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(71) Applicant(s):
Thales Holdings UK Plc
(Incorporated in the United Kingdom)
2 Dashwood Lang Road, The Bourne Business Park, Addlestone, NR WEYBRIDGE, Surrey, KT15 2NX, United Kingdom

(72) Inventor(s):
Andrew Gerald Stove

(74) Agent and/or Address for Service:
Marks & Clerk LLP
90 Long Acre, LONDON, WC2E 9RA, United Kingdom

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(56) Documents Cited:
US 6750809 B1 **US 4309703 A**
US 4161732 A **US 20070285302 A1**
US 20070188377 A1
Hu et al, "Study on non-linear stepped chirp radar system", Proceedings of International Conference on Communications, Circuits and Systems, ICCCAS 2008, IEEE, pages 881 to 885, ISBN 978-1-4244-2063-6

(58) Field of Search:
INT CL **G01S**
Other: **EPODOC, WPI, XPIEE, XPI3E, XPIOP, XPESP, INSPEC**

(54) Title of the Invention: **Radar**
Abstract Title: **Radar system synthesising a broadband waveform from a series of narrowband chirps and accounting for Doppler of a target between chirps**

(57) A radar system creates a wideband radio frequency signal by emitting a series of narrowband chirp signals of increasing frequency (A to H). To account for motion of a target between chirps of the waveform, one of the chirped signals (A') is repeated at the same frequency at a different point in the series. The Doppler shift caused by the radial velocity of the target maybe estimated from the two chirps of equal frequency (A and A') and used to correct for phase changes due to target motion over the duration of the synthesised broadband signal. The radar system may assume that the radial velocity is constant over the duratrion of the wideband signal, and apply a phase correction to each chirp (B to H) based on the phase difference between the identical chirps (A and A'). Alternative sequences of chirp transmission are also possible (see figures 3 to 5, not shown).

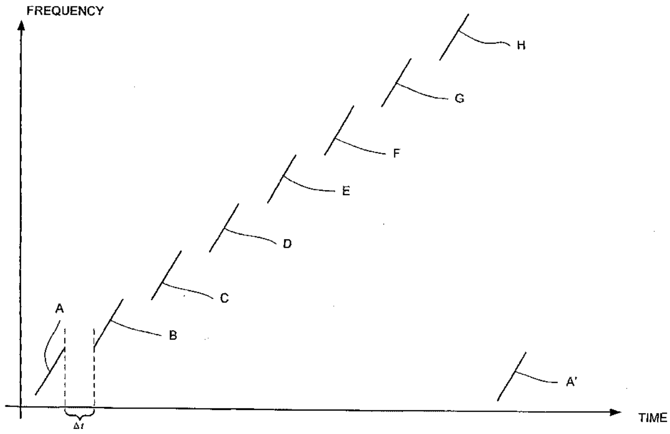

FIGURE 2

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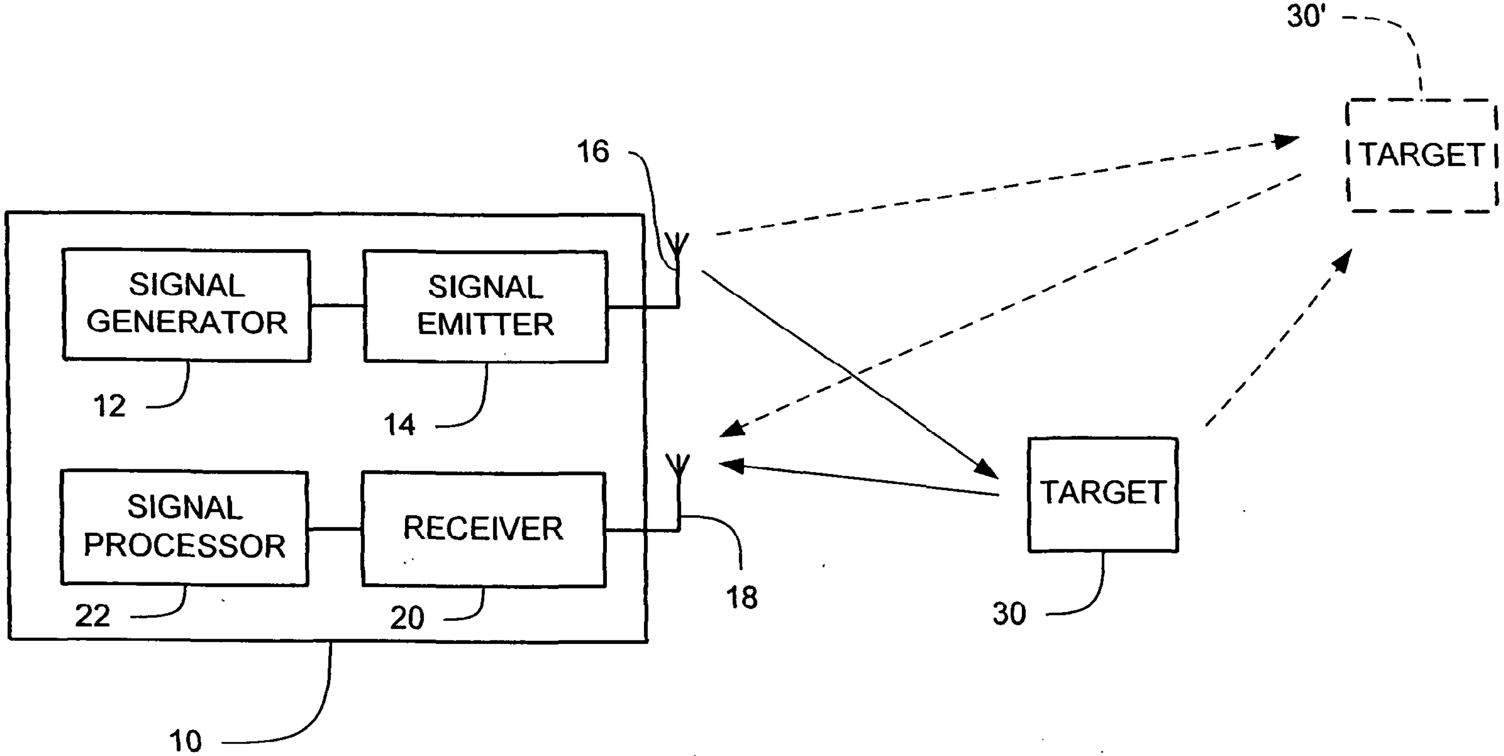
SIGNAL GENERATOR
12
SIGNAL EMITTER
14
SIGNAL PROCESSOR
22
RECEIVER
20
10
16
18
TARGET
30
TARGET
30'

FIGURE 1

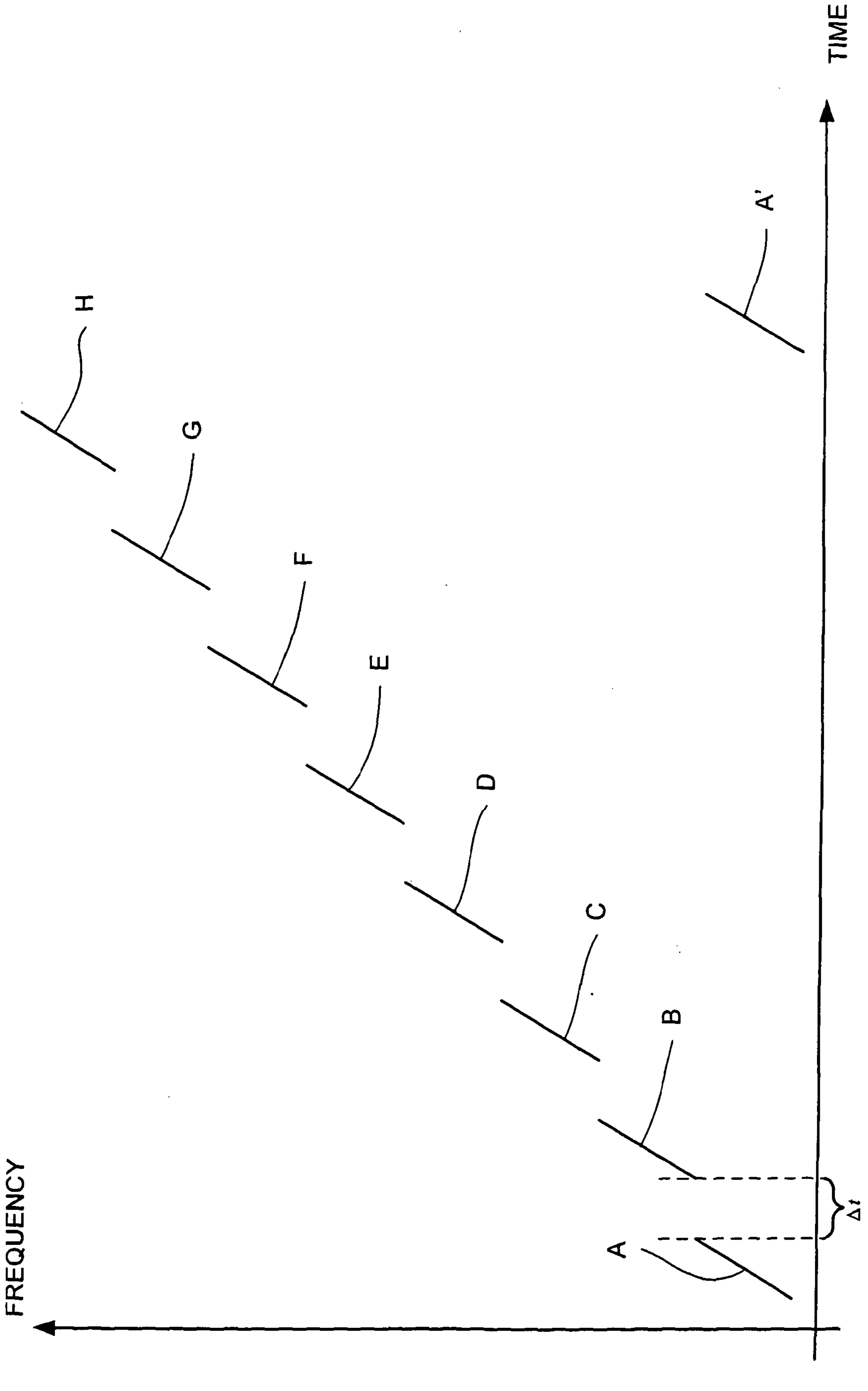

FIGURE 2

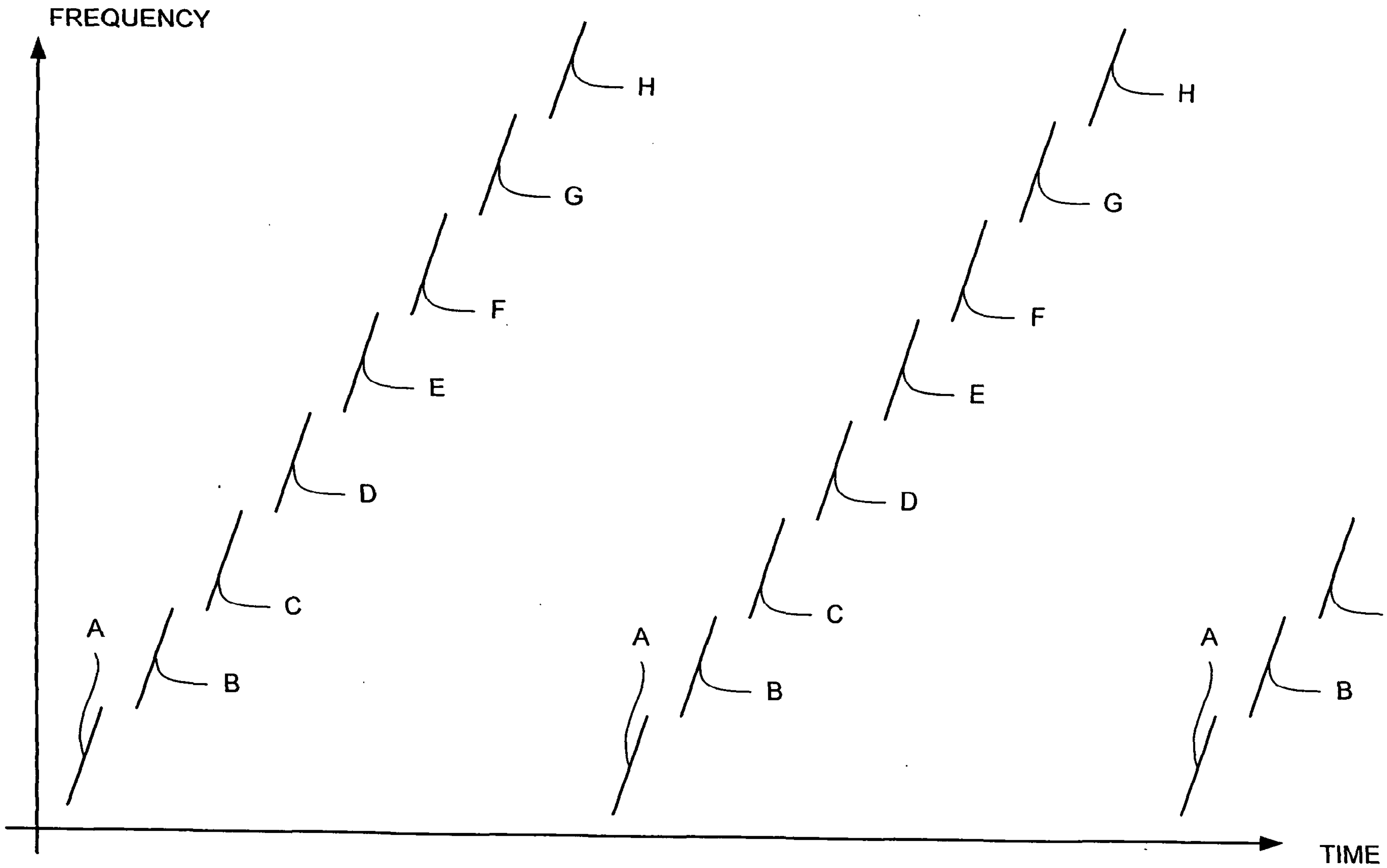

FIGURE 3

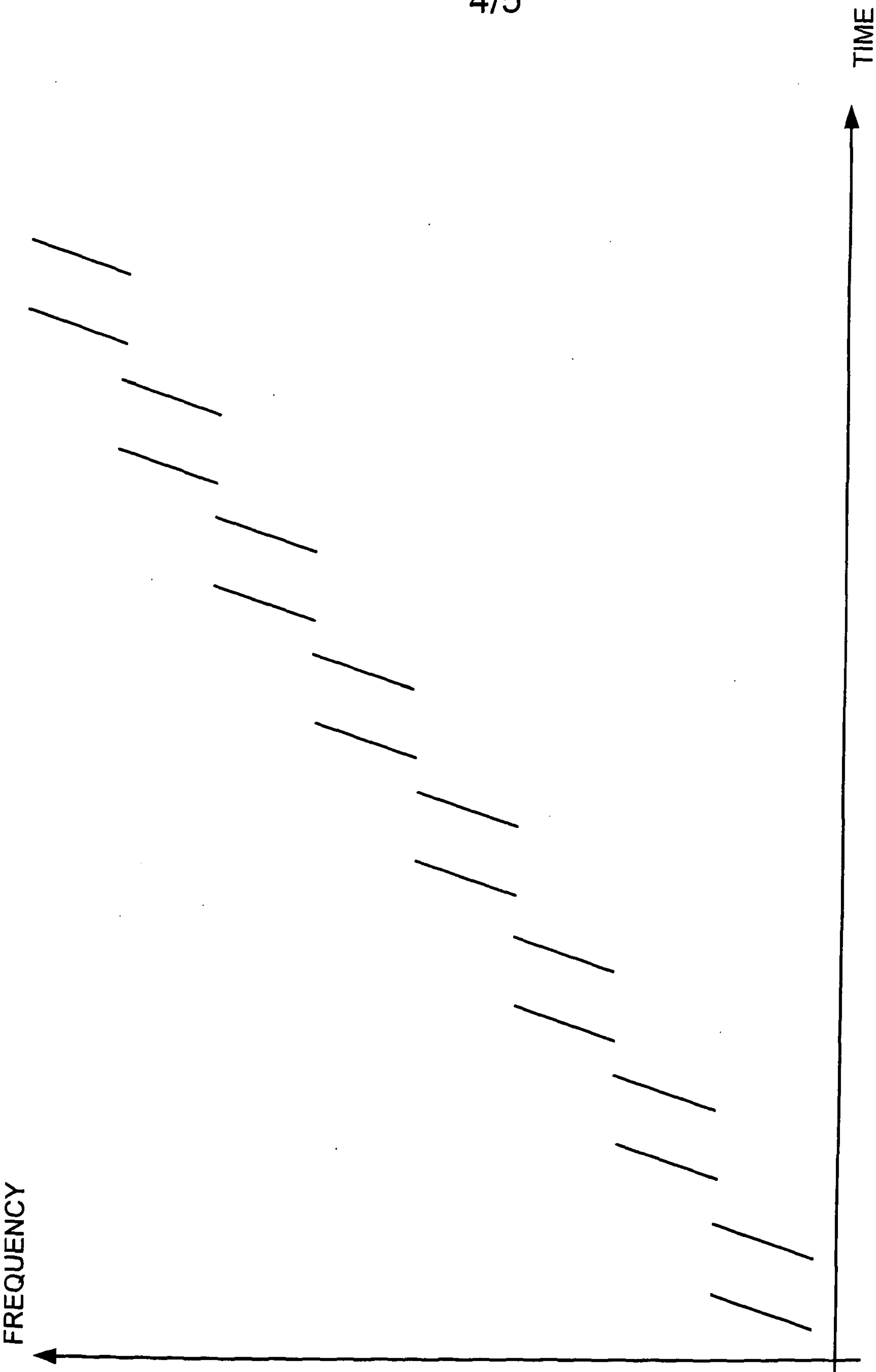

FIGURE 4

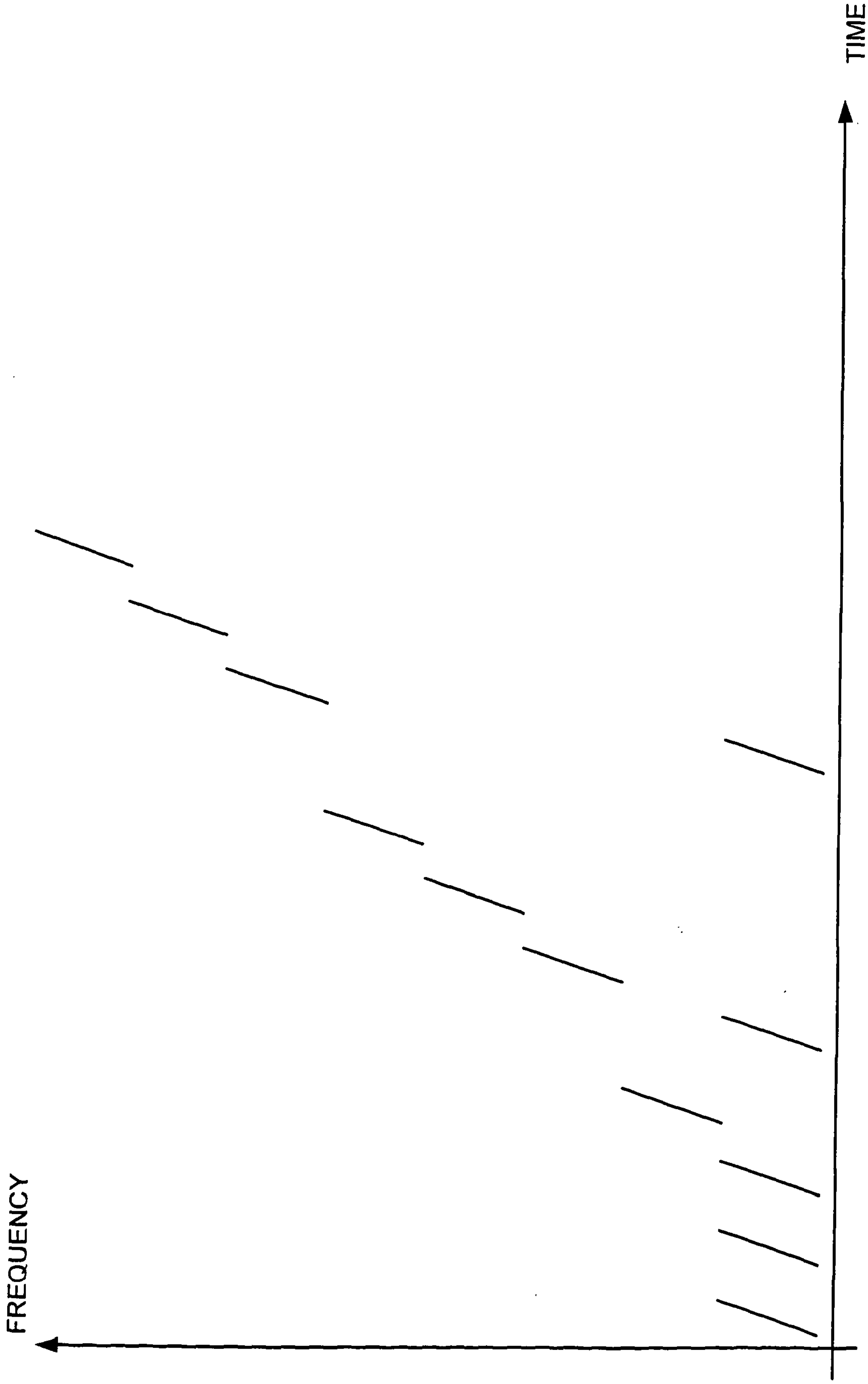

FIGURE 5

Radar

Embodiments described herein relate generally to radar.

It is known to modulate a radar signal with a linear "chirp". A chirp is a signal of finite duration whose frequency changes monotonically with time. A linear chirp is one where frequency varies linearly with time.

Range resolution of a radar system designed on this basis is proportional to the bandwidth of the radar signal. Thus, to achieve a high range resolution, very wideband signals, and correspondingly wide band receivers, are required. This can give rise to technical difficulties. One constraint on performance is the requirement, usual in modern systems, to convert received signals from analogue to digital representation. This requires use of an analogue to digital converter (ADC); provision of a high resolution, high bandwidth ADC can be problematic.

In order to ameliorate this, it has been known to synthesise a linear chirp based radar waveform as a sequence of step frequency waveforms. For instance, "A Stepped Chirp Technique for Range Resolution Enhancement" (McGrory, F. and Lindell, K., IEEE Nat. Telesystems Conf., 1991, pp. 121-6) discloses such an approach.

Such a technique involves emitting a plurality of waveforms of narrower bandwidth, but with different centre frequencies. The returns from these waveforms can then be "stitched" together on receipt. This provides the required range resolution but without the need to process high bandwidth signals. This approach is typically used to obtain high resolution range profiles of targets, using receivers having relatively narrow-band analogue to digital converters.

However, by emitting a sequence of narrowband waveforms in this way, rather than one high bandwidth chirp, and then relying on assembly of the responses to those narrowband waveforms as if the emitted signal were one high bandwidth chirp, any such system may be susceptible to phase changes from one narrowband waveform to the next. Motion of a target, for instance, may introduce a Doppler shift. If a wideband linear chirp is emitted without interruption, then this is not a problem, as changes in-phase can occur throughout a return, and can be processed without difficulty in a receiver. If a wideband linear chirp is emitted in narrowband sections, then the resultant returns may exhibit phase changes from one to the next. When attempting to stitch the returns together into a composite return signal, these phase changes can cause corruption.

An embodiment disclosed herein provides a radar signal emitter operable to emit a radio frequency signal, the emitter being operable, in use, to emit, consecutively in time, a plurality of narrowband signals, said narrowband signals being distributed in a wideband frequency domain, at least one of said narrowband signals being substantially the same as another preceding one of said narrowband signals.

An embodiment disclosed herein provides a radar system comprising a radar signal emitter as above and a radar signal receiver, wherein the receiver is operable to receive a return signal resulting from interaction of said emitted signal with a target in an external environment, and operable to determine, on the basis of comparison of a return signal corresponding to said narrowband signal, substantially the same frequency as a preceding one, and a return signal corresponding to said preceding one, a Doppler shift associated with any motion of said target, and to compensate return signals corresponding to said plurality of narrowband chirps on the basis of that determined Doppler shift, and to concatenate so compensated return signals to produce a composite signal equivalent to a return which would result from emission of a wideband signal across said wideband frequency domain.

An embodiment disclosed herein provides a method of emitting a radio frequency signal, comprising emitting, consecutively in time, a plurality of narrowband signals, said narrowband signals being distributed in a wideband frequency domain, at least one of said narrowband signals being substantially the same as another preceding one of said narrowband signals.

An embodiment disclosed herein provides a method of putting a radar system into effect comprising emitting a radar signal in accordance with the above, and receiving a radar return signal, wherein the receiving comprises receiving a return signal resulting from interaction of said emitted signal with a target in an external environment, comparing a return signal corresponding to said narrowband signal, substantially the same frequency as a preceding one, and a return signal corresponding to said preceding one, determining, on the basis of said comparing, a Doppler shift associated with any motion of said target, compensating return signals corresponding to said plurality of narrowband chirps on the basis of that determined Doppler shift, and concatenating so compensated return signals to produce a composite signal equivalent to a return which would result from emission of a wideband signal across said wideband frequency domain.

In general terms, an embodiment as disclosed herein provides a pulse compression radar, comprising arranging for emission of a plurality of narrowband pulses, within a wideband domain, and assembling a notional wideband return from the corresponding narrowband returns. To account for possible Doppler shift, an excess of narrowband pulses can be emitted, and any Doppler shift can be detected from comparison of two or more narrowband pulses of the same nature, spaced in time.

An embodiment will now be described with reference (by way of example only) to the drawings, in which:

Figure 1 is a schematic diagram of a radar system in accordance with a described embodiment;

Figure 2 is a graph of frequency against time, of an output from an emitter of the radar system, of the embodiment illustrated in figure 1, in accordance with a first configuration;

Figure 3 is a graph of frequency against time, of an output from an emitter of the radar system, of the embodiment illustrated in figure 1, in accordance with a second configuration;

Figure 4 is a graph of frequency against time, of an output from an emitter of the radar system, of the embodiment illustrated in figure 1, in accordance with a third configuration; and

Figure 5 is a graph of frequency against time, of an output from an emitter of the radar system, of the embodiment illustrated in figure 1, in accordance with a fourth configuration.

As shown in figure 1, a radar system 10 comprises a signal generator 12, a radar emitter 14, a transmitter antenna 16, a receiver antenna 18, a radar signal receiver 20, and a signal processor 22.

Whereas, in this embodiment, the transmit and receive parts of the radar system are provided in a single unit, the reader will appreciate that this need not be the case, and the transmit and receive parts could be deployed in separate units. The separate units, in that alternative approach, need not be juxtaposed.

Whereas, in this embodiment, the system comprises separate transmitter antenna 16 and receiver antenna 18, the reader will understand that the use of separate antennas for transmission and reception is for illustration only and is not material to the performance of the system, which will operate equally well if a single antenna were used, in conjunction with suitable switching means, for both functions.

A target 30 is also illustrated. As shown, the target 30 is in motion, and a second illustration 30′ of the target, representative of the position of the target some time later, is illustrated in broken line.

The signal generator 12 is operable to generate a signal which is then conditioned and modulated onto a radar frequency transmission by the signal emitter 14. The transmit antenna 16 then emits a radio frequency electromagnetic transmission accordingly. This antenna may be directional or omnidirectional, depending on the implementation. This feature is not material to the present disclosure.

The emitted radio frequency transmission is reflected from in-range targets, including, in this example, the target 30. In the first instance, the target 30 is in a first position, and a reflected radio wave is denoted by a solid arrow returning to the receiver antenna 18. In a second instance, after the first instance in time, the target is shown has having moved to the second position 30'; the relevant outward and return waves are denoted by broken arrows.

The return signals are received at the receiver antenna 18, and converted into electrical signals. The receiver 20 down-converts the signals, and passes the same to a signal processor 22 for further processing. Because, as will be described in due course, the radar system uses the transmission of a sequence of narrowband chirps, the receiver 20 can be a narrowband receiver. At this stage, demodulation does not take place, as the signal processor 22 (as will be described in due course) makes use of both phase and amplitude of the received narrowband signal fragments in order to construct a wideband return signal.

The signal generated by the signal generator 12 consists of a series of narrow bandwidth chirps, of linearly rising frequency. In a series of chirps, the centre frequency of a chirp is higher than its predecessor. In simple illustration, figure 2 shows a graph of a typical radar signal generated by the signal generator 12, in accordance with a first example. The graph of figure 2 is of frequency against time. Nothing is implied by the position of the origin of the graph relative to the positions of the lines on the graph.

As can be seen, in this example, the signal for transmission comprises a sequence of eight chirps, with frequency rising with time, the chirps being separated in time, followed by a repetition of the first chirp in the sequence. In the first eight chirps, the upper frequency bound of one chirp is coincident (or substantially so) with the lower frequency bound of the next. Chirps are labelled A to H, and then A', in figure 2.

The reader will understand that the use of eight narrowband chirps to cover the range of an intended wideband emission, in this example, is not limiting on the scope of the present disclosure.

The presence of the "extra" chirp A' will now be explained. In the field of the present disclosure, as noted above, radar systems have already been described which use an arrangement comprising a series of narrowband chirps to represent a wideband radar chirp. The narrowband chirps give rise to a corresponding series of narrowband return waveforms, which can be assembled by a receiver into a composite return which substantially equates with a signal which would have been received had a wideband chirp been emitted all along.

In a radar, it has also been recognised that the radial speed of a target will result in a Doppler shift in the return signal, which can usually be employed to determine radial speed relative to the antenna. However, an observation, which the present embodiment accounts for, is that the time inserted between chirps (indicated by Δt in figure 2) means that the Doppler shifts due to target motion cause phase changes from one narrowband return signal to the next. Thus, when the receiver tries to assemble a wideband return from such a series of narrowband returns, affected by phase shifts in this way, corruption of the high resolution range profile of the radar signal could arise if left uncorrected.

To account for this, the signal generator 12 causes the emission of the additional chirp, A', following the sequence of eight narrowband chirps constructing the intended wideband chirp range. The signal processor 22 is informed, prior to use, that the extra chirp A' is to be emitted after the eight chirp sequence A-H, and takes account of the phase difference between the return from chirp A' and that from chirp A. The phase difference between these two returns can be used to correct phase differences for the returns from chirps B to H.

The signal processor 22 compensates for these calculated phase differences in the returns from B to H, by insertion of appropriate phase shifts to cancel the shift from pulse to pulse due to the Doppler, and then splices together the returns from chirps A to H, to produce a consolidated return, representative of the return that would have been encountered from a wideband chirp equivalent to the narrowband chirps A to H in combination. This can then be processed, in accordance with standard pulse compression radar techniques, to produce target detection information describing the reflectivity, position and radial speed of the target. This is a non-exhaustive list of the types of characteristics that the receiver might be able to infer from the received signal: it may also be possible to determine identification information obtained from high range resolution information.

By assuming that, in the context of the time taken from one sequence of chirps to the next, the radial speed of the target is substantially constant, the signal processor 22 can apply a phase shift to each return proportional to its position in the sequence of chirps. That is, the signal processor 22 assumes, in the context of this example, that the Doppler phase is proportional to time from the start of the sequence.

To account for the second derivative of the distance of the target (i.e. the radial acceleration), the reader will recognise that it would also be possible to construct an example which enabled a signal processor to analyse returns from a further extra chirp as well, to obtain an estimate of the acceleration of the target. Further derivatives may also be calculable, in accordance with conventional numerical methods.

In the determination of radial speed (or higher derivatives of distance) by the signal processor 22, it will be apparent to the reader that a key assumption, made in drawing a conclusion from a phase difference, is that the motion of the target has produced a Doppler shift of less than one cycle of phase in the time between the first narrowband chirp A and the last narrowband chirp A'. It will be abundantly clear that this may not be the case, if the frequencies transmitted in the chirp are sufficiently high, the chirp rate is sufficiently low, inter-chirp time gaps are sufficiently long and/or the target is moving at sufficiently high radial speed.

As a result, the measured Doppler shift can be said (in mathematical terms) to represent the radial speed of the target subject to the modulus of the reciprocal of the time between the first and last pulses. If the target is moving sufficiently quickly that a full cycle (or more) of phase shift is imposed on returns, in the time lapsed from the first chirp A to the last chirp A', then this cannot be directly detected by measuring phase shift alone.

One example comprises providing the signal processor 22 with data storage means, to enable it to store information on past returns from the target in question. By tracking the target, then the signal processor 22 can determine a coarse estimate of the target, on the basis of which it can conclude a likely radial speed relative to the radar equipment. A sequence of target radial speed (and position) readings will determine whether an assumed radial speed from a single instance of the above described method is correct, or whether one or more cycles of phase shift should reasonably be inferred from a given return.

If the course of the target is not being tracked, and there is reason to believe that the estimate of the Doppler phase shift is ambiguous, then intermediate pulses can be inserted into the sequence of chirps to resolve ambiguities. In the presently described embodiment, with eight chirps in the sequence, three additional pulses will be sufficient to resolve the ambiguity.

It may be noted by the reader that, in some cases, the entire sequence of chirps may be repeated, perhaps several times, so that Doppler processing may be performed, either using a time delay canceller or a Doppler filter bank, to suppress the returns from stationary targets. So, as shown in figure 3, an example shows recurring emission of a sequence of eight narrowband chirps A-H, encompassing a wideband frequency sweep, as for the example illustrated in figure 2. A signal processor 22, pre-informed that the emitter is making an emission of this form, is able to use the various repetitions that this offers, to generate a measure of the target Doppler. This may in some circumstances be used to correct the phase of the sections of the step-frequency signal without the need for any additional pulses to be transmitted.

In other circumstances, the Doppler shifts may be ambiguous over the repetition period of the pulse sequence, so additional pulses, within the pulse sequence, according to the disclosed method, would still be required to resolve the ambiguities.

Another case where additional pulses will certainly be required is if no Doppler processing is performed. This case will often arise when a radar system detects a high-flying airborne target, which will be detectable at a distance exceeding the distance of the horizon from the receiver, such that there will be no clutter at the same range as the target.

Another way of arranging Doppler processing is to repeat the same frequency step a number of times, and only then to move to the next frequency. This arrangement is illustrated in figure 4. This arrangement can give better Doppler processing, because the pulses at the same frequency are closer in time so the unambiguous Doppler range is wider. On the other hand, the time between the first pulse at one frequency and the first pulse at the next frequency will be correspondingly longer, so the phase correction will be more sensitive to small Doppler shifts; extra pulses, in accordance with the disclosed method, will be needed to enable the Doppler to be estimated with sufficient accuracy.

In figure 5, an example is illustrated in which a narrowband chirp sequence comprises an eight chirp sequence into which a number of extra narrowband chirps have been interpolated. In the illustrated configuration, eight chirps make up the whole frequency sweep and extra pulses, at the lowest frequency, have been interpolated after the first pulse of the regular sequence (twice) after the second and after the fifth pulse. This gives a sequence of pulses at the lowest frequency separated by one, two, four and eight times the pulse repetition interval (PRI). This allows measurements of Doppler shifts in the range ±½ the Pulse Repetition Frequency (PRF) and down to 1/16 of the PRF without interpolation. The use of the sequence of eight pulses with four interpolated pulses is only for illustration and it is envisaged that a greater number of chirps could be used to represent a wider band sweep, or narrower band chirps could be used to make up the same width of sweep, in each case leading to the use of more than eight chirps. By using these exponentially increasing gaps between chirps at the same frequency, the compensation for target radial speed can be done efficiently and without significant cost in terms of time budget.

In the above embodiments, it is envisaged that phase shift introduced as a result of emitting a series of narrowband chirps can be resolved in ±½ a cycle over the time interval between the pulses, assuming that radial acceleration of the target is negligible. However, if the return from the target is free from clutter, for instance because it is beyond horizon, or because a sequence of pulses is transmitted on each frequency to allow moving target indication (MTI) processing to suppress the clutter, then the phase shift can be measured to an accuracy determined by the signal to noise ratio, so the phase errors in the stitching process can be corrected to a degree which will suppress the residual spurii into the noise, allowing greater flexibility in the placing of the extra chirps.

The above described approach suffers from a 'loss' in processing gain because of the need to take account of the returns from extra pulses, but it will be appreciated by the reader that this loss is modest, particularly in comparison with the operational benefit of being able to compensate for Doppler while deploying narrowband receiver components. For example, as shown in figure 5, a typical sequence of eight pulses might need, as a worst case, extra pulses separated from the first by 1, 2, 4 and 8 pulses, to resolve the set of possible Doppler ambiguities and retain sufficient Doppler resolution to correct the phase over the whole sequence of eight pulses. As illustrated, application of this technique may need four additional pulses, so only 8 out of every 12 pulses transmitted would, in this case, be used to synthesise the wide bandwidth chirp. This corresponds to a loss of 1.8dB. In many cases, other information, such as target tracking, can be used to obtain a coarse estimate of the radial speed of the target so only one or two extra pulses will be needed to refine that estimate and the losses will be correspondingly lower.

It will be appreciated that repetition of the first pulse, as used in the above described examples, is not limiting on the scope of the invention. Any one of the pulses could be repeated, without operational difference to the system.

Whereas the description has been set out in the context of "up-chirps", the reader will appreciate that "down-chirps" could equally be used.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the sprit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

CLAIMS:

1. A radar signal emitter operable to emit a radio frequency signal, the emitter being operable, in use, to emit, consecutively in time, a plurality of narrowband signals, said narrowband signals being distributed in a wideband frequency domain, at least one of said narrowband signals being substantially the same as another preceding one of said narrowband signals.

2. An emitter in accordance with claim 1 wherein said plurality of narrowband signals includes a sequence of narrowband signals, said sequence comprising signals with centre frequency changing monotonically with respect to time.

3. An emitter in accordance with claim 2 wherein said narrowband signal, substantially the same as a preceding one, immediately succeeds said preceding one.

4. An emitter in accordance with claim 1 operable to emit said narrowband signal, substantially the same frequency as a preceding one,. at a time relative to said preceding one determined to be appropriate for measurement, at a corresponding receiver, of Doppler shift arising from motion of a target relative to said receiver, by comparison of return signals resultant from interaction of said two emitted signals with said target.

5. An emitter in accordance with any preceding claim wherein each narrowband signal is a chirp.

6. An emitter in accordance with claim 5 wherein each chirp is a linear chirp.

7. An emitter in accordance with claim 5 or claim 6 wherein each chirp is chirped in the same direction as the change in frequency from chirp to chirp.

8. A radar system comprising a radar signal emitter in accordance with any preceding claim and a radar signal receiver, wherein the receiver is operable to receive a return signal resulting from interaction of said emitted signal with a target in an external environment, and operable to determine, on the basis of comparison of a return signal corresponding to said narrowband signal, substantially the same

frequency as a preceding one, and a return signal corresponding to said preceding one, a Doppler shift associated with any motion of said target, and to compensate return signals corresponding to said plurality of narrowband chirps on the basis of that determined Doppler shift, and to concatenate so compensated return signals to produce a composite signal equivalent to a return which would result from emission of a wideband signal across said wideband frequency domain.

9. A radar system in accordance with claim 8 wherein said emitter and receiver are substantially co-located.

10. A radar system in accordance with claim 8 or claim 9 wherein said receiver is operable to determine a radial speed of a detected target on the basis of detected Doppler shift.

11. A method of emitting a radio frequency signal, comprising emitting, consecutively in time, a plurality of narrowband signals, said narrowband signals being distributed in a wideband frequency domain, at least one of said narrowband signals being substantially the same as another preceding one of said narrowband signals.

12. A method in accordance with claim 11 wherein said plurality of narrowband signals includes a sequence of narrowband signals, said sequence comprising signals with centre frequency changing monotonically with respect to time.

13. A method in accordance with claim 12 wherein said narrowband signal, substantially the same as a preceding one, immediately succeeds said preceding one.

14. A method in accordance with claim 11 comprising emitting said narrowband signal, substantially the same frequency as a preceding one, at a time relative to said preceding one determined to be appropriate for measurement, at a corresponding receiver, of Doppler shift arising from motion of a target relative to said receiver, by comparing return signals resultant from interaction of said two emitted signals with said target.

15. A method in accordance with any one of claims 11 to 14 wherein each narrowband signal is a chirp.

16. A method in accordance with claim 15 wherein each chirp is a linear chirp.

17. A method in accordance with claim 15 or claim 16 wherein each chirp is chirped in the same direction as the change in frequency from chirp to chirp.

18. A method of putting a radar system into effect comprising emitting a radar signal in accordance with any one of claims 11 to 17 and receiving a radar return signal, wherein the receiving comprises receiving a return signal resulting from interaction of said emitted signal with a target in an external environment, comparing a return signal corresponding to said narrowband signal, substantially the same frequency as a preceding one, and a return signal corresponding to said preceding one, determining, on the basis of said comparing, a Doppler shift associated with any motion of said target, compensating return signals corresponding to said plurality of narrowband chirps on the basis of that determined Doppler shift, and concatenating so compensated return signals to produce a composite signal equivalent to a return which would result from emission of a wideband signal across said wideband frequency domain.

19. A method in accordance with claim 18 including performing said emitting and receiving at substantially the same location.

20. A method in accordance with claim 18 or claim 19 wherein said receiving comprises determining a radial speed of a detected target on the basis of detected Doppler shift.

Application No: GB1100839.8 **Examiner:** Ian Rees
Claims searched: 1 to 20 **Date of search:** 22 June 2011

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular reference
X	1 to 17	Hu et al, "Study on non-linear stepped chirp radar system", Proceedings of International Conference on Communications, Circuits and Systems, ICCCAS 2008, IEEE, pages 881 to 885, ISBN 978-1-4244-2063-6 See figure 1 and Section IV in particular.
X	1 and 11 at least	US 6750809 B1 CHO. See figures 2 and 3.
X	1 and 11 at least	US 2007/0285302 A1 AARSETH. See figures 1 and 2.
X	1 and 11 at least	US 2007/0188377 A1 KRIKORIAN. See figures 3A and 3B.
X	1 and 11 at least	US 4161732 A LONGUEMARE. See figure 3.
X	1 and 11 at least	US 4309703 A BLAHUT. See figure 2B.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC

Worldwide search of patent documents classified in the following areas of the IPC

G01S

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, XPIEE, XPI3E, XPIOP, XPESP, INSPEC