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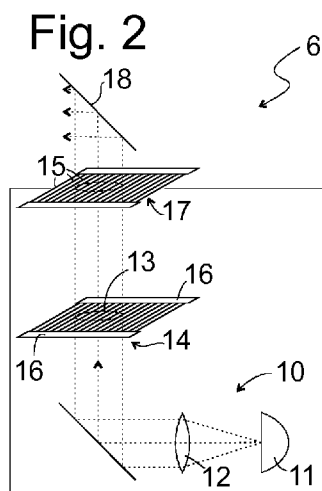
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(54) Title: RADAR SENSOR AND ROBOT USING THE SAME



(57) Abstract: A radar sensor (6, 7) comprises a transceiver unit (10) for emitting a radar beam (13) along a beam path in an outgoing direction and receiving radar radiation along said beam path in an incoming direction. Reference objects (15) are placed in said beam path for redirecting part of the outgoing radar beam (13) in the incoming direction. The size of the reference objects (15) in at least one dimension is smaller than the wavelength of the radar beam (13).



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ABB Schweiz AG

5 **Radar sensor and robot using the same**

The present invention relates to a radar sensor and to a robot in which the radar sensor is used.

10 Radar sensors are widely used in automotive technology for detecting persons and objects in the vicinity of a vehicle. For instance, DE 10 2013 010993 A1 describes a radar system which is mounted to the rear of a vehicle body and which triggers an
15 automatic opening of the vehicle boot if it detects the user approaching.

In robotics, it is a general practice to install sensors in the vicinity of a robot that are capable
20 to detect the presence of a person, in order to stop a movement of the robot if the person is close enough to be injured if hit by the robot.

In the case of DE 10 2013 010993 A1, if the radar
25 sensor isn't operating properly and fails to detect the approach of a person, the vehicle boot remains closed and has to be opened by hand. In a robot system, on the other hand, if the approach of a person goes undetected, the robot may be moving to
30 the same place as the person, and if both collide, there is a serious risk of injury. Therefore, in robotic applications, it is necessary to detect a possible failure of the radar sensor, so that operation of the robot may be enabled only if it has
35 been established unequivocally that the radar sen-

sor is operating correctly and is capable of detecting the approach of a person.

5 A conventional way to do so is by detecting a radar echo from a reference object which is placed outside the leakage zone of the radar sensor, in a region where the radar beam from a transceiver of the sensor is expected to propagate.

10 A drawback of this approach results from the fact that the distance between the transceiver and the sample object must be smaller than the distance in which the person must be detected, since otherwise detection of the reference object might be thwarted
15 by the presence of a person between the radar sensor and the reference object, but the smaller the distance is, the stronger is the radar echo of the reference object. So a situation may arise in which a strong echo from the reference object is detected,
20 ed, but a weaker echo from a person isn't, in which case the safety of the person cannot be ensured. Further, the presence of an echo from the reference object increases the noise from which the echo of a person has to be distinguished, so that it is desirable
25 not to receive both echoes simultaneously. Moveable components by which the radar beam can be directed selectively either on the reference object or into a region where a person is to be detected increase the probability of defects.

30 One object of the invention is, therefore, to provide a radar sensor the correct operation of which can be established with higher reliability.

35 This object is achieved by a radar sensor comprising a transceiver unit for emitting a radar beam

along a beam path in an outgoing direction and receiving radar radiation along said beam path in an incoming direction, a reference object placed in said beam path for redirecting part of the emitted radar beam towards the transceiver, wherein the reference object is one of a plurality of reference objects placed in the radar beam, and the size of the reference objects in at least one dimension is smaller than the wavelength of the radar beam.

10

At least some of the reference objects should be located beyond a leakage range of the transceiver unit.

15 By making the reference objects small in at least one direction, the intensity of their echo can be reduced in spite of their potentially close proximity to the radar transceiver. When the size of a reference object is smaller than the radar wavelength, its radar cross section is proportional to the fourth power of the size; therefore the power of the echo of the reference objects can be adjusted to be smaller than that of the echo of a person, so that if the transceiver is sensitive enough to detect the echo of the reference objects, any person will be detected a fortiori.

The size of the reference objects in said first dimension may be smaller than half the wavelength, preferably smaller than a fifth of the wavelength, and still more preferably, smaller than a tenth of the wavelength of the radar beam.

35 Since due to the small size of the reference object, the power of its echo can be made as small as desired, and there is no need to remove the refer-

ence object while monitoring the environment for the presence of a person. Therefore the at least one reference object can be stationarily mounted with respect to the transceiver, so that it is exposed to the radar beam at all times.

In a second dimension orthogonal to said first dimension the size of the at least one reference object can be larger than the wavelength of the radar beam. This facilitates mounting of the reference objects, in particular if at least one end of the elongate reference objects extends beyond the cross section of the radar beam.

Typically, the reference objects can be metallic wires.

Manufacture of the radar sensor is facilitated if each reference object is linear having first and second ends, and if the first and second ends of the reference objects are mounted in a frame.

In order to decrease the influence of possible inhomogeneity of the laser beam on the echo from the reference objects, a plurality of said reference objects should be distributed over the cross section of the radar beam, preferably in the form of one or more regular patterns.

Preferably, the reference objects or the patterns formed by these are arranged in at least one plane that intersects the beam.

If reference objects are arranged in first and second regular patterns, the first pattern extending in a first plane that intersects the beam, and the

second pattern extending in a second plane which is parallel to the first plane, the radar transceiver can be continuously or discretely tuneable, so as to be selectively operable at at least a first and
5 a second frequency. If the distance between the two patterns equals half the Talbot distance at said first frequency, the first pattern will generate a Talbot pattern in the plane of the second pattern, and the intensity of a radar echo from the second
10 pattern depends on whether its reference objects are located in bright or dark zones of the Talbot pattern.

Specifically, when the transceiver is operated at
15 said first frequency and the reference objects of the second regular pattern are located in dark zones of the Talbot pattern generated by said first regular pattern, they will produce no echo. In that way, although the radar beam propagates across said
20 second regular pattern, formation of a radar echo from the second regular pattern can be avoided, so that radar reflections from other objects can be detected with a minimum of background noise.

25 Reflection of a radar echo from the first regular pattern cannot be avoided, but this radar echo will go undetected if the first regular pattern is located in the leakage zone of the radar transceiver.

30 The radar sensor may be mounted on a robot arm, in order to detect persons in the vicinity of the robot and to control movements of the robot based on this detection so as to avoid collisions between the robot and a person.

35

Further features and advantages of the invention will become apparent from the following description of embodiments thereof.

5 Fig. 1 is a schematic view of a robot system in which the environment of the robot is monitored by radar sensors.

10 Fig. 2 is a schematic cross section of one of the radar sensors of Fig. 1;

15 Fig. 3 is an example of a radar echo received by the transceiver of the radar sensor according to a first embodiment; and

20 Fig. 4 is a graph illustrating the relative radar cross section of a metallic sphere as a function of relative frequency

25 Fig. 5 is an example of a radar echo received by the transceiver of the radar sensor according to a second embodiment.

30 Fig. 1 is a schematic view of a manufacturing robot 1 comprising a stationary base 2, an end effector 3 and a plurality of elongate links 4 that are pivotably connected to one another, to the base 2 and the end effector 3 by joints 5. The environment of the robot 1 is monitored for the presence of persons by radar sensors 6, 7. The radar sensor 6 is stationary and may be mounted on a workshop floor 8 in the vicinity of the robot base 2. The radar sensors 7 are installed in the links 4.

35 A controller 9 is connected to the radar sensors 6, 7 and is programmed to slow down or possibly stop

the robot 1 if the distance between the robot 1 and a person drops below a predetermined threshold.

A schematic cross section of the stationary radar sensor 6 is shown in Fig.2. A transceiver 10 is provided for transmitting and receiving radar signals. If necessary, a lens 12 may be provided for shaping, in particular collimating, the radar waves emanating from antenna 11 into a beam 13, and for focussing a reflected radar echo onto the transceiver 10.

A receiving channel of transceiver 10 is inherently sensitive to the radar wave emitted by a transmitting channel thereof. At the transceiver 10 the intensity of the radar wave being emitted is larger by several orders of magnitude than any radar echo reflected off some object in the vicinity of the radar sensor 6. Therefore, in case of the transceiver emitting radar pulses at a single frequency, the transceiver 10 is sensitive to an echo only while it is not transmitting an impulse that might "leak" into the receiving channel. Alternatively, the transceiver 10 can be of the FMCW (frequency modulated continuous wave) type, i.e. it emits a continuous radar wave the frequency of which is continuously ramped, so that a frequency difference between the transmitted wave and the echo received at the same time is representative of the distance between the transceiver and the object from which the echo originates. In that case, the frequency difference between the outgoing wave and the received echo must exceed a certain threshold in order for the echo to be detectable. In either case, the transceiver 10 is surrounded by a so-called leakage range in which objects cannot be detected

because their echo is made undetectable by the outgoing wave.

Within this leakage range, the radar beam 13 passes
5 through a grid 14 formed of thin metallic wires 15
arranged parallel to each other in a regular pattern
extending in a plane perpendicular to the propagation
direction of beam 13. The width of the beam 13 is
sufficient to irradiate a plurality of
10 said wires 15. The length of the wires 15 should
preferably be greater than the diameter of the beam
13, so that ends of the wires 15 can be mounted on
a frame 16 that doesn't block the beam 13.

15 The diameter of the wires 15 is smaller than the
wavelength of the radar beam 13; e.g. in case of
the radar beam having a mean frequency f_1 of 100
GHz, corresponding to a wavelength λ_1 of 3 mm, the
diameter of the wires is less than 3 mm, preferably
20 less than 0.6 mm, and still more preferably, less
than 0.3 mm, so that the wires do not cast a shadow
at the downstream side of the grid 14 and do not
reflect the radar beam 13, but merely scatter it.

25 Since the grid 14 is located within the leakage
range, radar waves that scattered back from it to
the transceiver 10 are not detected.

A second grid 17 having the same structure as grid
30 14 is provided in the path of beam 13 outside the
leakage range. The two grids 14, 17 extend in parallel
planes. The wires 15 of the two grids 14, 17 are
aligned with each other, i.e. when seen in the
propagation direction of beam 13, the wires 15 of
35 one grid overlap with those of the other. The distance
 d between the two grids 14, 17 equals $d_1^2/2\lambda_1$,

so that if the wavelength of the radar beam is λ_1 , the first grid 14, by Talbot effect, gives rise to an intensity distribution of the radar wave in the plane of the grid 17 which has the form of a line grid whose intensity minima coincide with the wires of the grid 17. Therefore, when the transceiver 10 operates at the wavelength λ_1 , or is ramped in a small interval around λ_1 , the second grid 17 has no effect on the propagation of the radar beam 13.

10

It has an effect, however, when the wavelength emitted by transceiver 10 is sufficiently different from λ_1 for the wires 15 of grid 17 to be exposed to a substantial amount of radar radiation. In that case the grid 17 contributes to the radar echo received at transceiver 10, and since the grid 17 is outside the leakage range, this contribution is detected.

20 For this reason, in the embodiment contemplated here, the transceiver 10 is adapted to switch between two frequency ranges for ramping the frequency of the radar wave, the first one being centered around $f_1=c/\lambda_1$, the other around a different frequency f_2 . When the radar sensor 6 of this embodiment starts to operate, the transceiver 10 first emits in the frequency range around f_2 , and a radar echo from grid 17 is detected by transceiver 10. If the intensity of this echo has an expected non-vanishing intensity, it is concluded that the sensor 6 is functional, and the frequency of the transceiver 10 is switched over to a range around f_1 . In this way, although the radar beam 13 still passes through the grids 14 and 17 on its way from and to the transceiver 10, the grids 14, 17 leave no trace in the radar echo received, and contribu-

tions of objects and persons in the vicinity of the robot 1 can be detected with a minimum of background noise.

5 As shown in Fig. 2, the sensor 2 can have a rotating mirror 18 or similar mobile element for redirecting the beam 13 and thus scanning the surroundings of the sensor 6. The structure of the sensors 7 can be identical to that of the sensor 6, except
10 for the rotating mirror 18, which isn't needed if, as shown in Fig. 1, several sensors 7 are distributed along a circumference of a link 4.

Fig. 3 gives schematic examples of echo signals detected by transceiver 10. If the frequency of the radar beam 13 is ramped linearly, the frequency difference between outgoing and incoming radar signals is directly representative of the distance between the transceiver 10 and an object which is the
15 source of an echo. Curve A of Fig. 3 is obtained with the sensor operating around f_2 ; at a small frequency difference Δf_1 , just above the leakage range represented by hatched area C, there is the echo from grid 17; at a larger difference Δf_2 ,
20 there is an echo from an object, e.g. from the robot 1 itself. When the sensor 6 is operating in the frequency range around f_1 , the radar beam 13 is unaffected by grid 17, and only the object contributes to the radar echo, but not the grid 17, as
25 shown by curve B.
30

Due to the small diameter of the wires 15, the radar echo from grid 17 can be limited to a low value which will not overshadow an echo from an outside
35 object, even if this outside object is close to the grid 17, and by appropriately choosing this diame-

ter, the intensity of the radar echo from grid 17 can be set to any desired value. As shown in the diagram of Fig. 4, when the diameter of a metallic sphere is much larger than the radar wavelength, i.e. at a relative frequency of 10 or above, the ratio between radar cross section and projected area of the sphere converges towards unity. On the other hand, when the diameter is smaller than the wavelength, this ratio is proportional to the fourth power of the frequency. A similar relation holds for the wires 15 of grids 14 and 17. Therefore, the diameter of the wires 15 can be chosen so that although the grid 17 extends across the entire cross section of beam 13, the echo that originates from the grid 17 is only slightly above the detection threshold of transceiver 10.

When the intensity of the echo from grid 17 is set as low as this, the radar sensor 6 can be simplified by dispensing with grid 14. In that case, the echo from the grid 17 is present continuously while the sensor 6 is operating, but this doesn't cause a problem, since this echo is too weak to conceal the echo of an outside object close to the leakage range that should be detected. Quite to the contrary, precisely because the echo from the grid 17 is weak, any malfunction of the sensor 6 is likely to cause it to drop below the detection threshold, whereby the malfunction is detected. An example of a typical radar echo signal according to this simplified embodiment is shown in Fig. 5 in a diagram analogous to that of Fig. 3.

According to this embodiment, the transceiver 10 can also be simplified, since there is no more need to switch between different frequency ranges. Since

the echo from grid 17 is present whenever the sensor 6 is operating, and not only if it is operating in the frequency range around f_2 , a malfunction of sensor 6 is detected as soon as it occurs.

P180602

Reference numerals

5	1 robot
	2 base
	3 end effector
	4 link
10	5 joint
	6 radar sensor
	7 radar sensor
	8 floor
	9 controller
15	10 transceiver unit
	11 antenna
	12 lens
	13 beam
	14 grid
20	15 wire
	16 frame
	17 grid
	18 mirror

P180602

Claims

5

1. A radar sensor (6, 7) comprising a transceiver unit (10) for emitting a radar beam (13) along a beam path in an outgoing direction and receiving radar radiation along said beam path
10 in an incoming direction, a reference object (15) placed in said beam path for redirecting part of the outgoing radar beam (13) in the incoming direction, characterized in that the reference object is one of a plurality of reference objects placed in the radar beam (13),
15 and that the size of the reference objects in at least one dimension is smaller than the wavelength of the radar beam (13).
- 20 2. The radar sensor of claim 1, wherein at least some of said plurality of reference objects are located beyond a leakage range of the transceiver unit (10).
- 25 3. The radar sensor of claim 1 or 2, wherein size of the reference object in said first dimension is smaller than half the wavelength, preferably smaller than a fifth of the wavelength, and still more preferably, smaller
30 than a tenth of the wavelength.
4. The radar sensor of claim 1, 2 or 3, wherein the at least one reference object is station-
35 arily mounted with respect to the transceiver (10).

5. The radar sensor of any of the preceding claims, wherein the size of the at least one reference object in a second dimension orthogonal to said first dimension is larger than the wavelength of the radar beam (13) and preferably larger than a diameter of the radar beam (13).
- 5
6. The radar sensor of any of the preceding claims, wherein the reference objects are metallic wires (15).
- 10
7. The radar sensor of any of the preceding claims, wherein each reference object is linear and has first and second ends, and wherein the first and second ends of the reference objects are mounted in a frame (16).
- 15
8. The radar sensor of any of the preceding claims, wherein a plurality of said reference objects are distributed over the cross section of the radar beam (13).
- 20
9. The radar sensor of claim 7, wherein the reference objects are arranged in at least one plane that intersects the radar beam (13).
- 25
10. The radar sensor of claim 7 or 8, wherein the reference objects are arranged in at least one regular pattern.
- 30
11. The radar sensor of claim 7, wherein the reference objects are arranged in first and second regular patterns, the first pattern (14) extending in a first plane that intersects the beam, and the second pattern (17) extending in a second plane which is parallel to the first plane, the radar transceiver (10) is selec-
- 35

tively operable at at least a first and a second frequency (f_1 , f_2), and the distance between the two patterns equals half the Talbot distance at said first frequency (f_1).

5

12. The radar sensor of claim 10, wherein when the transceiver (10) is operated at said first frequency (f_1) the reference objects of the second regular pattern are located in dark zones of a Talbot grid generated by said first regular pattern.

10

13. The radar sensor of claim 10 or 11, wherein the first regular pattern is located in a leakage zone of the radar transceiver (10).

15

14. A robot (1) comprising at least one link (4) which is rotatably connected to a base (2), to an end effector (3) or to another link (4), wherein said at least one link (4) is provided with at least one radar sensor (7) of any of the preceding claims.

20

Fig. 1

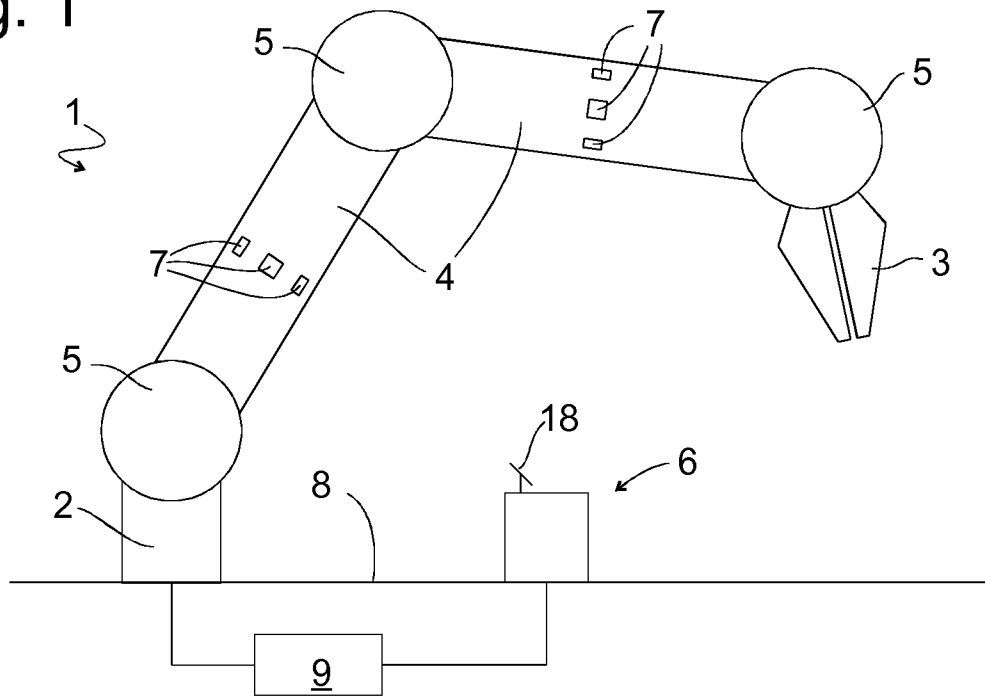


Fig. 2

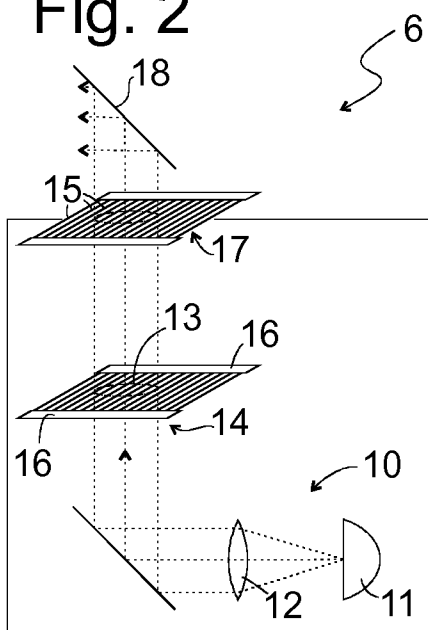


Fig. 3

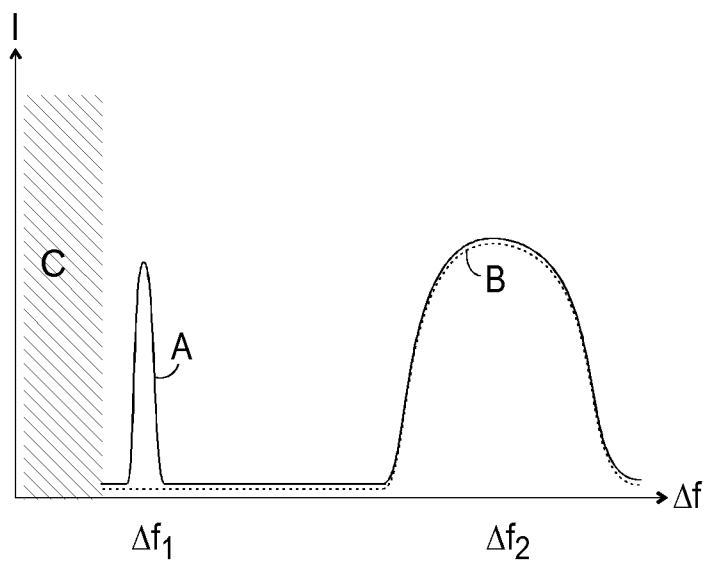


Fig. 4

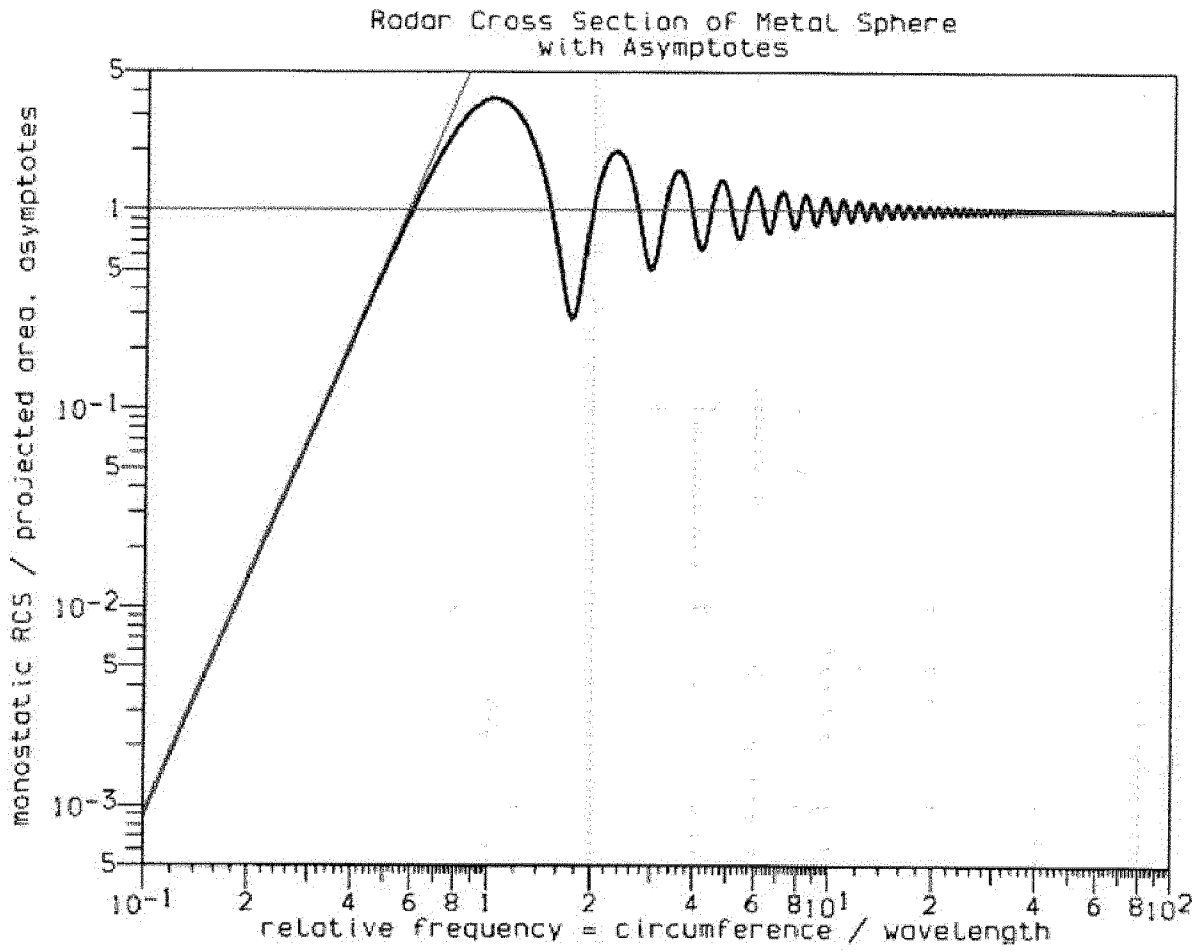
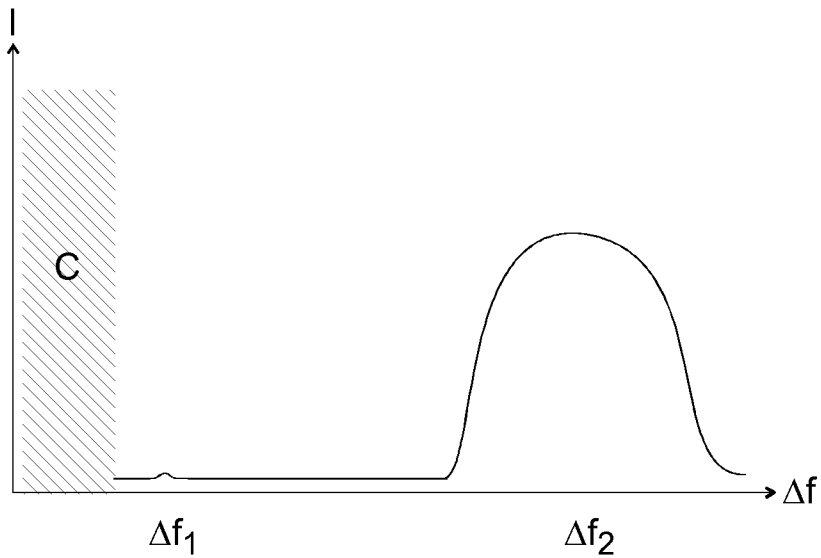


Fig. 5



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S13/88 G01S13/75 G01S7/40
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
G01S
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017/368892 A1 (HEUERMANN HOLGER [DE] ET AL) 28 December 2017 (2017-12-28) abstract paragraphs [0025] - [0029]; figures 1-3 -----	1-3,8-10
A	DE 20 2017 103676 U1 (SICK AG [DE]) 24 September 2018 (2018-09-24) abstract paragraphs [0009] - [0020], [0025]; figure 1 -----	1-14
A	DE 10 2014 017917 B3 (AUDI AG [DE]) 12 November 2015 (2015-11-12) abstract paragraphs [0007] - [0017]; figures 3-5 ----- -/--	1-14

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Date of the actual completion of the international search 9 July 2019	Date of mailing of the international search report 18/07/2019
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer van Norel, Jan

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/079090

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 10 2017 100780 A1 (ABB SCHWEIZ AG [CH]) 19 July 2018 (2018-07-19) abstract; figure 4	1-14
A	----- SWATHI N ET AL: "Radar RCS estimation of a perfectly conducting Sphere obtained from a spherical polar scattering geometry", 2015 INTERNATIONAL CONFERENCE ON ELECTRICAL, ELECTRONICS, SIGNALS, COMMUNICATION AND OPTIMIZATION (EESCO), IEEE, 24 January 2015 (2015-01-24), pages 1-7, XP033200283, DOI: 10.1109/EESCO.2015.7253809 ISBN: 978-1-4799-7676-8 [retrieved on 2015-09-09] abstract paragraph [00II]; figure 3 -----	1-14

INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2017368892 A1	28-12-2017	CN 107430185 A EP 3247576 A1 US 2017368892 A1 WO 2016116098 A1	01-12-2017 29-11-2017 28-12-2017 28-07-2016

DE 202017103676 U1	24-09-2018	NONE	

DE 102014017917 B3	12-11-2015	DE 102014017917 B3 EP 3227712 A1 WO 2016087010 A1	12-11-2015 11-10-2017 09-06-2016

DE 102017100780 A1	19-07-2018	DE 102017100780 A1 WO 2018134112 A1	19-07-2018 26-07-2018
