RADAR SENSOR

Abstract

A radar sensor which comprises a layer including at least one active region and at least one passive region. The active region includes a plurality of antenna elements being configured to transmit and to receive radar waves, and the passive region is free of antenna elements. The passive region is provided with a diffraction grating surface.

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Background/Summary

FIELD

[0002] This section provides background information related to the present disclosure which is not necessarily prior art.

[0003] The present disclosure relates to a radar sensor which may be an automotive radar sensor being installed on a vehicle.

BACKGROUND

[0004] Internal components of an automotive radar sensor are usually mounted in a sensor housing on top of which a radome is placed. The housing and the radome encapsulate and protect internal sensor components from environmental factors like dust, moisture, corrosion, rust and mechanical damage. For aerodynamic and aesthetic reasons, automotive radar sensors are usually integrated in or hidden behind other vehicle components, i.e. behind the outer shell of the vehicle. Such vehicle components may be a bumper, a facia, an emblem etc.

[0005] If another vehicle component is placed in front of antennas of an automotive radar sensor, for example, the performance of the radar sensor may be degraded with respect to its ideal performance. This may be due to the fact that the placement of the radar sensor behind the vehicle component may entail disturbing and unwanted effects including radome insertion and transmission losses, a boresight error, antenna main lobe ripples, a shrinkage of the beam width and of the field of view of the radar sensor, an increased level of side lobes, depolarization effects and others. Therefore, the design and the integration of a radome are critical and challenging tasks in automotive radar technologies.

[0006] Even if a radome of a radar sensor is properly designed and integrated in a vehicle, most of the above-mentioned disturbing effects may still remain e.g. due to destructive interference caused by specular multibounce reflections between metallic planar surfaces of the radar sensor and vehicle components. Such metallic surfaces may have a high reflectivity for radar waves and may be present within the radar sensor at a top surface of an antenna board and/or of the radome, and in addition at another vehicle component, e.g. a bumper or a facia of the vehicle.

[0007] The reflections between metallic surfaces of the radar sensor need also to be considered if a metallic waveguide antenna technology is applied to the radar sensor, e.g. air waveguide (AWG) antennas, ridge gap waveguide (RGW) antennas or groove gap waveguide (GGW) antennas. The metallic waveguide antenna technology generally suffers from its significant structural radar cross-section (RCS) due to the highly reflective metallic planar surfaces which are present in such radar sensors.

[0008] To overcome the disturbing effect as described above, known radar sensors may be provided with highly dissipative dielectric materials as absorber layers e.g. on top of antenna boards. By such materials, a good isolation may be achieved between antenna elements, and surface waves as well as multibounce reflections may be efficiently absorbed. However, the use of such absorbing materials may entail high cost for the radar sensor.

[0009] Accordingly, there is a need to have a radar sensor for which disturbing effects are mitigated when the radar sensor is mounted behind or close to another component in a vehicle.

SUMMARY

[0010] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0011] The present disclosure provides a radar sensor and a vehicle according to the independent claims. Embodiments are given in the subclaims, the description and the drawings.

[0012] In one aspect, the present disclosure is directed at a radar sensor which comprises a layer including at least one active region and at least one passive region. The active region includes a plurality of antenna elements being configured to transmit and to receive radar waves, and the passive region is free of antenna elements. The passive region is provided with a diffraction grating surface.

[0013] The radar sensor may comprise different layers including, for example, a layer or a board for electronic components like an MMIC (monolithic microwave integrated circuit), a layer formed as an antenna bottom lid, a layer formed as an antenna top lid and a layer formed as a radome. Within the layer formed as the antenna top lid, the passive region may be located which includes the diffraction grating surface.

[0014] The active region may include the antenna elements only without any further items like a structure including corrugations as described below. In other words, the layer of the radar sensor may just include antenna elements and the surface configured as diffraction grating.

[0015] Due to the diffraction grating surface, the contribution of the specular multibounce reflections may be scattered out of a radar cone corresponding to a field of view of the radar sensor. Moreover, such a diffraction grating surface may have the ability of tuning and optimizing diffraction modes of the radar waves regarding their scattering patterns.

[0016] Due to the diffraction of reflected radar waves in the passive region, specular reflections are reduced and a concentration of reflected energy at boresight is decreased. Hence, a structural radar cross-section in boresight direction is decreased since higher diffraction modes are deflected out of the field of view of the radar sensor. Moreover, different expensive materials, e.g. for absorbers, are not required for the radar sensor which therefore has a highly cost-effective design.

[0017] In summary, disturbing effects on the performance of the radar sensor are decreased due to the diffraction grating surface of the passive region. As a consequence, the angle finding performance of the radar sensor is improved, and there may be a coverage improvement in azimuth and elevation angles, respectively. This also holds true if the radar sensor is operated at different frequencies, e.g. within an entire bandwidth of 76 to 81 GHz which is currently used for automotive radar sensors, and also for frequencies beyond 100 GHz, e.g. for frequency bands around 120 GHz being relevant for advanced automotive radar sensors.

[0018] According to an embodiment, the diffraction grating surface may include a surface profile in which maxima and minima of the surface profile are arranged periodically. The periodic structure may extend, for example, in two directions being perpendicular to each other. Such a surface profile having the periodically arranged maxima and minima may act as the diffraction grating in order to scatter reflections of radar waves generated by multi-bounce effects out of a region corresponding to an instrumental field of view of the radar sensor. A surface structure including periodic maxima and minima may be manufactured at low cost. As an alternative, the passive region may also include a flat surface which may be provided with internal structures acting as a diffraction grating.

[0019] A periodicity of the maxima and minima of the surface profile may be adapted to at least two diffraction modes of the radar waves such that radar waves associated with the at least two diffraction modes may be scattered out of a predefined field of view of the radar sensor. The predefined field of view of the radar sensor may relate to an instrumental or instrumented field of view which may be defined by a certain range in azimuth and elevation angle with respect to a boresight direction of the radar sensor.

[0020] The periodicity of the maxima and minima may relate to one or two dimensions or directions within the surface profile. If the surface profile is sinusoidal for two directions, the periodicity may be represented by the frequency of a sine or cosine defining the surface of the surface profile in the respective perpendicular directions.

[0021] For example, if the surface profile is formed as a one-dimensional grating, i.e. having periodic structures along one axis only, there are a positive and a negative diffraction mode of first order in addition to a specular reflection as zeroth order. Hence, the periodicity of the one-dimensional grating may be configured such that radar waves of the two diffraction modes of first order are scattered out of the field of view of the radar sensor. As a second example, there are four diffraction modes of first order if the surface profile is formed as a two-dimensional grating having periodic structures along two axes being perpendicular to each other. In this case, the periodicity of the two-dimensional grating may be configured in two directions such that radar waves of the four diffraction modes of first order are scattered out of the field of view of the radar sensor.

[0022] Hence, a desired number of diffraction modes of the radar waves may be scattered out of the field of view of the radar sensor by adapting the periodicity of the maxima and minima within the surface profile accordingly. In detail, the diffraction angle of the respective diffraction mode may be directly influenced by the respective periodicity along at least one of the directions. Therefore, it may be possible to control and to optimize the influence of the cross-grating profile on the energy of the incident waves and on the mitigation of specular multibounce reflection effects. In addition, a distance between the maxima and minima, i.e. a height of the surface profile, may determine or define the power or energy distribution over the different diffraction modes.

[0023] The maxima and minima of the surface profile may have the same periodicity for two directions being perpendicular to each other. In other words, the surface profile may be symmetric with respect to the two perpendicular directions. For such a surface profile, the scattering behavior of the passive region may be independent from the polarization of the radar waves. Hence, such a passive region having the same periodicity for the maxima and minima in two perpendicular directions may be suitable for a bipolar radar sensor using two different polarization modes.

[0024] As an alternative, the maxima and minima of the surface profile may have different periodicities for two directions being perpendicular to each other. Such a configuration of the surface profile of the passive region may be relevant for automotive radars having a wider field of view with respect to the azimuth angle than with respect to the elevation angle. For such a configuration, the periodicity along one axis may be increased, whereas the periodicity along a perpendicular axis may be decreased in comparison to the symmetric surface profile as described above.

[0025] Due to the different periodicities of the maxima and minima along the two perpendicular directions or axes, more diffraction modes may be excited e.g. over the azimuth angles for which the automotive radar may have a wider field of view. This may lead to a better distribution of the scattered energy outside the radar cone or field of view such that the suppression of the specular reflection may be enhanced. Such a concept may be suitable for applications using a single polarization.

[0026] Furthermore, the surface profile may be sinusoidal for the two directions being perpendicular to each other. This may hold true for the symmetric and for the asymmetric surface profile, i.e. for a surface profile having the same periodicity of the maxima and minima in two perpendicular directions as well as for the surface profile having different periodicity.

[0027] According to a further embodiment, a respective dual-purpose structure may be associated with each antenna element of the active region, wherein each dual-purpose structure may be configured to isolate the associated antenna element from the other radar elements with respect to the transmitted and received radar waves. At the same time, each dual-purpose structure may be configured to suppress and to deflect reflections of incident radar waves, i.e. reflections arriving at the dual-purpose structure.

[0028] Within the layer formed as the antenna top lid, the respective dual-purpose structure associated with one of the antenna elements may be arranged, e.g. on both sides of the respective antenna element. The dual-purpose structure may include elements which may be able to prevent the surface wave propagation across the respective structure. By a proper alignment of the structure

between the antenna elements, the dual-purpose structure may therefore isolate the associated antenna element form the further antenna elements with respect to the propagation of the radar waves therebetween. Hence, disturbing effect between the antenna elements may be reduced or avoided.

[0029] At the same time, the elements of the dual-purpose structure may be able to suppress and to deflect reflections of incident radar waves which may be generated e.g. by multi-bounce effects, wherein the incident radar waves may be suppressed by deflecting these radar waves and/or by cancelling out back reflected radar waves due to destructive interference which may also be called "180° out of phase cancellation". For example, radar waves arriving at the dual-purpose structure may be deflected out of a spatial region corresponding to a field of view of the radar sensor, and furthermore, these radar waves may be additionally suppressed by destructive interference. By this means, a structural radar cross-section in boresight direction may be decreased by the dual-purpose structure.

[0030] Each dual-purpose structure may include a respective set of corrugations, and each corrugation may include a protrusion and a depression. Each set of corrugations may comprise at least one angled corrugation which may include at least one portion extending in a direction being different from a predefined alignment direction of the associated antenna element.

[0031] Since each set of corrugations may include the at least one angled corrugation, specular reflections may be reduced and the concentration of reflected energy at boresight may be further decreased. Moreover, a respective set of corrugations associated with one of the antenna elements may be arranged on both sides of the respective antenna element within the layer formed as antenna top lid. In such a manner, an air waveguide may be formed for isolating the respective antenna element from the further antenna elements within the active region.

[0032] According to a further embodiment, the respective set of corrugations may be covered at least partly by a dielectric layer. On top of the corrugations, for example, a material may be located having a dielectric permittivity greater than the dielectric permittivity of air. Due to this, an operational wavelength of the radar waves may be smaller inside the dielectric layer than a "free space" wavelength in air. Therefore, a depth between protrusions and depressions as well as the distance between adjacent protrusions and depressions may be reduced. This may lead to a more compact design of the entire radar sensor. Moreover, a portion of the energy of the incident radar waves may be dissipated within the dielectric layer which may result in a further reduction of the structural radar cross-section.

[0033] A pair of protrusions of the corrugations being adjacent to the respective associated antenna elements may extend in parallel to the predefined alignment direction of the respective antenna element. In other words, the first two corrugations around each antenna element may have protrusions extending in parallel to or straight along the respective antenna element. Due to this, an isolation between the antenna elements of the active region may be achieved and maintained while, at the same time, the angled corrugations reduce the structural radar cross-section of the entire layer.

[0034] The at least one angled corrugation may include two side portions which are arranged at opposite angles greater than zero with respect to the predefined alignment direction of the associated antenna element. One of the opposite angles may be positive and the other of the opposite angles may be negative with respect to the predefined alignment direction of the associated antenna element. In other words, the side portions may be slanted to the same side with respect to the alignment direction. The size or absolute value of the opposite angles may be the same.

[0035] The two side portions being angled or slanted with respect to the alignment direction of the antenna element may reduce the contribution of specular multibounce reflections to the detected radar signal of the radar sensor since this specular multibounce reflections are deflected out of the boresight direction by the angled or slanted side portions of the angled corrugation.

[0036] The at least one angled corrugation may also include a middle portion extending in parallel to the predefined alignment direction of the associated antenna element such that the side portions may extend from a respective end of the middle portion. Due to the middle portion extending along the associated antenna element, the respective antenna element may be properly isolated with respect to one or more neighboring antenna elements. However, the side portions may alternatively connect to each other directly without a middle portion therebetween.

[0037] Within each side portion of the at least one angled corrugation, the respective protrusion and the respective depression may extend in parallel to each other. More than one angled corrugation having such protrusions and depressions extending in parallel may be arranged adjacent to each other, and all sets of corrugations may include such angled corrugations with protrusions and depressions extending in parallel. Uniform slant angles may be provided for the protrusions and depressions within the side portions of the angled corrugations. Reflections from outer edges of the corrugations may be deflected directly due to the uniform slant. Moreover, the structural radar cross-section of the radar sensor may be decreased via a destructive interference of the radar waves between such angled corrugations.

[0038] Alternatively, within each side portion of the at least one angled corrugation, the respective protrusion and the respective depression may be arranged at opposite angles. Again, more than one angled corrugation having such protrusions and depressions arranged at opposite angles may be adjacent to each other, and within each set of corrugations associated with a respective antenna element, there may such angled corrugations having opposite angles of the protrusions and depressions in their side portions. The opposite slant angles of the respective protrusions and depressions may have the same size or absolute value. In addition, ends of the protrusions and depressions of the respective side portions may be connected to each other because of the opposite slant angles. Due to the opposite angles of the protrusions and depressions within the side portions, back reflections of the radar waves may be cancelled out by destructive interference.

[0039] In addition, a height of the protrusions with respect to the adjacent depressions, i.e. a maximum height in case of opposite slant angles therebetween, may be equal to a quarter of a wavelength, i.e. an operational wavelength, of the radar waves transmitted by the respective antenna element, wherein the height may have a tolerance of a sixteenth of the wavelength. Due to this, a phase cancellation effect which reduces the structural radar cross-section may be achieved for radar waves arriving at the dual-purpose structure. In addition, the requirements for an isolation functionality may be fulfilled or maintained completely along each antenna element.

[0040] The respective set of corrugations may further be a metallic antenna waveguide structure for the associated antenna element. Due to the metallic structure, no expensive dielectric materials may be required, e.g. as absorber layers. Hence, the layers of the radar sensor may be compatible with die cast molding production technologies requiring low cost. However, a dielectric layer may also be located on top of the corrugations as described above in order to enhance the dissipation of the incident radar waves. The set of corrugations may be regarded as an air waveguide (AWG). However, the concept of the angled corrugation may also be suitable for a radar sensor using a ridge gap waveguide (RGW) technology and/or or a groove gap waveguide (GGW) technology.

[0041] According to a further embodiment, a respective set of corrugations may be associated with each antenna element in the active region, and at least one set of corrugations may comprise at least one angled corrugation for which protrusions and depressions of respective side portions of the angled corrugation may be arranged at opposite angles, and at the same time, the passive region may be provided with a surface profile in which maxima and minima of the surface profile may have the same periodicity for two directions being perpendicular to each other.

[0042] As an alternative, a respective set of corrugations may be associated with each antenna element in the active region, and at least one set of corrugations may comprise at least one angled corrugation for which protrusions and depressions of respective side portions of the angled corrugation may extend in parallel to each other, and at the same time, the passive region may be

provided with a surface profile in which maxima and minima of the surface profile may have different periodicities for two directions being perpendicular to each other.

[0043] For such configurations, the active region and the passive region may contribute synergistically to the mitigation of the specular multibounce reflection effects, e.g. between an antenna board or layer and a radome of the radar sensor and between the radar sensor per se and a further vehicle component like a facia or a bumper if the radar sensor is installed in a vehicle. Due to such synergistic effects regarding the mitigation of disturbing effects, the structural radar cross-section may be strongly reduced in the boresight direction of the radar sensor.

[0044] In another aspect, the present disclosure is directed at a vehicle which comprises a vehicle component and a radar sensor as described above which is arranged in a vicinity of the vehicle component. The vehicle component may be a facia, a bumper or an emblem, for example.\ Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

Description

DRAWINGS

[0045] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0046] Exemplary embodiments and functions of the present disclosure are described herein in conjunction with the following drawings.

[0047] FIG. **1** schematically shows an illustration of a radar sensor installed in a vehicle.

[0048] FIG. **2** schematically shows an illustration of an exploded view of the radar sensor as shown in FIG. **1**.

[0049] FIG. **3** schematically shows an illustration of details for the radar sensor shown in FIGS. **1** and **2**.

[0050] FIG. **4** schematically shows an illustration of an embodiment of the radar sensor including corrugations in an active region of an antenna layer.

[0051] FIG. **5** schematically shows an illustration of a further embodiment of the radar sensor including corrugations in an active region of an antenna layer.

[0052] FIG. **6** schematically shows an illustration of corrugations being cover by a dielectric layer.

[0053] FIG. **7** schematically shows an illustration of a further embodiment of the radar sensor including a sinusoidal surface profile in a passive region of an antenna layer.

[0054] FIG. **8** schematically shows an illustration of a configuration of the sinusoidal surface profile and its diffraction properties for radar waves.

[0055] FIG. **9** schematically shows an illustration of a further configuration of the sinusoidal surface profile and its diffraction properties for radar waves.

[0056] Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

[0057] Example embodiments will now be described more fully with reference to the accompanying drawings.

[0058] FIG. **1**A schematically depicts a radar sensor **100** which is installed in a vehicle **110** behind a vehicle component **120**, e.g. a bumper or a facia of the vehicle **110**. Automotive radar sensors like the radar sensor **100** are generally located behind an outer shell of the vehicle **110** for aesthetic and aerodynamic reasons.

[0059] In FIG. **1**B, an enlarged perspective view of the radar sensor **100** is depicted. The radar

sensor **100** includes a housing **140** in which different boards or layers of the radar sensor are mounted as internal components. These include a board **150** for electronic components like a monolithic microwave integrated circuit (MMIC) and boards or layers **160** for air waveguide (AWG) antennas. In addition, the radar sensor **100** includes a radome **170**. The housing **140** and the radome **170** encapsulate and protect the internal components like the boards **150**, **160** of the radar sensor **100** from environmental factors like dust, moisture, corrosion, rust and mechanical damages.

[0060] The surfaces of the vehicle component **120** and of some boards or layers of the radar sensor **100** are formed as metallic planar surfaces. Therefore, these surfaces have a high reflectivity for radar waves being transmitted by the sensor **100**. Due to this, specular multibounce reflections occur which are illustrated by the arrows denoted by **130** in FIGS. **1**A and **1**B. The specular multibounce reflections **130** may be present between the radar sensor **100** and the vehicle component **120**. In addition, the specular multibounce reflections **130** may also be present between the planar metallic surfaces of the radome **170** and the layer or board **160** including the AWG antennas. The reflections **130** are accompanied by unwanted disturbing effects for the performance of the radar sensor **100**, such as radome insertion and transmission losses, a boresight error, antenna main lobe ripples, a shrinkage of the beam width and the field of view of the radar sensor **100**, increased side-lobe levels and depolarization effects, for example.

[0061] Even if the radome **170** is properly designed and mounted for minimizing such unwanted disturbing effects, a majority of these disturbing effects may remain due to the specular reflections. Therefore, the radar sensor **100** according to the disclosure is configured to reduce such disturbing effect as far as possible.

[0062] FIG. **2** depicts an exploded view of the radar sensor **100** including the housing **140**, the electronic board **150**, two antenna boards **160** and the radome **170**. The antenna boards **160** include an AWG antenna bottom lid or bottom layer **162** and an AWG antenna top lid or top layer **164** which includes antenna elements **312** and corrugations **314** which are described in detail below.

[0063] FIG. **3**A depicts an enlarged illustration of the AWG antenna top lid or top layer **164**. The layer **164** includes an active region **310** in which the antenna or radiator elements **312** of all transmitting and receiving (Tx and Rx) antennas of the radar sensor **100** are located, and a passive region **320** which is free of the antenna or radiator elements **312**.

[0064] On both sides of each antenna elements **12**, several corrugations **314** are located within the active region **310**. Hence, a respective set of corrugations **314** is associated with each antenna element **312** of the active region **310**. The respective set of corrugations **314** is also denoted as a dual-purpose structure **313**, and the two purposes of the structure **313** will be explained in detail below.

[0065] In FIG. **3**B, a further embodiment of the layer **164** is depicted. This embodiment includes the same elements as the embodiment of FIG. **3**A such that the description of FIG. **3**A is also valid for FIG. **3**B. The only difference relates to the arrangement of the active region **310** which includes two parts being spatially separated from each other. Hence, the active region **310** is not necessarily a continuous area within the layer **164**, but may include different areas which are separated by a part of the passive region **320** which may be located between the different areas of the active region **310**.

[0066] As shown in FIG. **3**C, each of the corrugations **314** of the structure **313** includes a protrusion **315** and a depression **316** which extend along an alignment direction of the respective antenna element **312**.

[0067] The corrugations **314** provide a cross isolation between adjacent antenna elements **312** by preventing the surface wave propagation across a respective isolation structure **313** (see also FIG. **3**C) formed by the corrugations **314** which are arranged between a pair of antenna elements **312**. As illustrated by the arrow **317** in FIG. **3**C, the corrugations **314** prevent the propagation of radar waves perpendicular to the direction in which the protrusions **315** and the depression **316** of the corrugations **314** extend. In contrast, the propagation of the radar waves is not blocked in a

direction parallel to the extension direction of the protrusions **315** and the depressions **316**, i.e. in parallel to the alignment direction of the antenna elements **312**. This is indicated by the arrow **318** in FIG. **3**C.

[0068] In other words, the structure **313** including the corrugations **314** as shown in FIG. **3**C may be regarded as an electromagnetic soft surface in the direction indicated by the arrow **317** extending perpendicularly to the protrusions **315** and the depressions **316**, and as an electromagnetic hard surface in the direction indicated by the arrow **318** extending along the protrusions **315** and the depressions **316**. That is, the protrusions **314** act as an air waveguide (AWG) for the radar waves transmitted by the antenna elements **312**.

[0069] In order to provide a proper isolation between the antenna elements **312** by blocking a surface wave propagation, an isolation structure **313** having at least three corrugations **314** are required per operating wavelength. Moreover, a height H of the protrusions **315** or, correspondingly, a depth of the depression **316** is equal to a quarter of the operational wavelength of the radar waves, wherein the height H has a tolerance of about a sixteenth of the operational wavelength. Moreover, a distance or a pitch P between neighboring protrusions **315** is selected to be smaller than or equal to a third of the operational wavelength.

[0070] In order to mitigate the disturbing effects of the specular multibounce reflections **130** as described in context of FIG. **1** above, embodiments of the radar sensor **100** are provided with modified corrugations **400** as shown in FIGS. **4** and **5**. That is, at least some corrugations **400** are modified with respect to the straight corrugations **314** as shown in FIG. **3**.

[0071] FIG. **4**A depicts a perspective view for a portion of the layer **164** including the active region **310** and a part of the passive region **320**. In the active region **310**, the isolation structures **313** are located which are associated with a respective antenna element **312**. That is, a respective isolation structure **313** is arranged on both sides of each antenna element **312**. In addition to the straight corrugations **314** having a straight protrusion extending in parallel to the respective antenna element **312**, the isolation structure further includes corrugations **400** which have two angled side portions **412**, **414** in addition to a middle portion **410**.

[0072] Due to the angled side portions **412**, **414** of the corrugations **400**, the isolation structure **313** is able to deflect incident radar waves and to cancel out incident radar waves by destructive interference, as will be explained in detail in context of FIG. **4**D. In addition to isolating the respective associated antenna element **312** from the further antenna elements **312** of the radar sensor **312**, the structure **313** is also configured to suppress and redirect reflections of incident radar waves due to the corrugations **314**, **400**. Therefore, the structure **313** including the corrugations **314**, **400** is denoted as dual-purpose structure **313**. Furthermore, the corrugations **400** are denoted as angled corrugations **400** due to their angled side portions **412**, **414**.

[0073] FIG. **4**B depicts a side view of one of the angled corrugations **400** which includes a middle portion **410** extending in parallel to an alignment direction **420** of the respective antenna elements **312** (see also FIG. **4**C), and angled or slanted side portions **412**, **414** extending from respective ends of the middle portion **410**. An extension direction of the angled side portions **412**, **414** of the corrugations **400** is indicated by **422**, and a slant angle between the extension direction **422** of the side portions **412** and the alignment direction **420** of the antenna elements **312** is indicated by the double arrow **424**.

[0074] FIG. **4**C also depicts a perspective view for a further portion of the layer **164** including the active region **310** and a part of the passive region **320**, i.e. in a similar manner as FIG. **4**A. However, the antenna elements **312** are arranged side by side in the portion as shown in FIG. **4**C. The alignment direction **420** of the respective antenna elements **312**, the extension direction **422** of the side portions **412** and the slant angle **424** are also shown in FIG. **4**C.

[0075] The two side portions **412**, **414** are arranged at opposite angles **424** with respect to the predefined alignment direction **420** of the respective antenna element **312** associated with a respective set of corrugations **314**, **400** which surrounds the antenna element **312** in a direction

perpendicular to the alignment direction **420** of the antenna element **312**. For the present embodiment, the slant angle **424** is approximately 7 degrees. However, this value is just an arbitrary choice related to the design of the active region **310**. Greater or smaller slant angles **424** may also be applied for providing similar technical effects.

[0076] Accordingly, a slant angle **424** greater than 7 degrees is depicted in FIGS. **4**B and **4**C.

[0077] The angled corrugations **400** of the embodiment as shown in FIG. **4** have uniform slant angles **424** for all side portions **412**, **414**. That is, the protrusions **315** and the depressions **316** of the angled protrusions **400** extend in parallel over the entire length of the respective angled corrugations **400**, as is shown most clearly in FIG. **4**B.

[0078] The distance H between a top of the protrusions **315** and a bottom of the depressions **316** is uniformly equal to a quarter of the operational wavelength of the radar waves transmitted by the antenna elements **312** in order to maintain a cross isolation functionality between the antenna elements **312**, wherein the height H has a tolerance of about a sixteenth of the operational wavelength. The isolation functionality of the structure **313** is also indicated by the arrows **317** in FIG. **4**D. In the direction of the arrows **317**, the structure **313** is an electromagnetic soft surface, i.e. over the entire length of the corrugations **400** in the middle portion **410** and in the side portions **412**, **414**.

[0079] For maintaining this isolation functionality in a similar manner as for an active region **310** including straight corrugations **314** only as shown in FIG. **3**, the protrusions **315** of the corrugations **314** which are adjacent to the respective antenna element **312** on both sides (see FIG. **4**A and FIG. **4**C) are kept unchanged, i.e. without being provided with the angled side portions **412**, **414**. In other words, straight corrugations **314** are directly adjacent to the respective antenna element **312** such that the protrusions **315** of the neighboring corrugations **314** of the respective antenna element **312** extend in parallel to the antenna element **312** over their entire length.

[0080] In the lower part of FIG. **4**D, a perspective view of the dual-purpose structure **313** (see FIG. **4**A) is depicted. For sake of clarity, the straight corrugations **314** are omitted such that three angled corrugations **400** are shown only. In the upper part, the same structure is shown in a more schematic and simplified manner.

[0081] Due to the angled side portions **412**, **414** of the corrugations **314**, specular multibounce reflections are directly deflected such that the structural radar cross-section of the layer **164** is reduced. This is illustrated by the waves **440** which are reflected at the respective angled side portion **412**, **414** of the angled corrugation **400**. In addition, an out-of-phase cancellation occurs for the waves **440** reflected at the protrusion **315** and at the depression **316**, respectively, of each angled corrugation **400** due to destructive interference. Such a destructive interference also occurs for waves **450** being reflected at the middle portion **410**. In summary, incident radar waves are suppressed by the angled corrugations **400** of the structure **313** due to deflection at the side portions **412**, **412** and due to destructive interference in all portions **410**, **412**, **414**.

[0082] A further reduction of the structural radar cross-section is caused by a destructive interference of the radar waves within a central region **430** (see FIG. **4**C) in which oppositely slanted side portions **412**, **414** of different sets of corrugations **400** are facing each other. For the present embodiment, the passive region **320** of the layer **164** is left unchanged with respect to the reference model of the radar sensor **100** as shown in FIG. **3**. That is, the passive region **320** includes a flat and uniform surface.

[0083] In FIG. **5**, a further embodiment is depicted for the layer **164** of the radar sensor **100**. Generally, the description provided above for the embodiment as shown in FIG. **4** is also valid for the embodiment as shown for FIG. **5** such that the description of the respective features is not repeated again. FIGS. **5**A and **5**C depict a respective perspective view of a portion of the layer **164**, whereas Fig. B depicts a side view of an angled corrugation **400** according to the present embodiment, and FIG. **5**D depicts a perspective view of the structure **313**.

[0084] The embodiment as shown in FIG. **5** differs from the embodiment as shown in FIG. **4** in that

within the structures **313**, i.e. within the sets of corrugations **314**, **400** associated with some of the antenna elements **312**, the angled corrugations **400** have side portions **412**, **414** in which the protrusions **315** and the depressions **316** are arranged at opposite slant angles **424**. As shown in the side view of FIG. **5B**, the protrusion **315** and the depression **316** of the angled corrugation **400** have respective slanted parts **512**, **513** which are arranged at opposite slant angles with respect to the alignment direction **420** of the antenna element **312**.

[0085] Since the protrusions **315** and the depressions **316** have opposite slant angles **424**, the protrusions **315** and the depressions **316** of these angled corrugations **400** are connected to each other at the respective end of the corrugations **400** along the respective antenna element **312**. In the middle region **410** of the corrugations **400** having such opposite slant angles of the protrusions **315** and of the depressions **316** within their side portions **412**, **414**, the height H of the protrusion with respect to the depression **316** is still equal to a quarter of the operational wavelength of the radar waves transmitted by the antenna element **312**. Such a distance being equal to a quarter wavelength maintains the isolation functionality of the corrugations **314** in the middle region **410**. The height H has a tolerance of approximately a sixteenth of the operational wavelength. The isolation functionality is again illustrated by the arrow **317** in the middle portion **410** depicted in FIG. **5D**.

[0086] Due to these opposite slant angles **424** of the slant parts **512**, **513**, back reflections of incident radar waves are deflected into different directions, as shown in FIG. **5D** by the waves **520**, **530**. In addition, waves reflected at the same deflection angle as illustrated by the pairs of waves **520**, **530**, **540** in FIG. **5D**, are cancelled out by destructive interference of radar waves. This is valid for the middle portion **410** and for the side portions **412**, **414**. For the side portions **412**, **414**, the respective distance **515** between the slanted part **512** of the protrusion **315** of one of the side portions **412**, **414** and the slanted part **513** of the depression **316** of the opposing side portion **412**, **414** is also approximately equal to a quarter of the operational wavelength, with a tolerance of the sixteenth of the wavelength. This favors the destructive interference between the pairs of waves **520**, **530**. In summary, the structural radar cross-section of the layer **164** is reduced again by deflection and destructive interference.

[0087] Moreover, the slant angle **424** of the oppositely slanted protrusions **315** and depressions **316** with respect to the alignment direction **420** of the antenna elements **312** is again approximately 7 degrees for the present embodiment. As mentioned above, this value is again an arbitrary choice related to the design of the active region **310**, and greater or smaller slant angles **424** may also be applied for providing similar technical effects. Accordingly, a slant angle **424** greater that 7 degrees is shown in FIG. **5** for illustration reasons.

[0088] According to a further embodiment as shown in FIG. **6**, the dual-purpose structure **313** and the respective set of corrugations **314**, **400** is covered at least partly by a dielectric layer **600**. On the left side of FIG. **6**, three angled corrugations **400** are depicted which have uniformly slanted protrusions **315** and depressions **316**, i.e. extending in parallel according to the embodiment as shown in FIG. **4**. On the right side of FIG. **6**, in contrast, three angles corrugations **400** are depicted which have oppositely slanted protrusions **315** and depressions **316**, i.e. arranged at opposite angles with respect to the alignment direction **420** of the antenna elements **312** according to the embodiment as shown in FIG. **5**.

[0089] On top of the corrugations, a material is therefore located which has a dielectric permittivity greater than the dielectric permittivity of air. Due to this, an operational wavelength of the radar waves is smaller inside the dielectric layer than a "free space" wavelength in air. Therefore, the depth H (the FIG. **3**) of depressions **316** between the protrusions **315** and the respective distance P between adjacent protrusions **315** and depressions **316** can be reduced in comparison to embodiments in which the corrugations **314**, **400** are not covered by the dielectric layer **600**. This leads to a more compact design of the entire radar sensor **100**. Moreover, a portion of the energy of the incident radar waves is dissipated within the dielectric layer **600** which results in a further reduction of the structural radar cross-section.

[0090] FIGS. **7**, **8** and **9** depict other embodiments of the radar sensor **100** for which the passive region **320** of the layer **164** (see also FIG. **3**) has a diffraction grating surface **700**, **800**, **900** such that the scattering pattern of the radar waves at the passive region is optimized in a special manner. For the embodiments as shown in FIGS. **7**, **8** and **9**, the surface **700**, **800**, **900** of the passive region **320** is sinusoidal for two directions perpendicular to each other, i.e. along the lengths l.sub.x and l.sub.y as indicated in FIG. **7**. The sinusoidal surface profile **700** of the passive region **320** can be analytically described by the following equation:

[00001] $z = f(x, y) = h\cos(\frac{2\pi x}{P_x})\sin(\frac{2\pi y}{P_y})$ (1)

[0091] wherein z denotes the local height of the surface profile **700** with respect to a plane surface (x-y-plane), h is an amplitude or height factor of the profile, P.sub.x is a period length along the x-axis, and P.sub.y is a period length along the y-axis. Hence, P.sub.x and P.sub.y determine the periodicity or frequency along of the sinusoidal profile in two directions being perpendicular to each other.

[0092] Such a sinusoidal surface profile **700** acts as a cross diffraction grating such that reflected radar waves, e.g. from a radome, a facia or bumper, are deflected over a wide range of angles to the outside of a field of view of the radar sensor. Generally, a surface profile having a periodic structure in two perpendicular directions is suitable for providing this technical effect of deflecting radar waves by diffraction. It is therefore not necessary that the surface profile **700** is sinusoidal. Instead, just a regular or periodic structure of maxima **702** and minima **704** is required for the surface profile **700**.

[0093] In FIG. **7**, a radar cone **710** corresponds to a field of view of the radar sensor **100**. An incident wave **720** which may be caused by a reflection at a radome, facia or bumper causes a specular reflection **730** within the field of view or radar cone **710**, i.e. a (0,0) order diffraction mode **730**, whereas higher order diffraction modes **732** are deflected out of the radar cone or field of view **710** of the radar sensor due to their diffraction of the radar waves at the surface profile **700**. Hence, the energy or intensity of the specular reflection **730** is strongly reduced since the higher order diffraction modes **732** are scattered or deflected out of the radar cone **710**. Therefore, the specular multibounce reflections **130** (see FIG. **1**) are also strongly decreased by surface profile **700** of the passive region **320**.

[0094] The sinusoidal surface profile **700** as described by the above formula (1) provides the ability of tuning and optimizing diffraction modes regarding their scattering pattern to be out of the radar cone or field of view of the radar sensor **100**. Generally, such scattering pattern of structured metallic surfaces may be described either by the periodic reflect array theorem, or anomalous reflections of diffraction grating structures may be described by a generalized Snell's law in the reflection regime.

[0095] When considering the analytic formula (1) as provided above, there are three parameters by which the scattering patterns of the surface profile **700** can be optimized. The amplitude or height factor h directly influences the power distribution over the different diffraction modes. The period lengths P.sub.x and P.sub.y along the x-axis and the y-axis, respectively, define the number and diffraction angles of possible diffraction modes along the x-axis and along the y-axis.

[0096] For the embodiment of the radar sensor **100** as shown in FIG. **8**, a surface profile **800** of the passive region **320** is provided with the same periodicity or period length along the x-axis and the y-axis, i.e. P.sub.x=P.sub.y. Hence, the surface profile **800** may also be referred to as a symmetric sinusoidal profile. In FIGS. **8** and **9**, the angle θ denotes an azimuth angle and the angle ψ denotes an elevation angle with respect to a boresight direction along the z axis.

[0097] The respective intensity of the different diffraction modes is depicted in FIG. **8** via respective polar representations, wherein the intensity of the specular reflection is denoted by **820** and the respective intensity of the higher diffraction modes is denoted by **830**. As can be recognized in FIG. **8**, the majority of the incident wave intensity is transferred to the higher

diffraction modes. Accordingly, the intensity **820** of the specular reflection is strongly reduced in comparison to the incident intensity.

[0098] Due to the same periodicities P.sub.x, P.sub.y of the surface profile **800** along the x-axis and the y-axis, the surface profile **800** of the passive region **320** has a scattering behavior being independent from the polarization of the transmitted radar waves. Therefore, the surface profile **800** being symmetric sinusoidal regarding the spatial period is suitable for a bipolar radar sensor using two different polarization modes.

[0099] Since many automotive radar sensors have a wider field of view regarding the azimuth angle θ than regarding the elevation angle ψ, a further embodiment of the radar sensor **100** as shown in FIG. **9** includes a surface profile **900** of the passive region **320** which has different periodicities along the x-axis and the y-axis. With respect to the equal periodicities for both axes as shown in FIG. **8**, the periodicity or period length P.sub.y is increased along the y-axis, whereas the periodicity or period length P.sub.x is decreased along the x-axis.

[0100] Regarding the periodicities of maxima and minima in the x- and y-directions, the sinusoidal surface profile **900** has therefore an asymmetric design. Due to this, more diffraction modes can be excited over the azimuth angle such that the intensity of the higher diffraction modes being scattered out of the radar cone or field of view of the radar sensor **100** is increased. This can be recognized by the polar representation of the intensity of the higher diffraction modes which is respectively denoted by **930**. Consequently, the intensity of the specular reflection which is denoted by **920** is even more suppressed in comparison to the intensity **820** as shown in FIG. **8**. The asymmetric surface profile **900** as shown in FIG. **9** is suitable for radar sensors **100** which use a single polarization mode.

[0101] In order to investigate the feasibility of the concepts described above, a respective bistatic radar cross-section (RCF) of the top antenna lid or layer **164** (see FIGS. **2** and **3**) has been simulated for different models across an entire relevant frequency band from 76 GHz to 81 GHz. For this simulation, an incident wave illuminating from the boresight and a purely horizontal polarization have been assumed as a prerequisite.

[0102] Model 1 (M1) used as a reference model is depicted e.g. in FIG. **3**A or **3**B and has straight corrugations **314** only in the active region **310** and a flat profile in the passive region **320**. Model 2 (M2) is depicted in FIG. **8** and has the symmetric sinusoidal surface profile **800** in the passive region **320** only, but just straight corrugations **314** and no angled corrugations **400** in the active region. Model 3 (M3) is depicted in FIG. **5** and has corrugations **400** with opposite slant angles **424** of the protrusions **315** and the depressions **316** in the active region **310** only, but a flat passive region **320** without a diffraction grating surface. Model 4 (M4) is a combination of the embodiments as shown in FIG. **5** and FIG. **8**. Therefore, M4 has the symmetric sinusoidal surface profile **800** in the passive region **320** (see FIG. **8**) and corrugations **400** with opposite slant angles **424** of the protrusions **315** and the depressions **316** in the active region **310** (see FIG. **5**).

[0103] Model 5 (M5) has the asymmetric sinusoidal surface profile **900** in the passive region **320** only (see FIG. **9**), but just straight corrugations **314** and no angled corrugations **400** in the active region **310**. Conversely, model 6 (M6) is provided with the corrugations **400** with uniform slant angles **424** in the active region **310** only (see FIG. **4**) but with a flat surface profile in the passive region **320** without a diffraction grating surface. Finally, model 7 (M7) is a combination of the embodiments as shown in FIG. **9** and FIG. **4**. Therefore, M7 has the asymmetric sinusoidal surface profile **900** in the passive region **320** (see FIG. **9**) and the angled corrugations **400** with uniform slant angles **424** in the active region **310** (see FIG. **4**).

[0104] The simulation results for the different models M1 to M7 are summarized in the table below. As can be recognized from the results for the models M2, M3, M5 and M6, the embodiment having either slanted corrugations **400** in the active region **310** or a sinusoidal surface profile **800** or **900** in the passive region **320** already lead to a significant reduction of the RCS value. However, the model M4 and M7 having a sinusoidal surface profile in the passive region and slanted

corrugations in the active region **310** have a strongly reduced structural radar cross-section ratio (RCSR ratio), i.e. an RCSR ratio of approximately 10 dB across the entire frequency band from 76 to 81 GHz. It is noted that the model M4 having the symmetric sinusoidal surface profile **800** and oppositely slanted corrugations **400** as well as the model M7 having an asymmetric sinusoidal surface profile **900** and uniformly slanted corrugations **400** show the best results.

TABLE-US-00001 76.5 GHz 81 GHz RCS RCSR RCS RCSR value Ratio value Ratio Simulation Model (dBsm) (dB) (dBsm) (dB) M1: Reference model 9.32 NA 9.76 NA (FIG. 3) M2: Symmetric 1.14 8.18 2.10 7.66 sinusoidal profile in passive region only (FIG. 7) M3: Corrugations with 1.93 7.39 2.22 7.54 opposite slant angles in active region only (FIG. 5) M4: Symmetric −1.46 11.78 −1.22 10.98 sinusoidal profile in passive region (FIG. 7) and corrugations with opposite slant angles in active region (FIG. 5) M5: Asymmetric 4.12 5.20 4.75 5.01 sinusoidal profile in passive region only (FIG. 8) M6: Corrugations with 6.29 3.03 5.79 3.97 uniform slant angles in active region only (FIG. 4) M7: Asymmetric −0.39 9.70 −0.49 10.25 sinusoidal profile in passive region (FIG. 8) and corrugations with uniform slant angles in active region (FIG. 4)

[0105] In addition, the impact of a facia on the azimuth and elevation coverage has been simulated for the models M1 to M7 described above. For the simulations, the radar sensor **100** including the models M1 to M7, respectively, has been combined with a fascia having a reflectivity of −14 dB and an elevation pitch of −4°. It has turned out that model M2 having the symmetric sinusoidal surface profile **800** in the passive region **320** (see FIG. **8**) already improves the azimuth and elevation coverage, i.e. even without the angled corrugations **400** as shown in FIGS. **4** and **5**. Moreover, the model M4 having the symmetric sinusoidal surface profile **800** in the passive region **320** and the corrugations **400** with opposite slant angles of the protrusions **315** and the depressions **316** (see FIG. **5**) further improves the radar integration result over the related art as provided by model M1.

[0106] Therefore, the radar sensor **100** having the angled corrugations **400** in the active region **310** and/or one of the sinusoidal surface profiles **800**, **900** in the passive region **320** shown improved capabilities regarding angle finding.

[0107] According to the disclosure, a radar sensor may comprise a layer including at least one active region and at least one passive region, the active region including a plurality of antenna elements being configured to transmit and to receive radar waves, and the passive region being free of antenna elements. The passive region may be provided with a diffraction grating surface.

[0108] According to various embodiments, the diffraction grating surface may include a surface profile in which maxima and minima of the surface profile are arranged periodically.

[0109] According to various embodiments, the surface profile may be sinusoidal for two directions being perpendicular to each other.

[0110] According to various embodiments, a periodicity of the maxima and minima of the surface profile may be adapted to at least two diffraction modes of the radar waves such that the radar waves associated with the at least two diffraction mode are scattered out of a predefined field of view of the radar sensor.

[0111] According to various embodiments, the maxima and the minima of the surface profile may have the same periodicity for two directions being perpendicular to each other.

[0112] According to various embodiments, the maxima and the minima of the surface profile may have different periodicities for two directions being perpendicular to each other.

[0113] According to various embodiments, a respective dual-purpose structure may be associated with each antenna element in the active region, wherein each dual-purpose structure may be configured to isolate the associated antenna element from the other antenna elements with respect to the transmitted and received radar waves and to suppress and redirect reflections of incident radar waves.

[0114] According to various embodiments, each dual-purpose structure may include a respective set of corrugations, each corrugation including a protrusion and a depression. Each set of

corrugations may comprise at least one angled corrugation which may include at least one portion extending in a direction being different from a predefined alignment direction of the associated antenna element.

[0115] According to various embodiments, the respective set of corrugations may be covered at least partly by a dielectric layer.

[0116] According to various embodiments, a pair of protrusions of the corrugations being adjacent to the respective antenna element may extend in parallel to the predefined alignment direction of the respective antenna element.

[0117] According to various embodiments, the at least one angled corrugation may include two side portions which may be arranged at opposite angles greater than zero with respect to the predefined alignment direction of the associated antenna element.

[0118] According to various embodiments, the respective protrusion and the respective depression within each side portion of the at least one angled corrugation may extend in parallel to each other.

[0119] According to various embodiments, the respective protrusion and the respective depression within each side portion of the at least one angled corrugation may be arranged at opposite angles.

[0120] According to various embodiments, the respective set of corrugations may be a metallic antenna waveguide structure for the associated antenna element.

[0121] According to various embodiments, a respective set of corrugations may be associated with each antenna element in the active region, and at least one set of corrugations may comprise at least one angled corrugation for which protrusions and depressions of respective side portions of the angled corrugation are arranged at opposite angles, and the passive region may be provided with a surface profile in which maxima and minima of the surface profile may have the same periodicity for two directions being perpendicular to each other.

[0122] According to various embodiments, a respective set of corrugations may be associated with each antenna element in the active region, and at least one set of corrugations may comprise at least one angled corrugation for which protrusions and the depressions of respective side portions of the angled corrugation may extend in parallel to each other, and the passive region may be provided with a surface profile in which maxima and minima of the surface profile may have different periodicities for two directions being perpendicular to each other.

[0123] Furthermore, a vehicle may comprise a vehicle component and a radar sensor as described above which may be arranged in a vicinity of the vehicle component.

REFERENCE NUMERAL LIST

[0124] **100** radar sensor [0125] **110** vehicle [0126] **120** vehicle component, e.g. facia or bumper [0127] **130** specular multibounce reflections [0128] **140** housing [0129] **150** electronic board [0130] **160** antenna layer [0131] **162** antenna bottom lid [0132] **164** antenna top lid [0133] **170** radome [0134] **310** active region [0135] **312** antenna element [0136] **313** dual-purpose structure [0137] **314** straight corrugation [0138] **315** protrusion [0139] **316** depression [0140] **317** electromagnetic soft surface [0141] **318** electromagnetic hard surface [0142] **400** angled corrugation [0143] **410** middle portion [0144] **412** side portion [0145] **414** side portion [0146] **420** alignment direction of antenna element [0147] **422** extension direction of angled corrugation [0148] **424** slant angle [0149] **430** area with oppositely slanted side portions [0150] **440** wave deflected at side portion [0151] **450** wave deflected at middle portion [0152] **512, 513** oppositely slanted parts [0153] **520** wave deflected at side portion [0154] **530** wave deflected at side portion [0155] **540** wave deflected at middle portion [0156] **600** dielectric layer [0157] **700** sinusoidal surface profile of passive region [0158] **710** radar cone or field of view [0159] **720** incident wave [0160] **730** specular reflection or zero order diffraction mode [0161] **732** higher diffraction mode [0162] **800** symmetric sinusoidal profile [0163] **820** intensity of specular reflection [0164] **830** intensity of higher diffraction modes [0165] **900** asymmetric sinusoidal profile [0166] **920** intensity of specular reflection [0167] **930** intensity of higher diffraction modes

Claims

1. A radar sensor, comprising: a layer including at least one active region and at least one passive region, the active region including a plurality of antenna elements being configured to transmit and to receive radar waves, and the passive region being free of antenna elements, wherein the passive region is provided with a diffraction grating surface, in the active region, a respective dual-purpose structure is associated with each antenna element, each dual-purpose structure being configured to isolate the associated antenna element from the other antenna elements with respect to the transmitted and received radar waves and to suppress and redirect reflections of incident radar waves, each dual-purpose structure includes a respective set of corrugations, each corrugation including a protrusion and a depression, and each set of corrugations comprises at least one angled corrugation which includes at least one portion extending in a direction being different from a predefined alignment direction of the associated antenna element.

2. The radar sensor according to claim 1, wherein the diffraction grating surface includes a surface profile in which maxima and minima of the surface profile are arranged periodically.

3. The radar sensor according to claim 1, wherein a periodicity of the maxima and minima of the surface profile is adapted to at least two diffraction modes of the radar waves such that radar waves associated with the at least two diffraction modes are scattered out of a predefined field of view of the radar sensor.

4. The radar sensor according to claim 1, wherein the maxima and the minima of the surface profile have the same periodicity for two directions being perpendicular to each other.

5. The radar sensor according to claim 1, wherein the maxima and the minima of the surface profile have different periodicities for two directions being perpendicular to each other.

6-7. (canceled)

8. The radar sensor according to claim 1, wherein the respective set of corrugations is covered at least partly by a dielectric layer.

9. The radar sensor according to claim 1, wherein a pair of protrusions of the corrugations being adjacent to the respective antenna element extends in parallel to the predefined alignment direction of the respective antenna element.

10. The radar sensor according to claim 1, wherein the at least one angled corrugation includes two side portions which are arranged at opposite angles greater than zero with respect to the predefined alignment direction of the associated antenna element.

11. The radar sensor according to claim 10, wherein within each side portion of the at least one angled corrugation, the respective protrusion and the respective depression extend in parallel to each other.

12. The radar sensor according to claim 10, wherein within each side portion of the at least one angled corrugation, the respective protrusion and the respective depression are arranged at opposite angles.

13. The radar sensor according to claim 1, wherein at least one set of corrugations comprises at least one angled corrugation for which protrusions and depressions of respective side portions of the angled corrugation are arranged at opposite angles, and the passive region is provided with a surface profile in which maxima and minima of the surface profile have the same periodicity for two directions being perpendicular to each other.

14. The radar sensor according to claim 1, wherein at least one set of corrugations comprises at least one angled corrugation for which protrusions and depressions of respective side portions of the angled corrugation extend in parallel to each other, and the passive region is provided with a surface profile in which maxima and minima of the surface profile have different periodicities for two directions being perpendicular to each other.

15. A vehicle, comprising: a vehicle component and the radar sensor according to claim 1, which is arranged in a vicinity of the vehicle component.