


Fig. 1

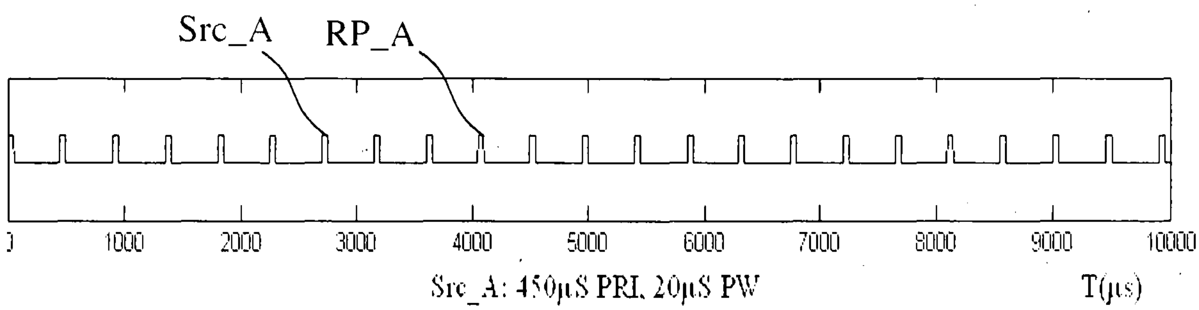


Fig. 2

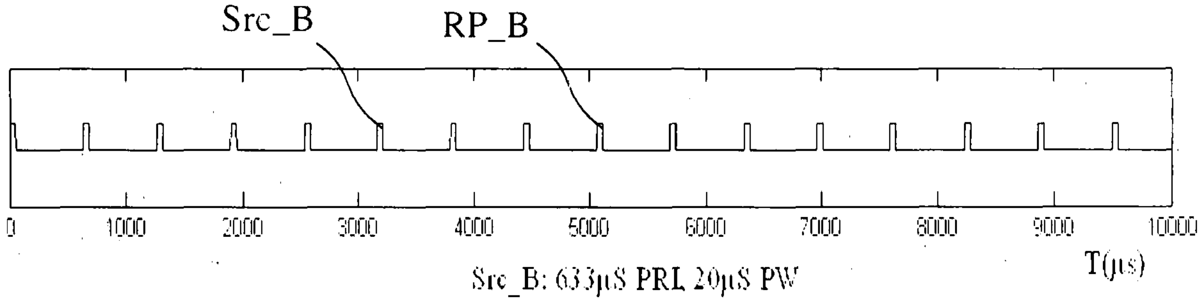


Fig. 3

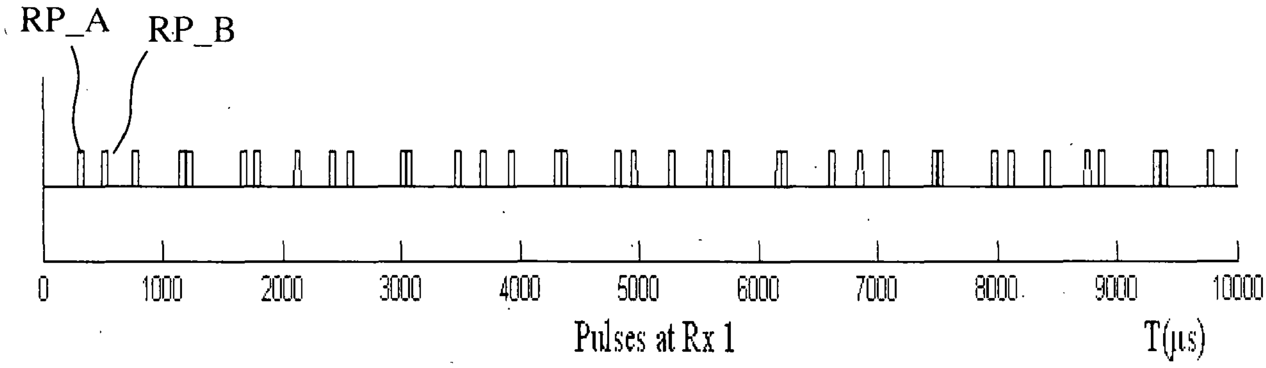


Fig. 4

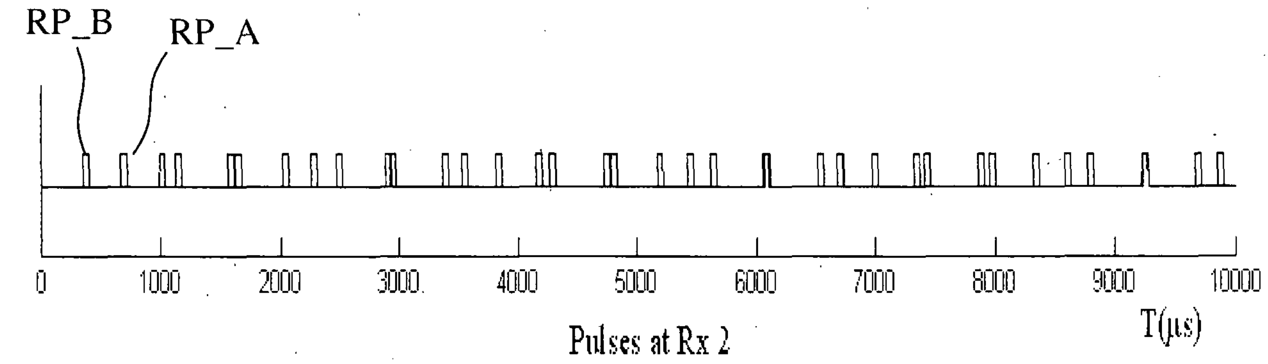


Fig. 5

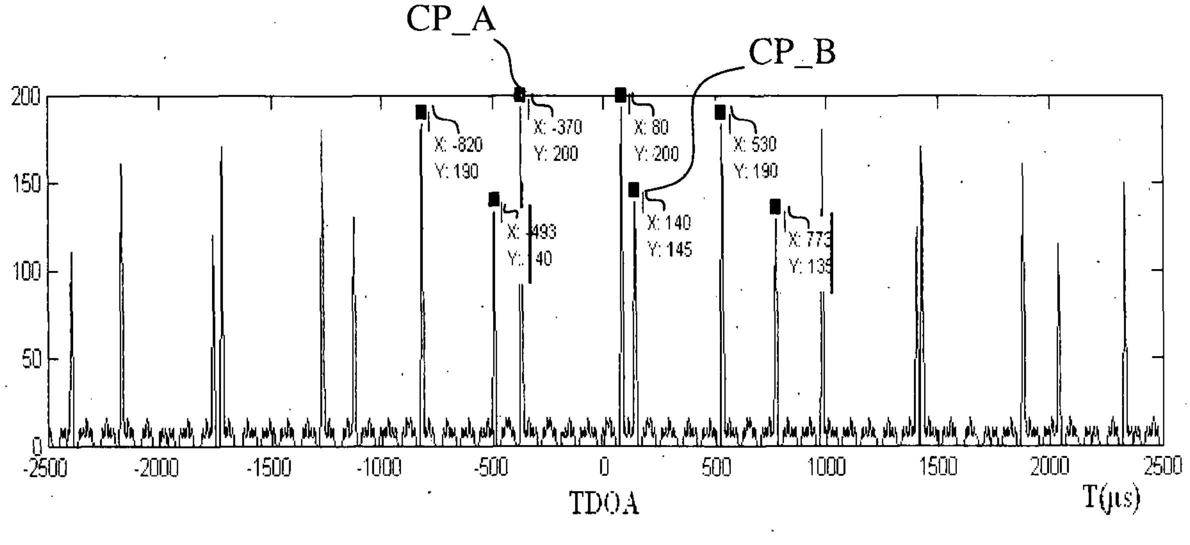
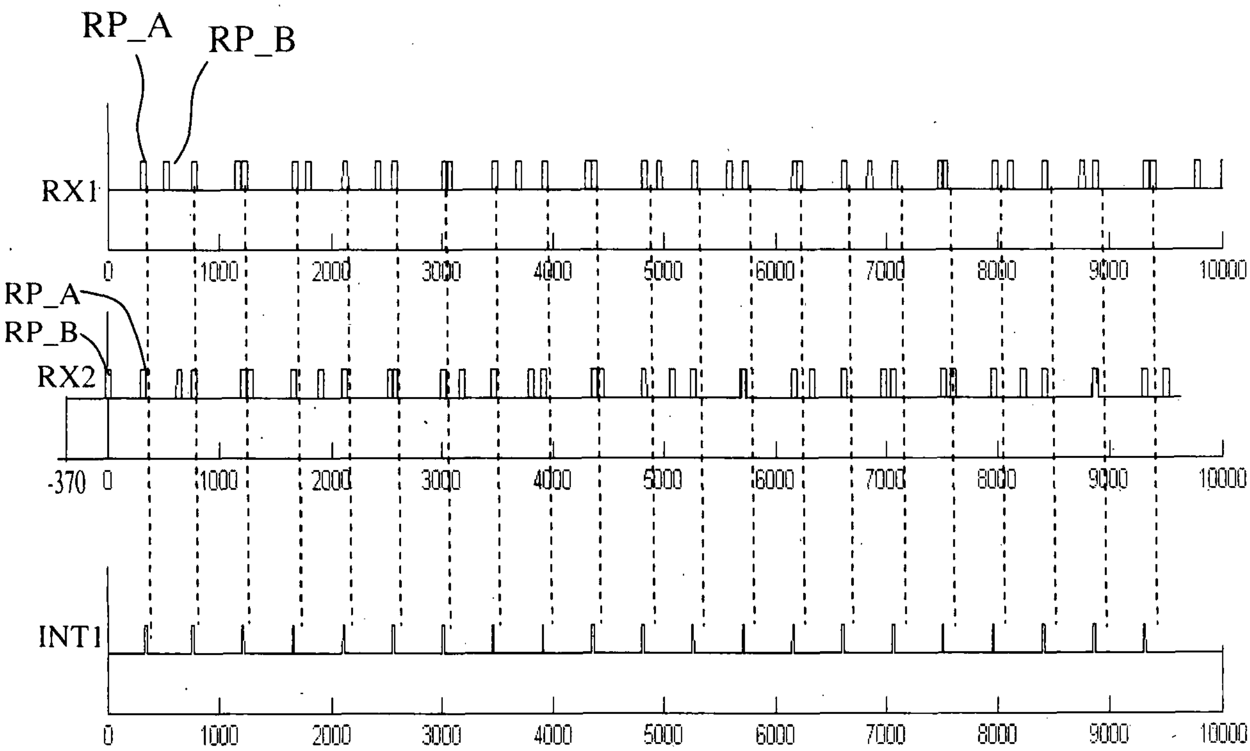


Fig. 6



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RP_B
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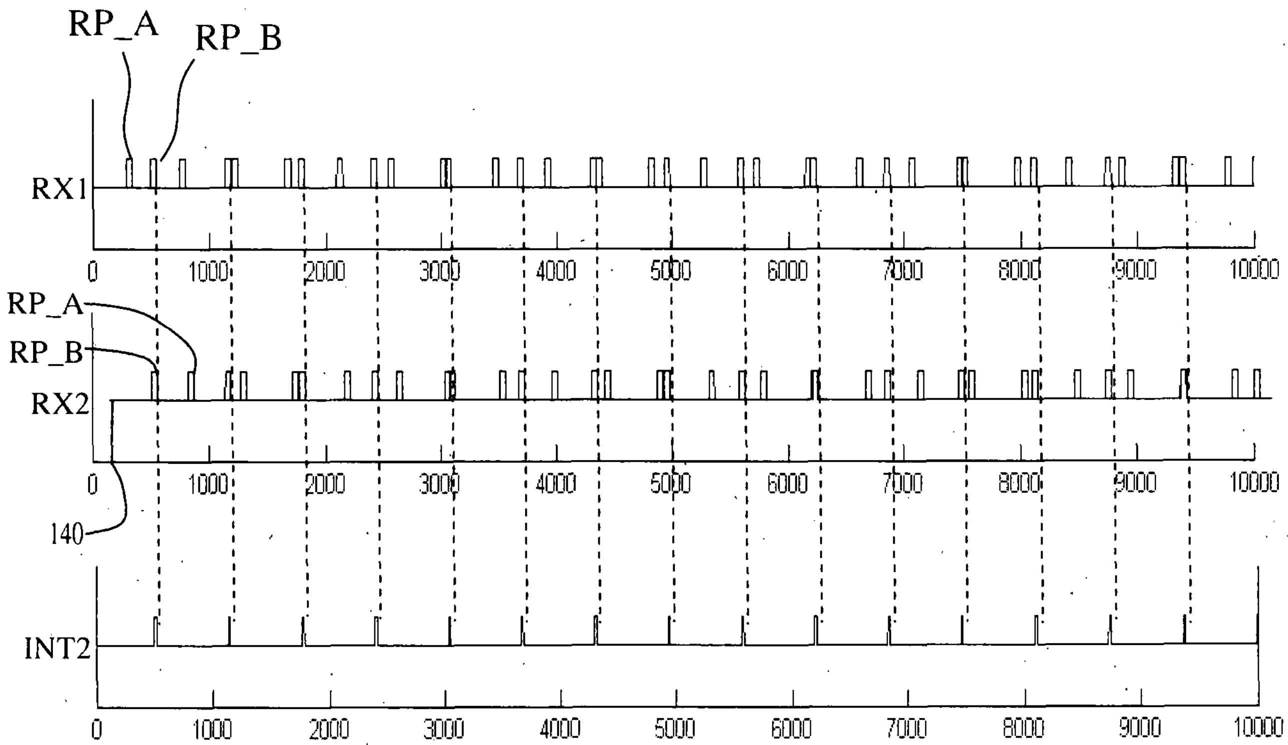
RP_A
RP_B
RX2
-370 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000
INT1
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Fig. 7



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RP_B
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RP_A
RP_B
RX2
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140
INT2
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Fig. 8

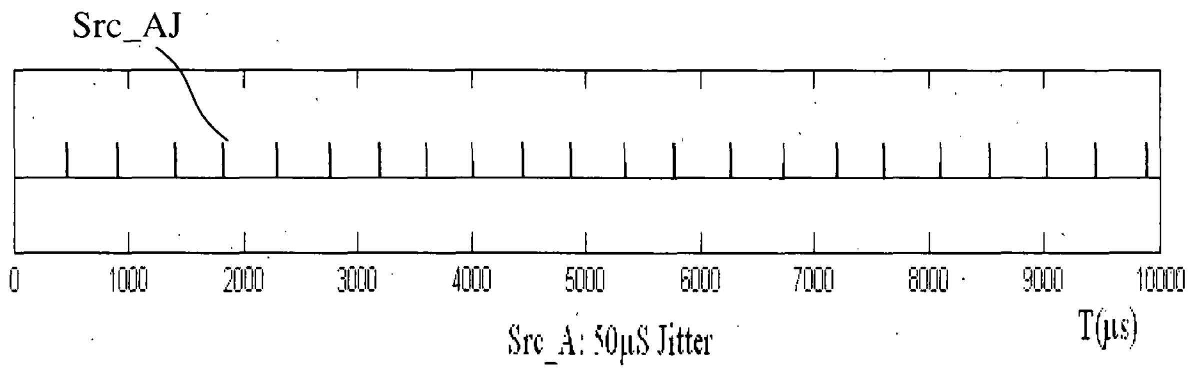


Fig. 9

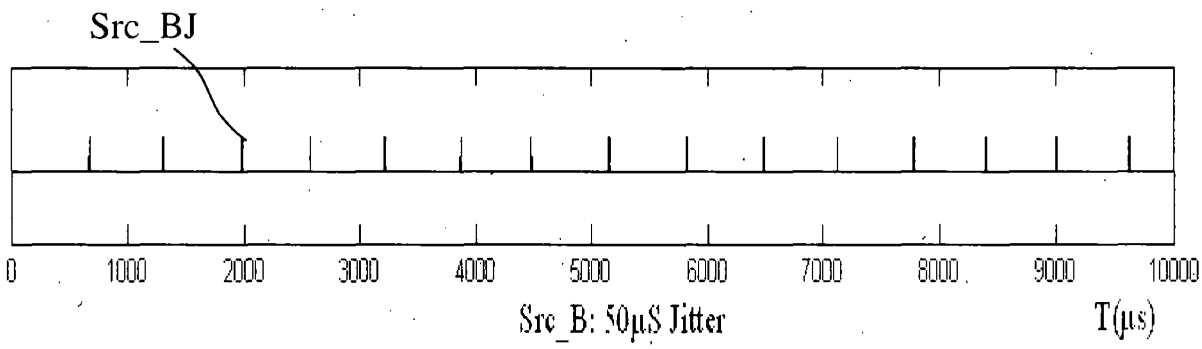


Fig. 10

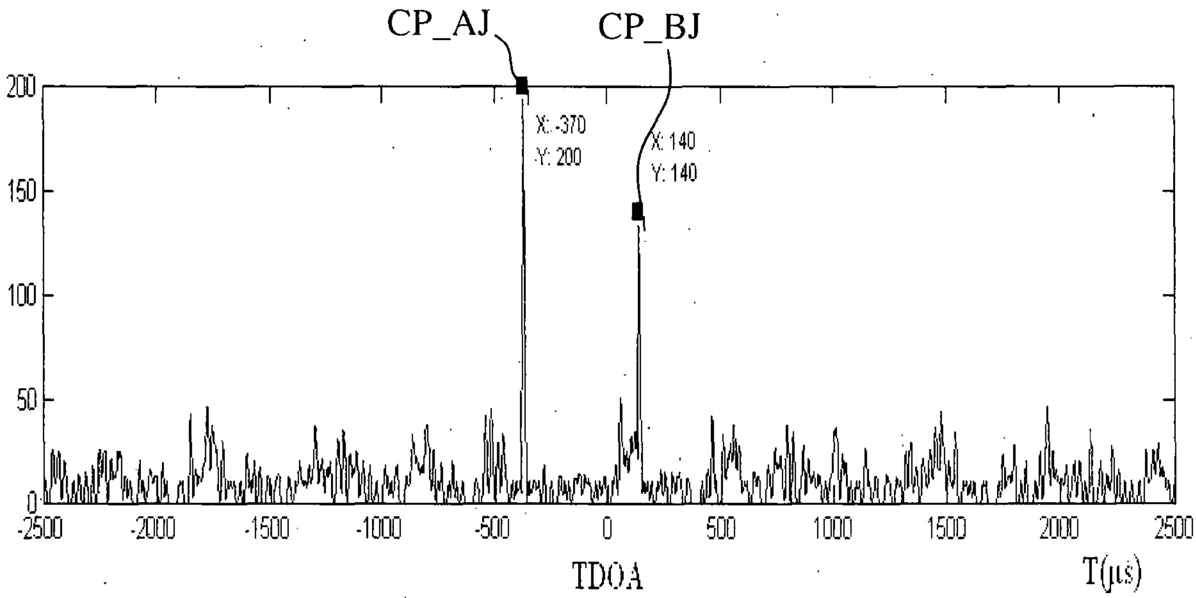
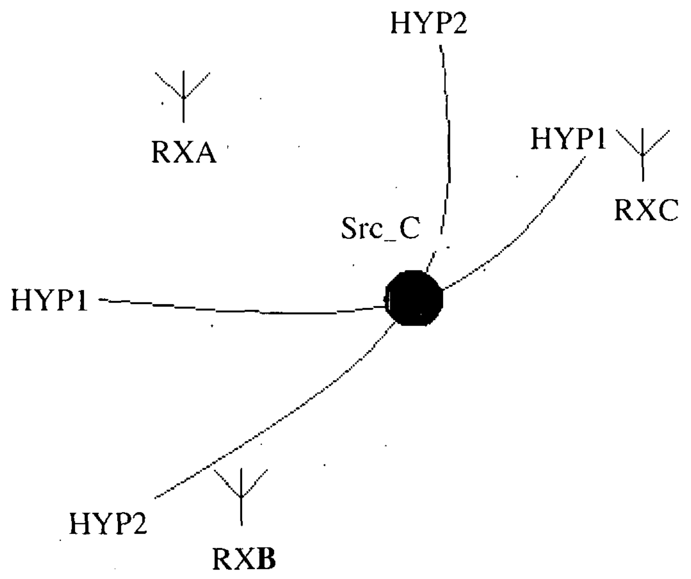


Fig. 11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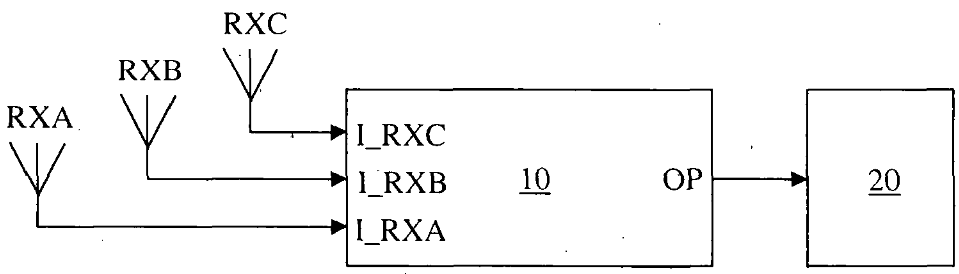
RXA
HYP1
RXC
Src_C
HYP1
HYP2
RXB

Fig. 12


RXC
RXB
RXA
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I_RXB
10
OP
I_RXA
20

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2014/000113

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S5/06 G01S7/02
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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 565 764 A (PRIEBE LESLIE A [US] ET AL) 15 October 1996 (1996-10-15) abstract; figures column 3, line 26 - line 42 column 6, line 3 - line 17 column 11, line 59 - column 12, line 13 -----	12,14 1,4-8, 10,11,15
X Y	US 5 285 209 A (SHARPIN DAVID L [US] ET AL) 8 February 1994 (1994-02-08) abstract; figures column 3, line 62 - column 4, line 61 -----	12,14 1,4-8, 10,11,15
A	EP 2 270 537 A1 (SIE SOC IT ELETTRONICA [IT]) 5 January 2011 (2011-01-05) abstract paragraphs [0006] - [0008], [0018], [0019] ----- -/--	1,7,8, 12,14,15

[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
8 August 2014	18/08/2014

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	Roost, Joseph

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 5 583 505 A (ANDERSEN DAVID P [US] ET AL) 10 December 1996 (1996-12-10) cited in the application abstract -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2014/000113

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			RU 2010125205	A	27-12-2011
			US 2010321239	A1	23-12-2010
US 5583505	A	10-12-1996	NONE		