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(54) **RADAR SENSOR INCLUDING A RADOME**

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See application file for complete search history.

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G01S 7/03 (2006.01)
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G01S 2013/9389 (2013.01); **H01Q 1/3233**
(2013.01)

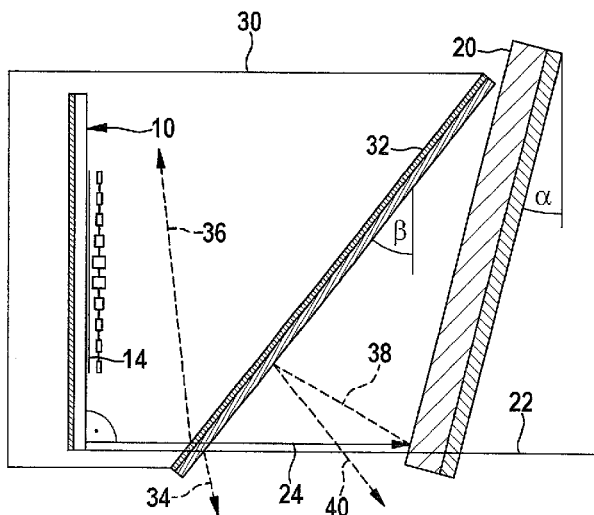
(57) **ABSTRACT**

A radar sensor for motor vehicles includes a printed circuit board which carries the mass and antenna structures of the radar sensor, and includes a housing accommodating the printed circuit board, the housing being formed on a transmit and receive side of the radar sensor by a radome which is transparent to radar radiation, characterized in that the radome has an essentially plane wall oriented obliquely to the printed circuit board.

(58) **Field of Classification Search**

CPC H01Q 1/42; H01Q 1/40; G01S 7/02; G01S 7/032; G01S 13/02

10 Claims, 2 Drawing Sheets



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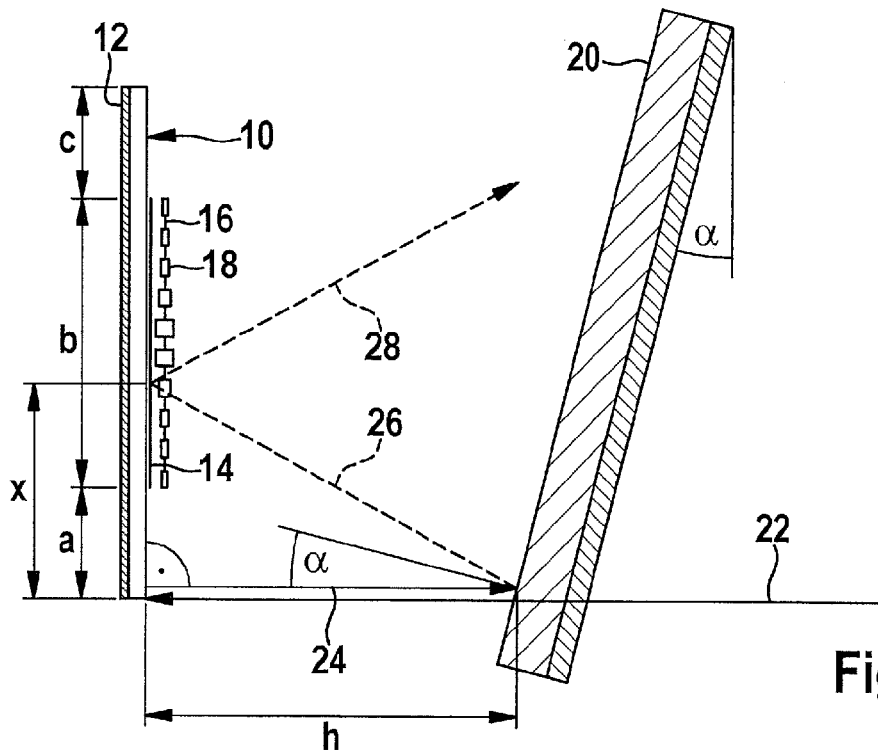


Fig. 1

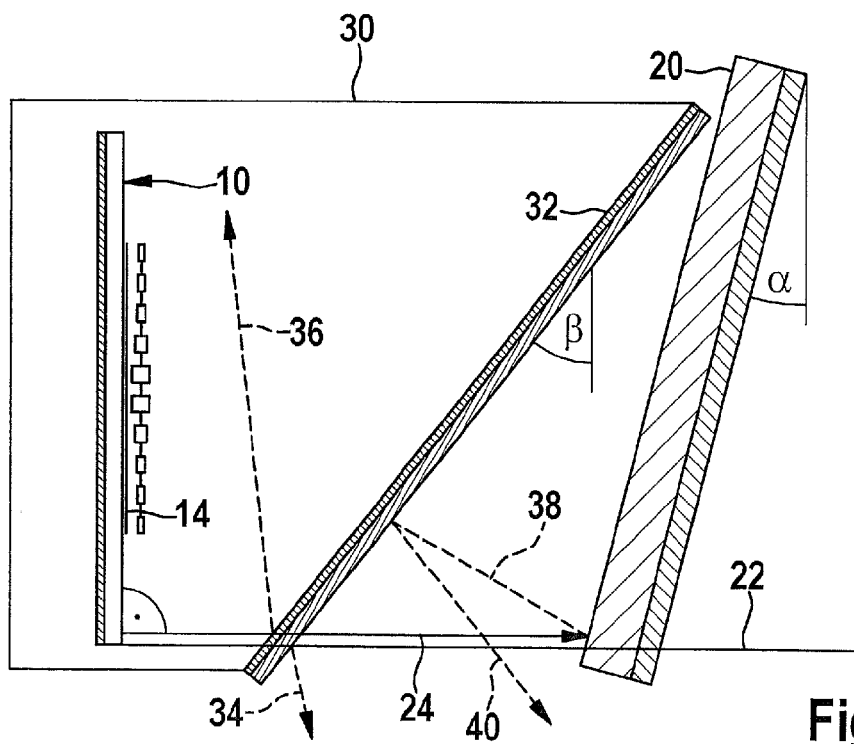


Fig. 2

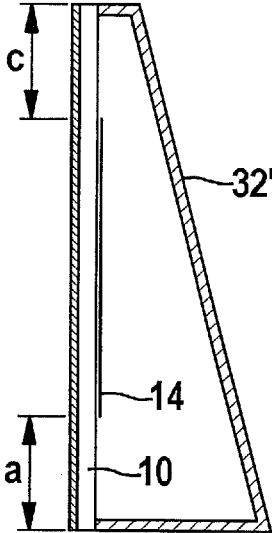


Fig. 3

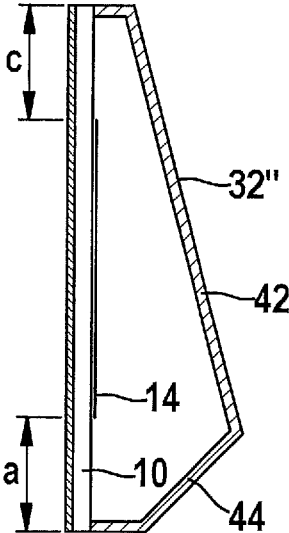


Fig. 4

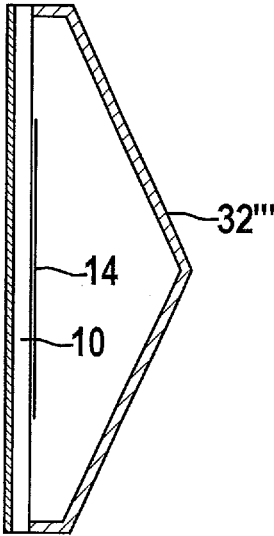


Fig. 5

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RADAR SENSOR INCLUDING A RADOME

RELATED APPLICATION INFORMATION

The present application claims priority to and the benefit
of German patent application no. 10 2013 220 259.8, which
was filed in Germany on Oct. 8, 2013, the disclosure of
which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to a radar sensor for motor
vehicles, including a printed circuit board which carries the
mass and antenna structures of the radar sensor, and includ-
ing a housing accommodating the printed circuit board, the
housing being formed on a transmit and receive side of the
radar sensor by a radome which is transparent to radar
radiation. The object of the present invention is moreover a
motor vehicle having such a radar sensor.

BACKGROUND INFORMATION

Radar sensors are used in motor vehicles, for example, for
measuring the distances and relative velocities of preceding
vehicles, so that, for example, a collision warning and/or an
automatic distance regulation is made possible. In the case
of these applications, the radar sensor is installed in the front
area of the vehicle body. The radome has the purpose of
protecting the sensitive electronic components of the radar
sensor against mechanical impact and weather conditions. In
several known radar sensors, the radome is formed as a radar
lens, which is used to simultaneously achieve collimation and
beam forming of the radar beam. In the case of other
known radar sensors the beam forming is solely carried out
by the geometry and activation of the antenna elements, for
example, according to the principle of a phased array
antenna. In this case, the radome may be formed simply by
a plane wall made of plastic.

Since the bumpers of vehicles today are usually made of
plastic and are consequently transparent to radar radiation, it
is frequently desired to install the radar sensor protected and
concealed behind the vehicle's bumper. However, a problem
exists that while the bumper made of plastic is largely
transparent to the radar radiation, it does have a certain
reflective capacity. Since, on the other hand, the incoming
radar waves are also reflected on the mass structures of the
printed circuit board after having passed through the bum-
per, multiple reflections may occur between the printed
circuit board and the vehicle's bumper. These multiple
reflections represent an undesirable interfering signal when
the radar signal is evaluated.

Such multiple reflections are particularly interfering in the
case of angle-resolving radar sensors, in which multiple
antenna elements are situated side by side across the width
of the vehicle, so that it is possible to measure or at least
estimate the azimuth angle of the located object by evalu-
ating the amplitude and phase relations between the radar
echoes received by the different antenna elements. The
multiple reflections may falsify the amplitudes and phases so
severely that the accuracy of the angle measurement is
considerably adversely affected.

A possible countermeasure is to tilt the bumper in such a
way that its reflective surface is no longer parallel to the
plane of the printed circuit board and consequently the radar
waves no longer strike the antenna structures after one or
repeated reflections. However, such a tilt of the bumper

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limits the constructional flexibility in designing the bumper
and in installing the radar sensor.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a radar
sensor, which is less sensitive to multiple reflections on the
vehicle's bumper.

According to the present invention, this objective is
achieved in that the radome has an essentially plane wall
oriented obliquely to the printed circuit board.

Before reaching the printed circuit board, the incoming
radar waves, which have passed through the vehicle's bum-
per, must also pass through the radome, a small component
of the radiation energy being reflected. After being reflected
on the printed circuit board, the radar waves are again
reflected on the radome. Due to the oblique position of the
radome, the reflected waves are deflected at an angle which
is double the angle between the plane of the radome and the
plane of the printed circuit board. An adequate oblique
position of the radome makes it possible to achieve that the
reflected waves no longer strike the antenna structures as
early as after the first reflection, but no later than after the
second or third reflection.

A certain component of the waves that return from the
printed circuit board to the radome pass through the radome
and are again reflected on the bumper. A certain component
of these waves are again reflected and deflected when they
again pass through the radome. Due to the additional reflec-
tion losses on the radome, the multiple reflections between
the printed circuit board and the bumper are generally
significantly more severely attenuated than in the case of a
radar sensor whose radome is oriented in parallel to the
printed circuit board. This makes it possible to obtain a
relatively interference-free signal even when the bumper is
not tilted or is tilted only slightly.

Advantageous refinements and embodiments of the pres-
ent invention are described herein.

Exemplary embodiments are explained in greater detail
below with reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic diagram of a radar sensor
without a radome, which is installed behind a tilted bumper.

FIG. 2 shows a similar schematic diagram for a radar
sensor including a radome according to the present inven-
tion.

FIG. 3 shows an additional exemplary embodiment which
differs in the geometry of the radome.

FIG. 4 shows an additional exemplary embodiment which
differs in the geometry of the radome.

FIG. 5 shows an additional exemplary embodiment which
differs in the geometry of the radome.

DETAILED DESCRIPTION

A side view of a printed circuit board **10** in the form of a
plane plate of a radar sensor of a motor vehicle is shown
schematically in FIG. 1, the printed circuit board being
mounted in a vertical orientation in the front area of the
motor vehicle, which is not shown. Printed circuit board **10**
carries mass structures **12**, which in the example shown have
the form of a metallization on the rear side of the printed
circuit board. Furthermore, on its front side, printed circuit
board **10** carries antenna structures **14**, for example, in the

form of multiple vertical gaps **16** of antenna elements **18**. A single one of these gaps **16** is shown schematically also in layout in FIG. 1.

Antenna elements **18** of each gap are connected in series to a high-frequency signal of an oscillator, which is not shown. The dimensions of antenna elements **18** and the distances between them are selected in such a way that the resonance vibrations excited in individual antenna elements **18** have phase and amplitude relationships, which result in a certain beam forming in elevation, more precisely, a bundling of the emitted radar radiation forward in the direction of travel of the motor vehicle (to the right in FIG. 1) in the case of a front radar.

As an example, it should be assumed that the radar sensor is a sensor including a monostatic antenna system. This means that antenna elements **18** which are used for emitting the radar signal are also used for receiving the radar echoes reflected by the located objects. The received radar echoes are evaluated separately in a known manner for each gap **16**.

If a radar echo arrives from an object whose line of sight is not exactly oriented at a right angle to the plane of printed circuit board **10**, i.e., from an object having an azimuth angle different from 0° , due to the different signal propagation delays, this results in characteristic amplitude and phase differences between the signals which are received in the different antenna gaps situated at a distance from one another in the transverse direction of the vehicle. Based on these characteristic differences, it is possible to determine the azimuth angle of the located object, at least approximately.

In the example shown in FIG. 1, the radar sensor is installed concealed behind a bumper **20** of the motor vehicle. Of bumper **20**, only a certain section of a wall of the bumper is shown schematically in cross section in FIG. 1. This wall of the bumper is formed by one or multiple layers of plastic materials and in the example shown, it is tilted about a certain angle α in relation to the vertical and consequently also in relation to the plane of printed circuit board **10**.

In FIG. 1, an incoming radar beam **22** is shown schematically, which (after reflection on an object which is not shown) passes through bumper **20** and strikes the outermost lower edge of printed circuit board **10**. The angle of elevation of radar beam **22** amounts to 0° , i.e., the beam strikes printed circuit board **10** in elevation at a right angle. Radar beam **22** is nearly completely reflected on printed circuit board **10**, in particular on its mass structures **12**, so that a reflected beam **24** returns to bumper **20** and strikes the inner surface of bumper **20** under an angle of incidence α , which is equal to the tilt of the bumper. A certain component of the radiation is again reflected here and forms a multiply reflected first-order beam **26**, which again strikes printed circuit board **10** at a certain vertical offset x . Here the beam must be reflected again, so that a reflected second-order beam **28** returns again to bumper **20**. This process may in principle be repeated multiple times, so that a cascade of multiple reflections is obtained, the intensity of which, however, decays exponentially due to losses occurring in each reflection.

When the multiply reflected first-order and higher order beams strike in the zone on printed circuit board **10**, in which gaps **16** of antenna elements **18** are located, the multiply reflected beams are received by the antenna elements, and they form an interference signal which falsifies the amplitude and phase relations between the signals received in different gaps **16** and thus makes it more difficult to measure the azimuth angle.

In the example shown in FIG. 1, the tilt of bumper **20** about angle α has the result that only multiply reflected first order beam **26** strikes antenna structures **14**, while multiply reflected second-order and higher order beams are already deflected far enough upwards that they no longer strike the antenna structures.

When bumper **20** is tilted about a larger angle α , this makes it possible for multiply reflected first-order beam **26** to also no longer strike antenna structures **14** (not even when incoming beam **22** strikes printed circuit board **10** on its outermost lower edge as in FIG. 1).

In FIG. 1, "a" denotes the vertical distance between the lower edge of printed circuit board **10** and the lower edge of antenna structures **14**, "b" denotes the height of antenna structures **14**, and "c" indicates the distance between the upper edge of antenna structures **14** and the upper edge of printed circuit board **10**. The condition that multiply reflected first-order beam **26** should also not strike antenna structures **14**, may then be expressed as inequality

$$x > a + b \quad (1)$$

Incoming beam **22**, multiply reflected beam **26** and the section of printed circuit board **10** which has the height x form a right triangle. Based on the law of reflection (angle of incidence equals angle of reflection), the angle which is diametrically opposed to the side of the triangle having length x has the value 2α . Therefore:

$$\tan(2\alpha) = x/h \quad (2)$$

h being the distance between printed circuit board **10** and bumper **20** at the height of incoming beam **22**.

Based on these relationships, it is possible to determine angle α on which bumper **20** should at least be tilted in order to avoid interfering multiple reflections. In practical specific embodiments, angle α amounts to at least 18° or more. However, there are installation situations and vehicle designs in which such a large tilt angle of the bumper is undesired.

In a diagram similar to FIG. 1, FIG. 2 illustrates a radar sensor according to the present invention in which the interfering multiple reflections may be largely suppressed independently of the tilt angle of the bumper.

In the case of this radar sensor, printed circuit board **10** is (as is customary per se) accommodated in a protective housing **30**, which is limited on the side toward which the radar radiation is emitted by a wall made of plastic, which is transparent to radar radiation, a so-called radome **32**. The particularity in this case is that radome **32** is tilted in relation to printed circuit board **10** about a certain angle β .

Incoming beam **22** must now not only pass through bumper **20** but also radome **32**, a certain reflection loss again occurring (beam **34**), which, however, does not significantly reduce the sensitivity of the radar sensor.

Reflected beam **24** must also pass through radome **32**, with the consequence that a certain radiation component (beam **36**) is already reflected on the radome. In the example shown, angle β is selected in such a way that multiply reflected first-order beam **36** does not strike antenna structures **14**. Angle β of the tilt of the radome required for this may be calculated using equations (1) and (2) provided above for angle α , by substituting β for α and the distance between printed circuit board **10** and radome **32** for h .

The larger share of reflected beam **24** will pass through radome **32** and strike bumper **20**, resulting in another multiply reflected beam **38**. In the case of unhindered propagation, this beam **38** could strike antenna structures **14**; however, it must again pass through radome **32**, a certain

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component of the radiation again being reflected (beam 40). Reflected beam 40 is in this case directed away from antenna structures 14. The component of multiply reflected first order beam 38, which ultimately strikes the antenna structures, is for that reason significantly attenuated by two additional reflections on radome 32 in addition to the reflection on bumper 20, so that the useful signal is less falsified and interfered with. In the case of multiple higher order reflections, the additional reflection losses result in a significantly faster decay of the beam intensity, so that the interfering influence of the multiple reflections may ultimately be effectively suppressed even when angle α , about which bumper 20 is tilted, is relatively small or even 0°.

The effect of radome 32 may, if necessary, be increased in that the rear side of radome 32, which faces printed circuit board 10, is "mirrored" by a suitable coating, so that it has a particularly high reflective capacity for the radar radiation having the frequency of the radar sensor and having angle of incidence β , and consequently the intensity of reflected beam 36 is increased at the expense of beam 24 which has passed through.

While in the example shown in FIG. 2, radome 32 is tilted in such a way that its lower edge is closer to printed circuit board 10 than its upper edge, specific embodiments are of course also possible in which radome 32 is tilted in the opposite direction. For determining angle β , in which multiply reflected first-order beam 36 no longer strikes antenna structures 14, variable "c" must be substituted for variable "a" in above inequality (1). A radome 32' configured in this way is shown in FIG. 3.

Optionally, the radar sensor may also have a roof-shaped radome 32", as shown in FIG. 4. This radome has two asymmetric roof surfaces 42, 44. Such a system may, for example, be advantageous when antenna structures 14 on printed circuit board 10 are also situated asymmetrically with regard to the edges of the printed circuit board (a≠c).

As another example, FIG. 5 finally shows a radome 32''' having a symmetrical roof form. This system is advantageous in particular when the bumper has only a relatively small tilt or no tilt, and makes it possible to reduce the overall height of the radome, so that the distance between the radar sensor and bumper 20 may also be correspondingly short.

What is claimed is:

1. A motor vehicle, comprising:

a bumper; and

a radar sensor arranged behind the bumper;

wherein:

the radar sensor includes a mass, antenna structures, a printed circuit board that carries the mass and antenna structures, and a housing accommodating the printed circuit board and including a radome at a transmit and receive side of the radar sensor;

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the radome is transparent to radar radiation, includes a wall that is essentially a plane oriented obliquely to a plane formed by the printed circuit board, and is positioned between the antenna structures and the bumper; and

the antenna structures are arranged and configured to detect radar beams including a radar beam that passes through the bumper and is incident on the antenna structures in a direction that is perpendicular to the plane of the printed circuit board.

2. The motor vehicle of claim 1, wherein the wall of the radome forms an angle with the printed circuit board which results in that, for all beams that are incident on the printed circuit board and are reflected from the printed circuit board back towards the radome, a respective associated multiply reflected first-order beam, that is formed by reflection by the radome of the beam reflected to the radome from the printed circuit board, travels away from the radome in a direction such that it no longer strikes the antenna structures on the printed circuit board.

3. The motor vehicle of claim 1, wherein the plane of the printed circuit board extends in vertically and the oblique orientation of the radome relative to the plane of the printed circuit board forms an angle with the vertical extension of the plane of the printed circuit board.

4. The motor vehicle of claim 3, wherein the antenna structures include a plurality of antenna elements that are separated from each other by respective gaps, and wherein the gaps are vertically oriented and situated next to one another.

5. The motor vehicle of claim 1, wherein the radome forms a panel-shaped roof of the housing.

6. The motor vehicle of claim 1, wherein the radome forms a pointed roof of the housing.

7. The motor vehicle of claim 6, wherein the radome forms a symmetrical pointed roof.

8. The motor vehicle of claim 1, wherein the radar sensor is installed behind a wall of the bumper that is tilted in relation to the plane of the printed circuit board of the radar sensor by less than 15°.

9. The motor vehicle of claim 1, wherein the radome includes, on a side of the radome facing towards the printed circuit board and away from the bumper, a coating that is highly reflective for the radar beams, so that the side of the radome facing towards the printed circuit board and away from the bumper is more reflective for the radar beams than an opposite side of the radome that faces away from the printed circuit board and towards the bumper.

10. The motor vehicle of claim 1, wherein the bumper, at a region of the bumper that is in at least one plane that passes perpendicularly through the printed circuit board, is oriented obliquely to the plane of the printed circuit board.

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