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(54) Title: CONROLLLING RADAR TRANSMISSION TO ENABLE INTERFERENCE MITIGATION

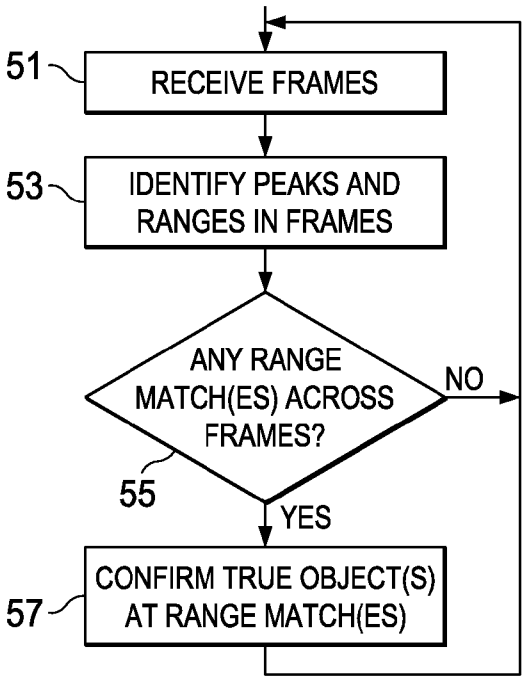


FIG. 5

(57) Abstract: In described examples, radar detection of an object is achieved by identifying (53) a first range associated with a possible object based on a first return from a first radar transmission having a first chirp rate, and identifying (53) a second range associated with the possible object based on a second return from a second radar transmission having a second chirp rate that differs from the first chirp rate. The first and second ranges are evaluated together (55) to determine whether the possible object is a true object.

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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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CONROLLLING RADAR TRANSMISSION TO ENABLE INTERFERENCE MITIGATION

[0001] This relates generally to radar apparatus, and more particularly to mitigation of interference in the radar return.

BACKGROUND

[0002] Radar has many and varied uses. For example, frequency modulated continuous wave (FMCW) radar is useful in automotive and industrial applications. The sensitivity of the radar is normally an important feature. Sensitivity refers to the ability of the radar reliably to detect objects that produce a weak radar return. However, as the radar receiver's sensitivity increases, it becomes more susceptible to interference. For example, a spur resulting from a modulation of the power supply can potentially be detected as a true object, resulting in a false alarm. Conventional approaches to mitigating the effects of spurs typically employ external spur mitigation schemes, such as dithering the power supply.

[0003] In view of the foregoing, a high sensitivity radar with integrated interference mitigation is desirable.

SUMMARY

[0004] In described examples, radar detection of an object is achieved by identifying a first range associated with a possible object based on a first return from a first radar transmission having a first chirp rate, and identifying a second range associated with the possible object based on a second return from a second radar transmission having a second chirp rate that differs from the first chirp rate. The first and second ranges are evaluated together to determine whether the possible object is a true object.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIGS. 1 and 2 graphically illustrate concepts in accordance with example embodiments.

[0006] FIG. 3 diagrammatically illustrates a radar apparatus according to example embodiments.

[0007] FIG. 4 diagrammatically illustrates a portion of the apparatus of FIG. 3 in more detail according to example embodiments.

[0008] FIGS. 5 and 6 illustrate operations according to example embodiments.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0009] Example embodiments provide radar with integrated interference mitigation that identifies interferers (e.g., spurs such as mentioned above) in the spectrum of the radar return, and prevents them from being detected as true objects. It is particularly useful in identifying multiplicative spurs, such as those arising from power source ripple on the power amplifier (PA) supply, or other interferers to the PA. It is also applicable to additive spurs and other interferers. According to example embodiments, first and second radar transmissions have first and second chirp rates, respectively, that differ from one another. First and second ranges associated with a possible object are identified, based respectively on first and second returns from the first and second radar transmissions. The first and second ranges are evaluated together to determine whether the possible object is a true object.

[0010] Some embodiments transmit two consecutive radar transmission frames that have slightly different chirp rates (also referred to herein as chirp slopes). This permits identification of a spur or other interferer, because the spur or other interferer will occupy different locations (i.e., appear at different ranges), respectively, in the corresponding return frames. This is in contrast to a true object, which will appear at the same range location in both return frames. The range locations of possible objects detected in the two return frames are compared across the frames, in order to identify and remove interferers that might otherwise be falsely identified as true objects. In some embodiments, the chirp duration in one of the transmission frames is selected, such that the transmission frame provides the same range resolution as the other transmission frame.

[0011] As an interferer example, consider a multiplicative spur at frequency fs from the carrier, due to an aggressor object at range da. The radar return associated with the spur will exhibit a frequency fa_spur = (S)(2)(da)/c + fs, where S is the chirp slope, and c is the speed of light. The radar return of a true object at range db will exhibit the frequency fb = (S)(2)(db)/c. Multiplying the above frequencies by c/2S yields their equivalent range estimates, which are: (a) fa_spur => da + (fs)(c)/2S; and (b) fb => db. Thus, the estimated range of a multiplicative spur depends on the chirp slope S, while the estimated range of a true object is independent of the chirp slope S. The technique also works for additive spurs, in which case da = 0 in the above equations.

[0012] FIG. 1 illustrates the concepts described above. FFT v. range plots are shown for two consecutive radar return frames, designated as frame 1 and frame 2, which respectively

correspond to two radar transmit frames that have been transmitted consecutively and have slightly different chirp slopes. Each of the radar transmission frames described herein may contain one or more chirps with identical chirp slopes. The peaks shown at 11 and 13 are caused by interferers, and the peaks shown at 15 and 17 are caused by true objects. Each of the peaks 11 and 13 appears at a different range location in frame 1 than in frame 2, whereas each of the peaks 15 and 17 appears at the same range location in both frame 1 and frame 2. Thus, the interferer peaks 11 and 13 may be distinguished from the true object peaks 15 and 17 by comparing the range values of the peaks detected in frame 1 with the range values of the peaks detected in frame 2. Any range value match corresponds to a true object.

[0013] Example embodiments guarantee interference-free detection of a true object peak in at least one of frame 1 and frame 2, because an interferer peak and a true object peak cannot coincide (i.e., appear at the same range) in both frames. This is shown in FIG. 2, where interferer peak 21 coincides in range with true object peak 23 in frame 1, but is range-shifted relative to true object peak 23 in frame 2. Again, a range match of peaks in frame 1 and frame 2 corresponds to a true object.

[0014] At the transmitter, consider an example in which: the chirp duration is Tc; the chirp slope of the transmit frame associated with return frame 1 is S1; the chirp slope of the transmit frame associated with return frame 2 is S2; and the chirp slopes S1 and S2 are related by a factor α, such that $S2 = \alpha S1$. If the range resolution is kept constant across the two frames, such that the chirp durations of the transmit frames respectively associated with return frame 1 and return frame 2 are Tc and Tc/α, then, for a given spur (interferer) frequency fs, the number of range bins by which the interferer peak is displaced in frame 2 relative to frame 1 is:

$$\Delta range_idx = T_c f_s \left(1 - \frac{1}{\alpha}\right)$$

A range bin is defined as the range resolution of the radar and given by c/[2(S)(Tc)], where S and Tc are the chirp slope and chirp duration, respectively. A true object peak that coincides with an interferer peak in frame 1 will be separated from the interferer peak in frame 2 by Δf Hz, where

$$\Delta f = f_s(1 - \alpha)$$

[0015] For example, consider a spur at 1.5MHz. In some embodiments, Tc = 125 us (example of a higher resolution chirp), and $\alpha = 0.9$, yielding $\Delta range_idx = 21$ and $\Delta f = 0.15$ MHz. In some embodiments, Tc = 30 us (example of a lower resolution chirp), and $\alpha = 0.85$, yielding

Δrange_idx = 8 and Δf = 0.225 MHz.

[0016] FIG. 3 diagrammatically illustrates a radar apparatus according to example embodiments. In some embodiments, the apparatus is a FMCW radar apparatus. A radar signal generator 31 produces two radar transmit signals having respective chirp slopes S1 and S2. A selector 33 selects between the two transmit signals in accordance with the frame timing, such that two consecutive frames transmitted at 32 have respective chirp slopes S1 and S2.

[0017] A receiver 35 receives at 34 return frames associated with the frames transmitted at 32. The receiver 35 performs conventional radar receive processing (including FFT processing as indicated in FIGS. 1 and 2) on two consecutive return frames (see also frame 1 and frame 2 in FIGS. 1 and 2), which correspond respectively to two frames that have been consecutively transmitted at 32 with different chirp slopes. The receive processing results produced by the receiver 35 include detected peaks at range locations in frame 1 and frame 2 (see also FIGS. 1 and 2). The receive processing results are passed at 36 to a filter 37 that compares the range values of the detected peaks, across frame 1 and frame 2. Based on the comparison, the filter 37 distinguishes interferers from true objects and eliminates the interferers. The receive processing results associated with the identified true objects may then be passed on at 38 for further conventional processing (shown generally at 39).

[0018] FIG. 4 diagrammatically illustrates the filter 37 of FIG. 3 in more detail according to example embodiments. Receive processing results for frame 1 and frame 2 are provided by receiver 35, as shown generally at 41 and 43. Logic 45 implements a match detection function that compares the range values of peaks in frame 1 with the range values of peaks in frame 2, and identifies only comparison matches as true objects. The receive processing results associated with true objects may then be passed on at 38 for further processing at 39 (see also FIG. 3).

[0019] FIG. 5 illustrates operations that may be performed according to example embodiments. In some embodiments, the apparatus described above relative to FIGS. 3 and 4 is capable of performing the operations shown in FIG. 5. At 51, consecutive return frames are received. At 53, any peaks and their respectively corresponding ranges are identified (see also FIGS. 1 and 2), for both of the return frames. At 55, it is determined whether any range matches exist across the two frames. If not, then no true objects have been identified, and operations return to 51. If range matches exist across the two frames at 55, then these matches are confirmed as true objects at 57, and operations return to 51.

[0020] FIG. 6 illustrates further operations that may be performed according to example embodiments. In some embodiments, the apparatus described above relative to FIG. 3 is capable of performing the operations shown in FIG. 6. At 61, radar transmission (designated by XMIT) occurs at a first chirp rate (CR1) for a first chirp duration (CD1) in a first frame (F1). Thereafter, at 62, radar transmission occurs at a second chirp rate (CR2) for a second chirp duration (CD2) in a second frame (F2), where: the second chirp rate differs from the first chirp rate; the second frame follows consecutively after the first frame; and the second chirp duration is selected, such that the second frame has the same range resolution as the first frame.

[0021] Referring again to the situation depicted in FIG. 2 in which a true object peak 23 and an interferer peak 21 coincide in one of the frames, it may be often required (for further processing) to determine the amplitude (and/or phase) of the true object peak 23. The range value for the peak 23 may be discerned as described above and, if the amplitudes (and/or phases) of the peaks at that range value differ significantly between the two frames (as shown in FIG. 2), one can infer that a coinciding interferer exists in one of the frames. Such detection of a significant amplitude (and/or phase) difference (e.g., beyond a predetermined threshold) between peaks at the same range may be performed, such as by the logic 45 of FIG. 4. However, at the outset, it is unclear about which of the two frames presents an interference-free view of the true object peak 23. Hence, determining the amplitude (and/or phase) of the true object peak 23 will require further processing. Example embodiments use various techniques to make this determination.

[0022] The frame that presents an "interference-free" view of the true object peak 23 will contain an additional peak that corresponds to the interferer, and some embodiments exploit this fact. This is peak 21 in the frame 2 FFT plot of FIG. 2. This additional peak 21 is, of course, not separately detectable in the frame 1 FFT plot where the interferer peak 21 and the true object peak 23 coincide. By simply determining which of the frames contains the additional peak (frame 2 in the FIG. 2 example), the frame that presents an interference-free view of the true object peak 23 (frame 1 in the FIG. 2 example) may be identified. The true amplitude (and/or phase) of the true object peak 23 may therefore be determined by inspecting the peak 23 in frame 1. The above-described analysis may be performed, such as by the logic 45 of FIG. 4.

[0023] In some embodiments, if the logic 45 determines that a true object peak coincides with an interfere peak in one of the two return frames, the logic 45 signals the radar signal generator (see 31 in FIG. 3) to transmit a third frame with a chirp slope that differs from the chirp slopes of

the frame transmissions corresponding to frame 1 and frame 2. Interference-free viewing of the true object peak is guaranteed in the spectrum of at least two of the three return frames corresponding to the three frame transmissions. Accordingly, in at least two of the three return frames, the amplitude (and/or phase) of the true object peak will be approximately equal (e.g., within a specified threshold that accounts for variations due to noise). This will correspond to the true amplitude (and/or phase) of the true object peak. A suitable three-way comparison between the amplitude (and/or phase) of the three peaks at the identified range of the true object may be performed, such as by the logic 45 of FIG. 4.

[0024] Example embodiments achieve various advantages, some examples of which are: no external spur mitigation technique is needed; they are effective, even if spurs are dynamically changing; performance is independent of the number of chirps in a frame (e.g., effective even in industrial scenarios with only one chirp per frame); they require no change in intra-frame 2D FFT processing associated with conventional radar receiver apparatus; only a modest percentage difference is needed between chirp slopes in consecutive frames (e.g., an α parameter around 0.9); they are effective for both multiplicative and additive spurs, and for other interferers; and they are effective, even for non-zero velocity objects.

[0025] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. A method for radar detection of an object, comprising:

identifying a first range associated with a possible object based on a first return from a first radar transmission having a first chirp rate;

identifying a second range associated with the possible object based on a second return from a second radar transmission having a second chirp rate that differs from the first chirp rate; and

evaluating the first and second ranges together to determine whether the possible object is a true object.

2. The method of claim 1, wherein the evaluating includes comparing the first and second ranges.

3. The method of claim 2, wherein a true object is determined if the first and second ranges are the same.

4. The method of claim 1, wherein the first and second radar transmissions are consecutive transmissions.

5. The method of claim 4, wherein one of the first and second chirp rates is approximately 90% of the other of the first and second chirp rates.

6. The method of claim 4, wherein one of the first and second radar transmissions has a chirp duration selected, such that the one of the first and second radar transmissions provides a same range resolution as the other of the first and second radar transmissions.

7. Apparatus for radar detection of an object, comprising:

a receiver configured for identifying a first range associated with a possible object based on a first return from a first radar transmission having a first chirp rate, and for identifying a second range associated with the possible object based on a second return from a second radar transmission having a second chirp rate that differs from the first chirp rate; and

logic coupled to the receiver and configured for evaluating the first and second ranges together to determine whether the possible object is a true object.

8. The apparatus of claim 7, wherein the evaluating includes comparing the first and second ranges.

9. The apparatus of claim 8, wherein a true object is determined if the first and second

ranges are the same.

10. The apparatus of claim 7, wherein the first and second radar transmissions are consecutive transmissions.

11. The apparatus of claim 10, wherein one of the first and second chirp rates is approximately 90% of the other of the first and second chirp rates.

12. The apparatus of claim 10, wherein one of the first and second radar transmissions has a chirp duration selected, such that the one of the first and second radar transmissions provides a same range resolution as the other of the first and second radar transmissions.

13. The apparatus of claim 7, wherein the apparatus is a frequency modulated continuous wave radar apparatus.

14. A radar apparatus, comprising: a radar signal generator configured to produce first and second radar signals having respective first and second chirp rates that differ from one another and having respective first and second chirp durations that differ from one another; and a selector coupled to the radar signal generator and configured to select, based on transmit timing of the radar apparatus, the first and second radar signals for use in first and second consecutive radar transmissions, respectively.

15. The apparatus of claim 14, wherein one of the first and second chirp rates is approximately 90% of the other of the first and second chirp rates.

16. The apparatus of claim 14, wherein the first and second radar transmissions have a same range resolution.

17. The apparatus of claim 14, wherein each of the first and second radar transmissions consists of one chirp.

18. The apparatus of claim 14, wherein each of the first and second radar transmissions includes a plurality of chirps.

19. The apparatus of claim 14, including a receiver configured for identifying a first range associated with a possible object based on a first return from the first radar transmission, and for identifying a second range associated with the possible object based on a second return from the second radar transmission, and logic coupled to the receiver and configured for evaluating the first and second ranges together to determine whether the possible object is a true object.

20. The apparatus of claim 14, wherein the apparatus is a frequency modulated continuous wave radar apparatus.

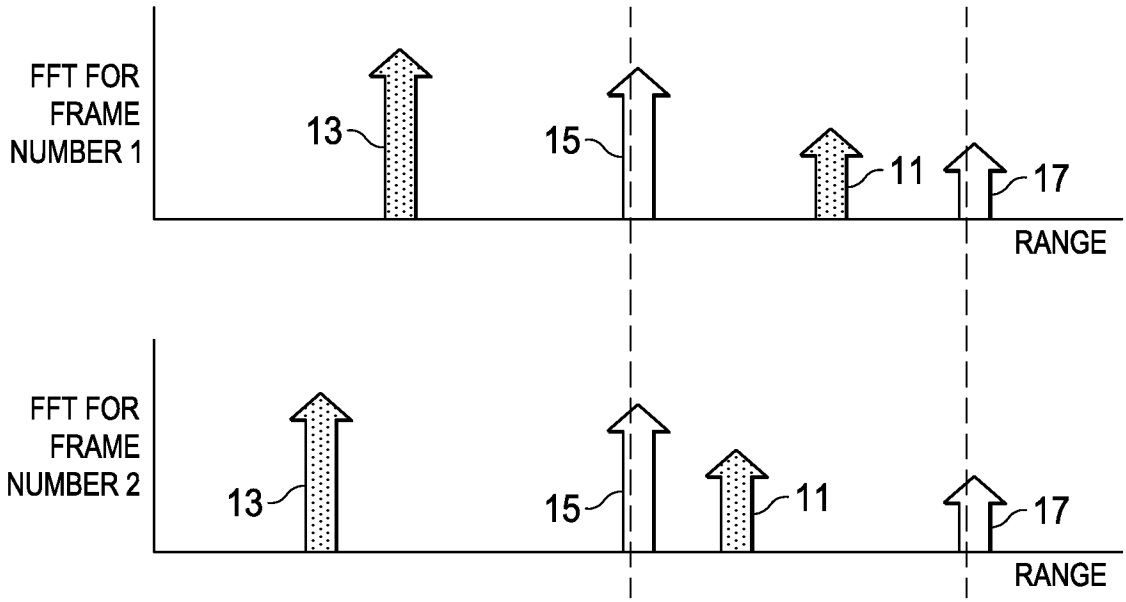

FFT FOR FRAME NUMBER 1
13
15
11
17
RANGE
FFT FOR FRAME NUMBER 2
13
15
11
17
RANGE

FIG. 1

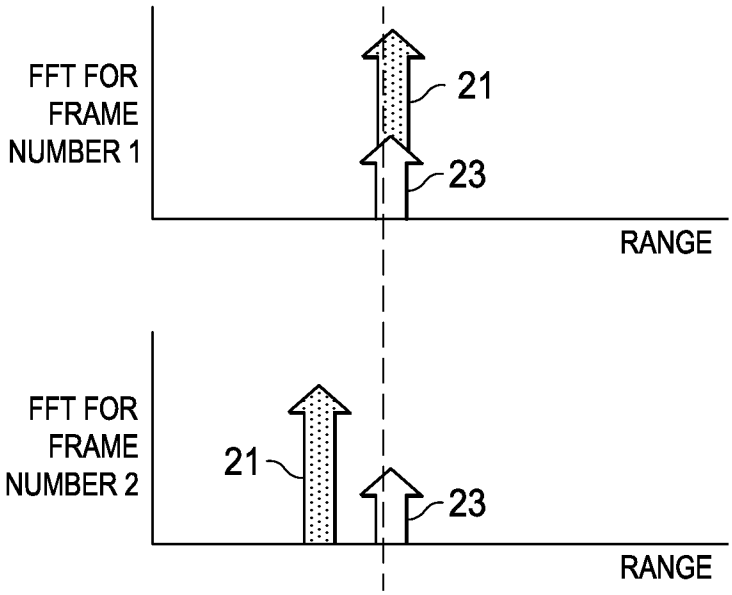

FFT FOR FRAME NUMBER 1
21
23
RANGE
FFT FOR FRAME NUMBER 2
21
23
RANGE

FIG. 2

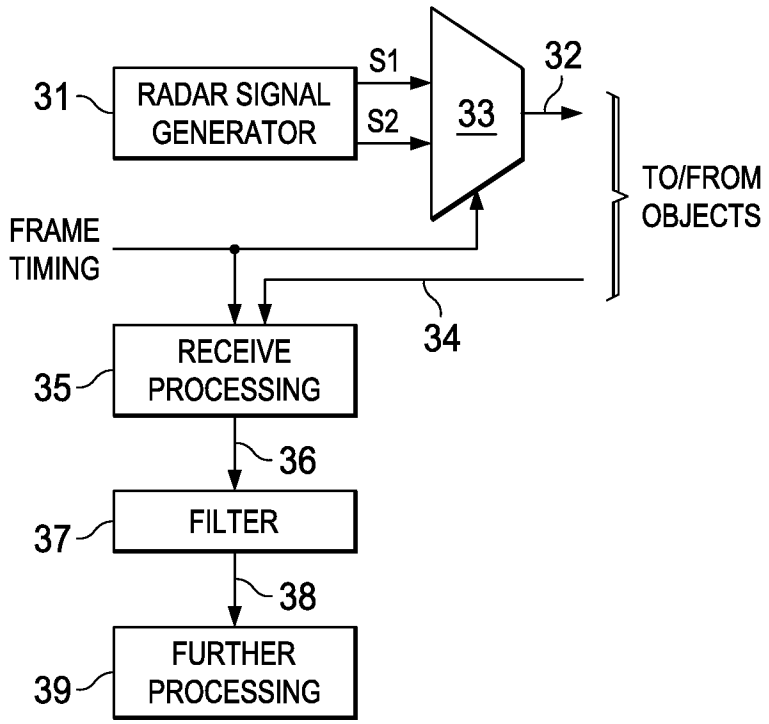


FIG. 3

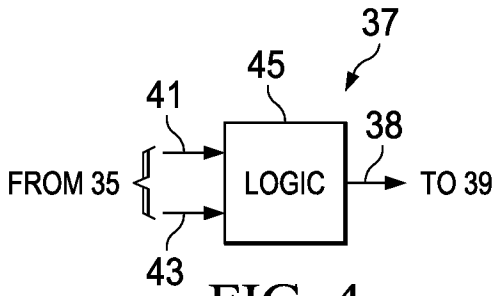


FIG. 4

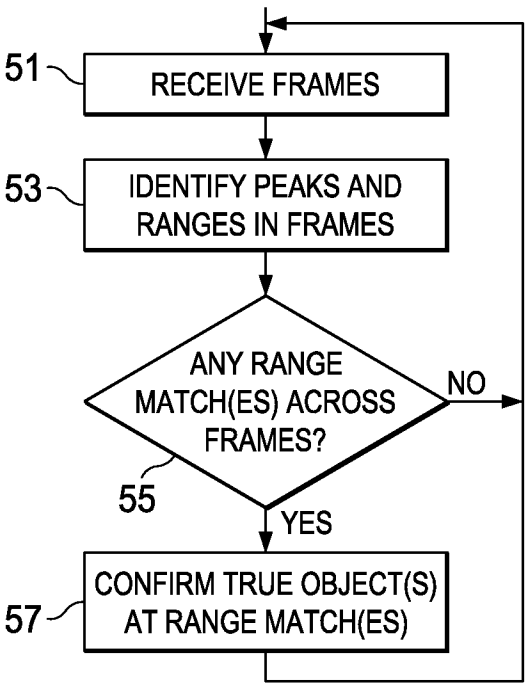


FIG. 5

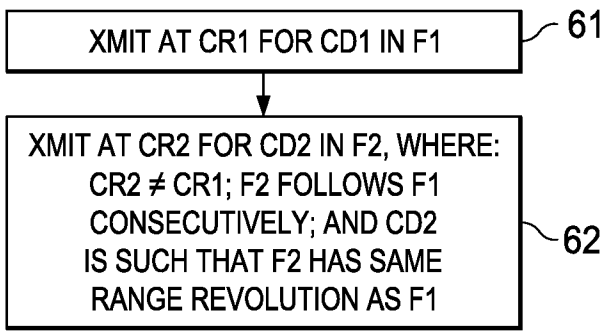


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 2015/062466

A. CLASSIFICATION OF SUBJECT MATTER

G01S 13/56 *(2006.01)*
G01S 7/41 *(2006.01)*

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 13/00, 13/02-13/08, 13/34, 13/48, 13/50, 13/52, 13/536, 13/56, 13/58, 13/74, 13/88, 7/00, 7/02, 7/28 - 7/292, 7/32, 7/34, 7/36, 7/40, 7/41, H04B 1/00, 1/02, 1/06, 1/10, 1/12, 1/38, 1/48

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)

Espacenet, PAJ, PatSearch (RUPTO internal), USPTO, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2500744 A1 (SONY CORPORATION) 19.09.2012, abstract, fig. 1, claim 1, paragraphs [0006], [0007], [0010], [0015], [0029], [0033], [0035], [0036], [0048]	1-20
A	WO 2007/148199 A2 (TELESPAZIO S.P.A. et al.) 27.12.2007	1-20

☐ 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	Date of mailing of the international search report
01 February 2016 (01.02.2016)	24 March 2016 (24.03.2016)

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