



- (51) **International Patent Classification:**
H01Q 1/52 (2006.01) **H01Q 21/28** (2006.01)
H01Q 21/30 (2006.01)
- (21) **International Application Number:**
PCT/EP2016/060211
- (22) **International Filing Date:**
6 May 2016 (06.05.2016)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
15166990.0 8 May 2015 (08.05.2015) EP
- (71) **Applicants:** **TE CONNECTIVITY NEDERLAND BV**
[NL/NL]; Rietveldweg 32, 5222 AR s'Hertogenbosch
(NL). **TE CONNECTIVITY GERMANY GMBH**
[DE/DE]; Amperstrasse 12-14, D-64625 Bensheim (DE).
- (72) **Inventors:** **VAN GILS, Wijnand**; Schapendonk 72, 4942
CG Raamsdonksveer (NL). **VAN DOMMELEN, Luc**;

Marjolein 12, 5071 GK Udenhout (NL). **PAN, Sheng-Gen**; Sichelweg 15, 47475 Kamp-Lintfort (DE). **RUSCH, Christian**; Bernsteinstrasse 7, 76189 Karlsruhe (DE). **WINKELMANN, Andreas**; Watzmannstrasse 51, 71067 Sindelfingen (DE). **VOLKMANN, Daniel**; Roemerweg 17, 64686 Lautertal (DE).

(74) **Agent:** **KEANE, David**; Murgitroyd & Company, Scotland House, 165-169 Scotland Street, Glasgow Strathclyde G5 8PL (GB).

(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

[Continued on next page]

(54) **Title:** ANTENNA SYSTEM AND ANTENNA MODULE WITH REDUCED INTERFERENCE BETWEEN RADIATING PATTERNS

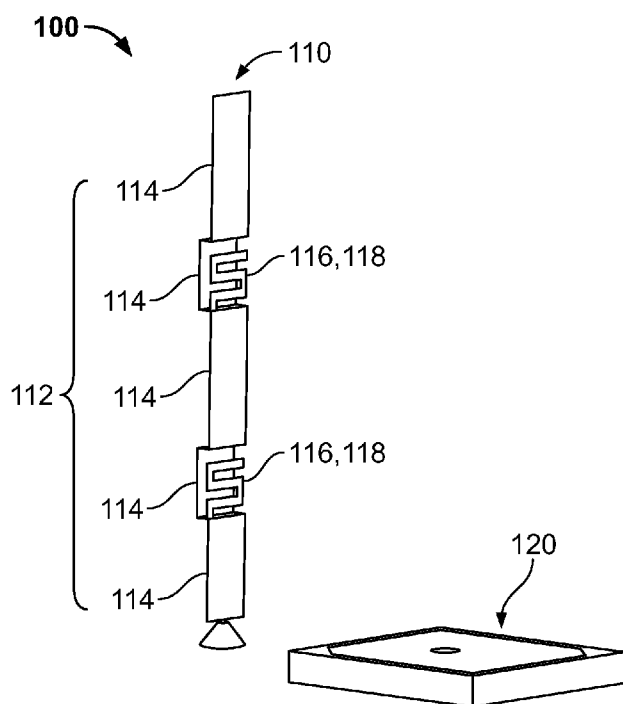


Fig. 1A

(57) **Abstract:** The invention relates to an improved antenna system and antenna module incorporating same. The antenna system comprises: a first antenna element adapted to a first frequency band; and a second antenna element adapted to a second frequency band which is different from the first frequency band. The first antenna element includes: a radiating structure comprising at least one planar radiating element, where the radiating structure is configured to radiate at a frequency in the first frequency band. The first antenna element further includes: at least one band-stop filter structure comprising at least one planar conductive element, where the at least one band-stop filter structure is configured to attenuate a current flow at a frequency in the second frequency band.



(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- with international search report (*Art. 21(3)*)
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (*Rule 48.2(h)*)

**Antenna System and Antenna Module
with Reduced Interference between Radiating Patterns**

The invention relates to an improved antenna system comprising a first and a second antenna element where the configuration of at least one of the antenna elements allows for a reduced interference between the radiating patterns of each of the antenna elements. Further, the invention relates to an antenna module incorporating same antenna system.

In the context of the invention, an antenna system is to be understood as an antenna arrangement comprising a first antenna element and a second antenna element.

Generally, antenna systems are widely discussed in technology because the grouping of plural antenna elements in one system provides for various structural advantages. Particularly the assembly of an antenna system as a single structural module allows mechanical and electrical components to be shared between the plural antenna elements.

Accordingly, in an antenna system the plural antenna elements may be arranged within and hence share a same housing, a same base, may share same PCB circuitry, and may share a same electrically connection for transmitting/receiving electrical signals from the outside to/from the plural antenna elements within the antenna system, respectively.

However, the arrangement of plural antenna elements in an antenna system suffers from disadvantages, particularly when the plural antenna elements are arranged in the near-field to each other. In this case, the plural antenna elements suffer from mutual interference effects particularly regarding their respective radiating patterns.

In WO 98/26471 A1, it is proposed to apply frequency selective surfaces in an antenna system to reduce mutual interference effects between two antenna elements. In more detail, the suggested antenna system comprises a first and a second antenna element. The first antenna element is capable of transmitting in a first frequency range, and the second antenna element is capable of transmitting in a second – i.e. non-overlapping – frequency range.

In order to reduce interference effects, the antenna system additionally includes a frequency selective surface which is conductive to radio frequency energy in the first frequency range and reflective to radio frequency energy in the second frequency range. The frequency selective surface comprises preferably repetitive metallization pattern structures that display quasi band-pass or quasi band-reject filter characteristics to radio frequency signals impinging upon the frequency selective surface.

Further, US 6,917,340 B2 also relates to an antenna system comprising two antenna elements. In order to reduce the coupling and hence interference effects, one of the two antenna elements is subdivided into segments which have an electrical length corresponding to three/eight of the wavelength of the other antenna element.

Further, the segments of the one antenna element are electrically interconnected via electric reactance circuits which possess sufficiently high impedance in the frequency range of the other antenna element and sufficiently low impedance in the frequency range of the one antenna element.

Even though the above described approaches allow for a reduced inference in the radiation patterns of two antenna elements, the design of the antenna system comprising the two antenna elements becomes more complicated in view of the incorporation of additional components, namely the manufacturing and arrangement of the incorporation of electric reactance circuits.

In particular, the design of the electric reactance circuits and their arrangement on the respective antenna element is complex and necessitates additional development steps. Further the components of the electric reactance circuit as well as the, for instance soldered, electrical connection to the antenna elements introduces unacceptable variances to the frequency characteristic.

In this respect, it is an object of the invention to suggest an improved antenna system which overcomes the disadvantages noted above, e.g. to avoid additional assembly steps. Furthermore, it is another object of the invention to propose an antenna system with reduced interference between radiating patterns of the plural antenna elements comprised therein.

According to a first aspect, an antenna system comprises one or more band-stop filter structure(s) which is/are placed near to the first antenna element. One or both end(s) of each filter structure is/are connected to the first antenna element. The filter structure attenuates a current flow at a frequency in the second frequency band to which the first antenna element is adapted. Hence, the first antenna element in the antenna system allows reducing interference effects at the frequency of the second frequency band which the second antenna element is adapted. Consequently, a reduction in interference of the first antenna element to the radiating pattern of the second antenna is also achieved. According to an embodiment, an antenna system is proposed comprising: a first antenna element adapted to a first frequency band; and a second antenna element adapted to a second frequency band which is different from the first frequency band. The first antenna element includes: a radiating structure comprising at least one planar radiating element, where the radiating structure is configured to radiate at a frequency in the first frequency band. The first antenna element further includes: at least one band-stop filter structure comprising at least one planar

conductive element, where the at least one band-stop filter structure is configured to attenuate a current flow at a frequency in the second frequency band.

The at least one planar conductive element is arranged in form of a meander pattern, and is, at one end, electrically connected to the at least one planar radiating element. Further, the at least one planar conductive element extends in a direction substantially in parallel to a direction of the at least one planar radiating element; and the at least one planar conductive element has an electrical length which corresponds to substantially a quarter of a wavelength of the frequency in the second frequency band.

According to another embodiment, an antenna system is suggested comprising: a first antenna element adapted to a first frequency band; a second antenna element adapted to a second frequency band which is different from the first frequency band. The first antenna element includes: a radiating structure comprising at least one planar radiating element, where the radiating structure is configured to radiate at a frequency in the first frequency band. The first antenna element further includes: at least one band-stop filter structure comprising at least one planar conductive element, where the at least one band-stop filter structure is configured to attenuate a current flow at a frequency in the second frequency band.

The at least one planar conductive element is arranged in form of a meander pattern, and is, at both ends, electrically connected to the at least one planar radiating element such that it forms a parallel circuit therewith. Further, the at least one planar conductive element extends in a direction substantially in parallel to a direction of the at least one planar radiating element; and the at least one planar conductive element has an electrical length which exceeds the electrical length of the at least one planar radiating element by a half of a wavelength of the frequency in the second frequency band.

According to an embodiment of the antenna system, the second antenna element is arranged within the near-field of the first antenna element.

According to another embodiment of the antenna system, the at least one planar conductive element of the at least one band-stop filter structure and the at least one planar radiating element of the radiating structure are both arranged in a same or in two, substantially parallel planes such that the at least one planar conductive element is adjacent to or faces the at least one planar radiating element, respectively.

According to a further embodiment of the antenna system, the at least one planar conductive element of the at least one band-stop filter structure is shaped such that it covers the width of the at least one planar radiating element of the radiating structure.

According to yet another embodiment of the antenna system, the at least one planar conductive element of the at least one band-stop filter structure is dimensions such that it has a same width of the at least one planar radiating element of the radiating structure.

According to an even further embodiment of the antenna system, the at least one planar conductive element of the at least one band-stop filter structure and the at least one planar radiating element of the radiating structure are both provided on two opposing surfaces of a dielectric substrate.

According to another embodiment of the antenna system, the at least one planar conductive element of the at least one band-stop filter structure and the at least one planar radiating element of the radiating structure are both provided on the same surface of a dielectric substrate.

According to a further embodiment of the antenna system, the radiating structure of the first antenna element comprises a plurality of the planar radiating elements, each of which has an electrical length of less than or equal to three/eighth of the wavelength of the frequency in the second frequency band, and the first antenna element comprises a plurality of the band-stop filter structures, each of which includes the at least one planar conductive element arranged in form of a meander pattern, and electrically connected to a different one of the plurality of the planar radiating elements.

According to a further embodiment, an antenna system is proposed comprising: a first antenna element adapted to a first frequency band; a second antenna element adapted to a second frequency band which is different from the first frequency band. The first antenna element includes: a least one radiating structure comprising at least one planar radiating element, where the radiating structure is configured to radiate at a frequency in the first frequency band: The first antenna element further includes: at least one sleeve structure comprising at least two planar conductive elements, where the at least one sleeve structure is configured to attenuate a current flow at a frequency in the second frequency band.

The at least two planar conductive elements are, at one end, electrically connected to the at least one planar radiating element. Further, the at least two planar conductive elements extend in a direction substantially in parallel to a direction of the at least one planar radiating element; and the at least two planar conductive elements have an electrical length which corresponds to substantially quarter of a wavelength of the frequency in the second frequency band.

According to an embodiment of the antenna system, the second antenna element is arranged within the near-field of the first antenna element.

According to another embodiment of the antenna system, the at least two planar conductive elements of the at least one sleeve structure and the at least one planar radiating element of the at least one radiating structure are both arranged in a same plane such that the at least two planar conductive element are adjacent to the at least one planar radiating element, respectively.

According to a further embodiment of the antenna system, each of the at least two planar conductive elements of the at least one sleeve structure is arranged equidistantly to the at least one planar radiating element of the at least one radiating structure.

According to yet another embodiment of the antenna system, at least two slits are provided between each of the at least two planar conductive elements of the at least one sleeve structure and the at least one planar radiating element of the at least one radiating structure, where each of the at least two slits extends laterally from the tip of the at least one planar radiating element of the at least one radiating structure to the electrical connection between the respective one of the at least two planar conductive elements and the at least one planar radiating element.

According to an even further embodiment of the antenna system, the first planar antenna element includes: a plurality of interconnected radiating structures each of which is configured to radiate at a different frequency in the first frequency band, a plurality sleeve structures, each of which is configured to attenuate a current flow at a same frequency in the second frequency band, where each of the plurality of sleeve structures includes at least two planar conductive elements which are electrically connected to the at least one planar radiating element of a different of the plurality of radiating structures.

According to another embodiment of the antenna system, the first planar antenna element is a multi-band planar inverted-F antenna element.

According to a further embodiment of the antenna system, the second antenna element is a corner-truncated rectangular patch antenna element.

Further, an antenna module is suggested for use on a vehicle rooftop, comprising: an antenna system according to one of previous embodiments, wherein the vehicle rooftop provides for a ground plane to the first planar antenna element and the second antenna element.

The accompanying drawings are incorporated into the specification and form a part of the specification to illustrate several embodiments of the present invention. These drawings, together with a description, serve to explain the principles of the invention.

The drawings are merely for the purpose of illustrating the preferred and alternative examples of how the invention can be made and used, and are not to be construed as limiting the invention to only the illustrated and described embodiments.

Furthermore, several aspects of the embodiments may form - individually or in different combinations - solutions according to the present invention. Further features and advantages will become apparent from the following more particular description of the various embodiments of the invention as illustrated in the accompanying drawings, in which like references refer to like elements, and wherein:

- Figs. 1a and 1b** show schematically an antenna system according to a first embodiment of the invention and a simulated radiating pattern thereof;
- Figs. 2a and 2b** show a sectional view of the first antenna element of the first embodiment and results of a two-port scattering parameter (or s-parameter) simulation thereof;
- Figs. 3a and 3b** show a sectional view of an antenna system according to the second embodiment, and a sectional view of another antenna system according to the third embodiment of the invention;
- Figs. 4a and 4b** show a sectional view of the first antenna element of the second embodiment and results of a two-port scattering parameter (or s-parameter) simulation;
- Figs. 5a and 5b** show a sectional view of the first antenna element of the fourth embodiment and results of a two-port scattering parameter (or s-parameter) simulation;
- Figs. 6a and 6b** show schematically an antenna system according to a fifth embodiment of the invention together with a front view of the first antenna element comprised in the antenna system;
- Figs. 7a and 7b** show schematically an antenna system according to a sixth embodiment of the invention together with a front view of the first antenna element comprised in the antenna system; and
- Figs. 7c, 7d, and 7e** illustrate simulation results of the antenna system according to the sixth embodiment.

Referring now to Figs. 1a and 1b, an exemplary schematic diagram of the antenna system 100 according to a first embodiment of the invention and a simulated radiating pattern are shown. Particularly, the simulated radiating pattern in Fig. 1b illustrates the advantageous effect, namely of a reduced interference in-between the antenna elements of the antenna system 100

The antenna system 100 comprises a first antenna element 110 and the second antenna element 120 which are both arranged within the near-field to each other. Accordingly, the radiation pattern of the second antenna element 120 is exposed to interference effects from the first antenna element 110 and vice-versa.

In the context of the invention, the term near-field has to be understood as the region around each of the first and second antenna element 110 and 120 where their radiating pattern is dominated by interference effects from the respective other of the first and second antenna element 110 and 120. For example, in case the first and second antenna elements 110 and 120 are shorter than half of the wavelength λ they are adapted to emit, the near-field is defined as the region with a radius r , where $r < \lambda$.

The first antenna element 110 is adapted to transmit/receive electromagnetic waves of a first frequency band. In other words, the first antenna element 110 is adapted to the first frequency band. For exemplary purposes, the first antenna element 110 is shown as a monopole antenna. However, the first antenna element 110 shall not be restricted in this respect. Moreover, the first antenna element 110 may be, for instance, a dipole antenna, a planar inverted-F, PIFA, antenna, or a multi-band antenna.

The second antenna element 120 is adapted to transmit/receive electromagnetic waves of a second frequency band. In other words, the second antenna element 120 is adapted to the second frequency band. For exemplary purposes, also the second antenna element 120 is shown as a planar antenna element, namely as a corner-truncated patch antenna. However, the second antenna element 120 shall also not be restricted in this respect.

Particularly, the first frequency band, to which the first antenna element 110 is adapted, and the second frequency band, to which the second antenna element 120 is adapted, are different from each other, namely where the first frequency band is lower than the second frequency band. In other words, the first frequency band includes frequencies which are smaller than that of the second frequency band.

This includes cases where the first and the second frequency band have no overlap in frequency with each other. Furthermore, if one or both antenna elements 110 and 120 is/are multi-band antenna(s), the first frequency band may also encompass the second frequency band without overlap with same second frequency band(s).

The first antenna element 110 comprises at least one radiating structure 112 configured to radiate at a frequency in the first frequency band. For exemplary purposes, the first antenna element 110 is shown to comprise a single radiating structure 112. However, the first antenna element 110 shall not be restricted in this respect. Moreover, in case the first antenna element 110 is a multi-band antenna, same first antenna element 110 comprises a plurality of radiating structures each of which radiates at a different frequency in the first frequency band.

Further, in the first antenna element 110, the at least one radiating structure 112 comprises at least one planar radiating element 114. In other words, the at least one radiating structure 112 is formed of segments of at least one or plural planar radiating elements 114. For exemplary purposes, the single radiating structure 112 is shown to comprise five planar radiating elements 114. However, the radiating structure 112 shall not be restricted in this respect.

In an exemplary configuration of the antenna system 100, the five planar radiating elements 114 of the single radiating structure 112 are arranged on two parallel planes in an interleaved manner, such that the first, the third and the fifth radiating element 114 is provided on one plane of the two parallel planes and the second and the fourth radiating element 114 is provided on the other of the two parallel planes.

This single radiating structure 112 can be manufactured by folding the radiating structure 112 so as to form the different planar radiating elements 114. Alternatively, the radiating structure 112 may be realized by printing/etching consecutive planar radiating elements 114 on opposite surfaces of a dielectric substrate. In the latter case, the consecutive planar radiating elements 114 can be electrically connected by means of a through connection (e.g. via) in-between the opposite surface of the dielectric substrate.

These examples detail alternatives to the realization of the radiating structures 112 where, the radiating structure 112, comprising at least one or plural planar radiating elements 114, is as such not planar but is arranged on two parallel planes.

The first antenna element 110 further comprises at least one band-stop filter structure 116 configured to attenuate a current flow at a frequency in the second frequency band within the first antenna element 110. In other words, the at least one band-stop filter structure 116 suppresses current from flowing within the at least one radiating structure 114 which has a frequency in the second frequency band.

For this purpose, the at least one band-stop filter structure 116 comprises at least one planar conductive element 118 which is electrically connected at one end (which is the case for antenna system 100) or at both ends (which is the case for the antenna system 200, and 300

described below) to the at least one planar radiating element 114 of the at least one radiating structure 112.

For exemplary purposes, each of the at least one band-stop filter structures 116 is shown to comprise one planar conductive element 118. However, the at least one band-stop filter structure 116 shall not be restricted in this respect.

Moreover, in case each of the at least one band-stop filter structure comprises, for instance, two planar conductive elements, each of these two planar conductive elements is electrically connected at one end to the same of the at least one planar radiating element 114 at different portions thereof.

Further, the at least one planar conductive element 118 of the at least one band-stop filter structure 116 is arranged in form of a meander pattern. In the context of the invention, the at least one planar conductive element 118 is said to be arranged in form of a meander pattern provided it has consecutive loops of conductive segments pointing in opposite traverse directions.

In this respect, the meander pattern of the at least one planar conductive element 118 allows for an excessive electrical length compared to the dimension (i.e. length and width) of the area in which it extends. Exemplarily, the at least one planar conductive element 118 of the antenna system 100 comprises three consecutive loops of conductive segments pointing in opposite traverse directions.

More particularly, in the antenna system 100 where the at least one planar conductive element 118 is electrically connected at one end to the at least one planar radiating element 114 of the radiating structure 112, the at least one planar conductive element 118 has a predetermined electrical length, namely the at least one planar conductive element 118 has an electrical length which corresponds to a quarter of a wavelength ($\lambda/4$) of the frequency in the second frequency band.

Even further, the at least one planar conductive element 118 of the at least one band-stop filter structure 116 extends in a direction substantially in parallel to a direction of the at least one planar radiating element 114 of the at least one radiating structure 112. In other words, the at least one planar conductive element 118 extends in the same direction as the at least one planar radiating element 114.

Thereby, the at least one planar conductive element 118 and the at least one radiating element 114 are both exposed to a same radiating pattern of the second antenna element 120 inducing a current of a same magnitude and directivity therein.

In an exemplary configuration of the antenna system 100, the at least one planar conductive element 118 of the at least one band-stop filter structure 116 and the at least one planar

radiating element 114 of the at least one radiating structure 112 are both arranged facing each other in two, parallel planes. This arrangement of the at least one planar conductive element 118 and least one planar radiating element 114 advantageously increases the coupling there-between.

Particularly, the coupling between the at least one planar conductive element 118 and at least one planar radiating element 114 enhances the filtering effect of the at least one band-stop filter structure 116 in which the at least one planar conductive element 118 is comprised.

In another exemplary configuration of the antenna system 100, the at least one planar conductive element 118 of the at least one band-stop filter structure 116 is shaped such that it covers the width of the at least one planar radiating element 114 of the at least one radiating structure 112. Thereby, the overlap between the at least one planar conductive element 118 and the at least one planar radiating element 114 is increased, further enhancing the coupling there-between.

In a further exemplary configuration of the antenna system 100, the at least one planar conductive element 118 of the at least one band-stop filter structure 116 and the at least one planar radiating element 114 of the at least one radiating structure 112 are both provided on two opposing surfaces of a dielectric substrate where a suitably small relative permittivity ϵ_r of the dielectric substrate further enhances the coupling there-between.

In yet another exemplary configuration of the antenna system 100, the at least one radiating structure 112 of the first antenna element 110 comprises a plurality of electrically interconnected planar radiating elements 114. Each of the electrically interconnected planar radiating elements 114 has an electrical length of less than or equal to three-eighth of the wavelength of the frequency in the second frequency band.

Further to this exemplary configuration of the antenna system 100, the first antenna element 112 comprises a plurality of band-stop filter structures 116. Each of the plurality of band-stop filter structures 116 includes the at least one planar conductive element 118 in form of a meander pattern. Further, each of the at least one planar conductive element 118 is electrically connected to a different one of the plurality of planar radiating elements 114.

In the example shown in Fig. 1a, one radiating structure 112 of the first antenna element 100 comprises five electrically interconnected planar radiating elements 114 and two band-stop filter structures 118 each of which includes one planar conductive element 118. The one planar conductive element 118 of each of the two band-stop filter structures 118 is electrically connected to every other of the five electrically interconnected planar radiating elements 114.

In summary, due to this configuration of the at least one planar conductive element 118 and of the at least one planar radiating element 114 to which it is electrically connected, the at least one band-stop filter structure 116 act as a band-stop filter for an induced current at the frequency in the second frequency band, thereby attenuating a current flow at a frequency in the second frequency band.

More particularly, a current which is induced in the at least one planar conductive element 118 is reflected at the not electrically connected end of the at least one planar conductive element and hence is exposed to an electrical length of twice a quarter of the wavelength ($2 \cdot \lambda/4 = \lambda/2$) of the frequency of the second frequency band compared to a current induced in the at least one planar radiating element 114. With a phase offset of half of the wavelength ($\lambda/2$) of the frequency of the second frequency band both currents destructively interfere (i.e. cancel each other out).

In other words, the structure, dimension and arrangement of the at least one planar conductive element 118 provide for the band-stop filter structure 116 which attenuates a current flow at a frequency in the second frequency band. Accordingly, even if the second antenna element 120 induces a current in the first antenna element 110, the at least one planar conductive element 118 of the band-stop filter structure 116 suppresses the induced current at the frequency of the second frequency band.

Consequently, the first antenna element 110 is configured to reduce interference effects at the frequency of the second frequency band, namely the frequency to which the second antenna element 120 is adapted. The first antenna element 110 can be said to be transparent to the second antenna element 120. Accordingly, the radiating pattern of the second antenna element 120 is exposed to a reduced amount of interference from the first antenna element 110, even if the first antenna element 110 is arranged within the near-field thereof.

A same effect of a reduction in interference to the radiating pattern of the second antenna element 120 can also be appreciated from the simulation results shown in Fig. 1b. There, the radiating pattern of the second antenna element 120 is nearly concentric and only marginal deformations are with respect to the x-axis, i.e. the direction in which the first antenna element 110 was arranged for simulation purposes.

Referring now to Figs. 2a and 2b, a sectional view of the first antenna element 110 of the first embodiment and results of a two-port scattering parameter (or s-parameter) simulation are shown. For the simulation, the left and the right section of the first antenna element 110 are the ports to the two-port s-parameter simulation.

As can be appreciated from the simulation results, the forward gain and the reverse gain coefficients S_{12} and S_{21} show a high attenuation at the frequency of 2.3014 GHz corresponding to the frequency of the second frequency range for which each of the at least one band-stop filter structure is configured. The reflection coefficients S_{11} and S_{22} show an inverse behavior.

Referring now to Figs. 3a and 3b, a sectional view of an antenna system 200 and 300 according to the second and third embodiment of the invention are shown. Each of the antenna system 200 and 300 comprises a first antenna element 210, 310 and a second antenna element 120 which has been omitted from the respective sectional view. The antenna systems 200 and 300 are based on the antenna system 100 of Fig. 1 where corresponding parts are given corresponding reference numerals and terms. The description of corresponding parts has been omitted for reasons of conciseness.

The antenna systems 200 and 300 of Figs. 3a and 3b differ from the antenna system 100 in that the number of planar radiating elements 114 comprised in the radiating structure 112 of the first antenna element 210 and 310 is two, and four, respectively; and the number of band-stop filter structure(s) 216 of the first antenna element 210, and 310 is one, and two, respectively.

A more important difference is that the antenna systems 200 and 300 include at least one band-stop filter structure 216 comprising at least one planar conductive element 218 which has another shape and structure as shall be discussed in the following in more detail.

Each of the antenna systems 200 and 300 comprises a first antenna element 210, and 310, and a not-shown second antenna element 120. The first antenna element 210, 220 is adapted to a first frequency band; the second antenna element 120 is adapted to a second frequency band which is different from the first frequency band, namely where the first frequency band is lower than the second frequency band. In other words, the first frequency band includes frequencies which are smaller than that of the second frequency band.

Each of the first antenna elements 210, 310 includes at least one radiating structure 112, and at least one band-stop filter structure 216. For a more detailed description of the at least one radiating structure 112, reference is made to the above discussion thereof.

Further, the following description of the at least one band-stop filter structure 216 equally applies to that comprised in the first antenna element 210 of the antenna system 200 of the second embodiment and to that comprised in the first antenna element 310 of the antenna system 300 of the third embodiment. In this respect, the following description is given abstractly and equally applies to both embodiments.

The least one band-stop filter structure 216 is configured to attenuate a current flow at a frequency in the second frequency band within the first antenna element 210. In other words, the at least one band-stop filter structure 216 suppresses current from flowing within the at least one radiating structure 114 which has a frequency in the second frequency band.

For this purpose, the at least one band-stop filter structure 216 comprises at least one planar conductive element 218 which is electrically connected at both ends at both ends to the at least one planar radiating element 114 of the at least one radiating structure 112 such that it forms a parallel circuit therewith.

For exemplary purposes, each of the at least one band-stop filter structures 216 is shown to comprise one planar conductive element 218. However, the at least one band-stop filter structure 216 shall not be restricted in this respect.

Moreover, in case each of the at least one band-stop filter structure comprises, for instance, two planar conductive elements, each of these two planar conductive elements is electrically connected at both ends to the same portions of the at least one planar radiating element 114 such that both form a parallel circuit therewith.

Further, the at least one planar conductive element 218 of the at least one band-stop filter structure 216 is arranged in form of a meander pattern. In this respect, the meander pattern of the at least one planar conductive element 218 allows for an excessive electrical length compared to the dimension (i.e. length and width) of the area in which it extends. Exemplarily, the at least one planar conductive element 218 of the antenna system 100 comprises three consecutive loops of conductive segments pointing in opposite traverse directions.

More particularly, in the antenna systems 200 and 300 where the at least one planar conductive element 218 is electrically connected at both ends to the at least one planar radiating element 114 of the radiating structure 112 in order to form a parallel circuit therewith, the at least one planar conductive element 218 has an electrical length which exceeds the electrical length of the at least one planar radiating element 114 to which it is connected in parallel by a half of a wavelength ($\lambda/2$) of the frequency in the second frequency band.

Even further, the at least one planar conductive element 218 of the at least one band-stop filter structure 216 extends in a direction substantially in parallel to a direction of the at least one planar radiating element 114 of the at least one radiating structure 112. In other words, the conductive element 218 extends in the same direction as the at least one planar radiating element 114.

Thereby, the at least one planar conductive element 218 and the at least one radiating element 114 are both exposed to a same radiating pattern of the second antenna element 120 inducing a current of a same magnitude and directivity therein.

In an exemplary configuration of the antenna systems 200 and 300, the at least one planar conductive element 218 of the at least one band-stop filter structure 216 and the at least one planar radiating element 114 of the at least one radiating structure 112 are both arranged facing each other in two, parallel planes. This arrangement of the at least one planar conductive element 218 and least one planar radiating element 214 advantageously increases the coupling there-between.

Particularly, the coupling between the at least one planar conductive element 218 and least one planar radiating element 114 enhances the filtering effect of the at least one band-stop filter structure 216 in which the at least one planar conductive element 218 is comprised.

In another exemplary configuration of the antenna systems 200 and 300, the at least one planar conductive element 218 of the at least one band-stop filter structure 216 is shaped such that it covers the width of the at least one planar radiating element 114 of the at least one radiating structure 112. Thereby, the overlap between the at least one planar conductive element 218 and the at least one planar radiating element 214 is increased, further enhancing the coupling there-between.

In summary, also due to this configuration of the at least one planar conductive element 218 and of the at least one planar radiating element 114 to which it is connected in parallel, the at least one band-stop filter structure 216 act as a band-stop filter for an induced current at the frequency in the second frequency band, thereby attenuating a current flow at a frequency in the second frequency band.

More particularly, a current which is induced in the at least one planar conductive element 218 is exposed to an excessive electrical length of half of the wavelength ($\lambda/2$) of the frequency of the second frequency band compared to a current induced in the at least one planar radiating element 114. With a phase offset of half of the wavelength ($\lambda/2$) of the frequency of the second frequency band both currents destructively interfere (i.e. cancel each other out).

In other words, the structure, dimension and arrangement of the at least one planar conductive element 118 provide for the band-stop filter structure 116 which attenuates a current flow at a frequency in the second frequency band. Accordingly, even if the second antenna element 120 induces a current in the first antenna element 210 or 310, the at least one planar conductive element 118 of the band-stop filter structure 116 suppresses the induced current at the frequency of the second frequency band.

Consequently, also in this case the first antenna elements 210 and 310 are configured to reduce interference effects at the frequency of the second frequency band, namely the frequency to which the second antenna element 120 is adapted. Accordingly, the radiating pattern of the second antenna element 120 is exposed to a reduced amount of interference from either one of the first antenna elements 210 and 310, even if the first antenna element 210 or 310 is arranged within the near-field thereof.

Referring now to Figs. 4a and 4b, a sectional view of the first antenna element 210 of the second embodiment (which equally applies to the first element 310 of the third embodiment) and results of a two-port scattering parameter (or s-parameter) simulation are shown. For the simulation, the left and the right section of the first antenna element 210 are the ports to the two-port s-parameter simulation.

As can be appreciated from the simulation results, the forward gain and the reverse gain coefficients S_{12} and S_{21} show a high attenuation at the frequency of approximately 2.3 GHz corresponding to the frequency of the second frequency range for which each of the at least one band-stop filter structure is configured. The reflection coefficients S_{11} and S_{22} show an inverse behavior.

Referring now to Figs. 5a and 5b, a sectional view of the antenna system of the fourth embodiment and results of a two-port scattering parameter (or s-parameter) simulation are shown. For the simulation, the left and the right section of the first antenna element 410 are the ports to the two-port s-parameter simulation.

The fourth embodiment apply the same design principles already discussed in connection with the previous embodiments such that the description of an according antenna system comprising a first antenna element 410 of which the sectional view is illustrated and a second antenna element has been omitted for reasons of conciseness.

It is particular to this embodiment the at least one planar conductive element 218 of the at least one band-stop filter structure 216 and the at least one planar radiating element 414 of the radiating structure 412 are both arranged in a same plane such that the at least one planar conductive element 218 is adjacent to the at least one planar radiating element 414 to which it is electrically connected in parallel.

Even in this less complex structure of the first antenna element 410, due to configuration of the at least one planar conductive element 218 and of the at least one planar radiating element 414 to which it is connected in parallel, the at least one band-stop filter structure 216 act as a band-stop filter for an induced current at the frequency in the second frequency band, thereby attenuating a current flow at a frequency in the second frequency band.

This can also be appreciated from the simulation results where the forward gain coefficient S12 show a high attenuation at the frequency of approximately 2.3 GHz corresponding to the frequency of the second frequency range for which each of the at least one band-stop filter structure is configured. The reflection coefficients S11 show an inverse behavior.

Referring now to Figs. 6a and 6b, an exemplary schematic diagram of an antenna system 500 according to a fifth embodiment of the invention is shown together with a front view of the first antenna element comprised in the antenna system 500.

The antenna system 500 comprises a first antenna element 510 and the second antenna element 120 which are both arranged within the near-field to each other. Accordingly, the radiation pattern of the second antenna element 120 is exposed to interference effects from the first antenna element 510 and vice-versa.

In the context of the invention, the term near-field has to be understood as the region around each of the first and second antenna element 510 and 120 where their radiating pattern is dominated by interference effects from the respective other of the first and second antenna element 510 and 120. For example, in case the first and second antenna elements 510 and 120 are shorter than half of the wavelength λ they are adapted to emit, the near-field is defined as the region with a radius r , where $r < \lambda$.

The first antenna element 510 is adapted to transmit/receive electromagnetic waves of a first frequency band. In other words, the first antenna element 510 is adapted to the first frequency band. For exemplary purposes, the first antenna element 510 is shown as a multi-band planar inverted-F, PIFA, antenna. However, the first antenna element 510 shall not be restricted in this respect. Moreover, the first antenna element 510 includes a feeding point which is indicated as "P2E".

The second antenna element 120 is adapted to transmit/receive electromagnetic waves of a second frequency band. In other words, the second antenna element 120 is adapted to the second frequency band. For exemplary purposes, also the second antenna element 120 is shown as a planar antenna element, namely as a corner-truncated patch antenna. However, the second antenna element 120 shall also not be restricted in this respect. Moreover, the second antenna element 120 includes a feeding point which is indicated as "P1E".

Particularly, the first frequency band, to which the first antenna element 510 is adapted, and the second frequency band, to which the second antenna element 120 is adapted, are different from each other, namely where the first frequency band is lower than the second frequency band. In other words, the first frequency band includes frequencies which are smaller than that of the second frequency band..

The first antenna element 510 comprises at least one radiating structure 512-1, 512-2 configured to radiate at a frequency in the first frequency band. For exemplary purposes, the first antenna element 510 is shown to comprise three interconnected radiating structure 512-1, 512-2. Particularly, the shown first antenna element 510 includes:

- a first antenna structure 512-1 which includes a branch (a) extending along the ground plane of the first antenna element 510 and another branch (b) pointing away from the ground plane,
- a second antenna structure 512-2 which includes branch (c) extending away from the ground plane and branches (d) and (e) forming a semi-circle pointing towards the ground plane, and
- a third antenna structure which includes the two above antenna structures 512-1, 512-2 with the branches (a), (b), (c), (d) and (e).

Each of the three shown antenna structures 512-1, 512-2 of the first antenna element 510 is configured to radiate at a different frequency in the first frequency band. However, the first antenna element 510 shall not be restricted in this respect.

Further, in the first antenna element 510, the at least one radiating structure 512-1, 512-2 comprises at least one planar radiating element 514. For exemplary purposes, the multi-band radiating structure 512-1, 512-2 is shown to comprise one planar radiating element 514. However, the radiating structure 512-1, 512-2 shall not be restricted in this respect.

The first antenna element 510 further comprises at least one sleeve structure 516 configured to attenuate a current flow at a frequency in the second frequency band within the first antenna element 510. In other words, the at least one sleeve structure 516 suppresses current from flowing within the at least one radiating structure 514 which has the frequency in the second frequency band to which the at least one sleeve structure 516 is configured. In general meanings, a sleeve structure 516 can be regarded as an open-short transmission resonator, which is one form of a band-stop filter.

For this purpose, the at least one sleeve structure 516 comprises at least two planar conductive elements 518-1, 518-2 which are electrically connected at one end to the at least one planar radiating element 514 of the at least one radiating structure 512-1, 512-2.

For exemplary purposes, the at least one sleeve structure 516 is shown to comprise two planar conductive elements 518-1, 518-2. However, the at least one band-stop filter structure 516 shall not be restricted in this respect. Moreover the at least one sleeve structure may also have four sleeve structures which are arranged in the front and back and to the left and right of the at least one radiating structure.

Further, each of the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 has an electrical length which correspond to substantially a quarter of a wavelength ($\lambda/4$) of the frequency in the second frequency band. In other words, each of the at least two planar conductive elements 518-1, 518-2 has an individual electrical length which deviates from a quarter of a wavelength ($\lambda/4$) of the frequency in the second frequency band, for instance, in the region of 0 – 5 %.

It has proven advantageous to individually configure the electrical length of the at least two planar conductive elements 518-1, 518-2 since their adjacent arrangement on both sides of the at least one planar radiating element 514 results in a highly-coupled resonant behavior. This highly-coupled resonant behavior may mistune the at least one sleeve structure 516.

Even further, the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 extend in a direction substantially in parallel to a direction of the at least one planar radiating element 514 of the at least one radiating structure 512-1, 512-2. In other words, the at least two planar conductive elements 518-1, 518-2 extend in the same direction as the at least one planar radiating element 514.

For exemplary purposes, the at least one planar radiating element 514 is shown to have an inverted-L shape and hence extends in two directions, namely in a horizontal and a lateral direction with respect to a ground plane. The at least two planar conductive elements 518-1, 518-2 also extend in two directions, namely where both directions are substantially in parallel to the respective of the horizontal and lateral direction in which the at least one planar radiating element 514 extends.

In an exemplary configuration of the antenna system 500, the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 and the at least one planar radiating element 514 of the at least one radiating structure 512-1, 512-2 are both arranged in a same plane. For exemplary purposes, the at least one planar radiating element 514 and the at least two planar conductive element 518-1, 518-2 are shown as being provided on a same surface of a dielectric substrate (for instance by printing/etching).

In further exemplary configuration of the antenna system 500, the at least one planar radiating element 514 and the at least two planar conductive element 518-1, 518-2 not only extend in directions which are substantially in parallel to each other but also, each of the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 is arranged equidistantly to the at least one planar radiating element 514 of the at least one radiating structure 512-1, 512-2.

Due to this equidistant arrangement, both the at least one planar radiating element 514 and the at least two planar conductive elements 518-1, 518-2 have opposing edges, namely on

the inside of the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 and on the outside of the at least one radiating element 514 of the at least one radiating structure 512-1, 512-2. Hence, electric current which flows on both the at least one planar radiating element 514 and the at least two planar conductive elements 518-1, 518-2 counteract with each other.

In another exemplary configuration of the antenna system 500, between each of the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 and the at least one planar radiating element 514 of the at least one radiating structure 512-1, 512-2, a respective slit is formed. In other words, the at least two slit are defined by the area which is surrounded (or enclosed) by each of the at least two planar conductive elements 518-1, 518-2 and the at least one planar radiating element 514, respectively.

Each of these at least two slits extends laterally from the tip of the at least one planar radiating element of the at least one radiating structure 514 to the electrical connection between the respective one of the at least two planar conductive elements 518-1, 518-2 and the at least one planar radiating element 514. Accordingly, at the tip each of the at least two planar conductive elements 518-1, 518-2 and the at least one radiating element 514 are flush with each other.

In summary, due to this configuration of the at least two planar conductive elements 518-1, 518-2 and of the at least one planar radiating element 514 to which both are electrically connected, the at least one sleeve structure 516 suppresses current from flowing at the frequency in the second frequency band, thereby attenuating – in the far-field – the radiation power in the second frequency band.

Particularly, the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 act as a transmission line which is short circuited at the end. By applying Gauss' Law any current which flows on the inside of the at least two planar conductive elements 518-1, 518-2 has to be opposite of another current which flows on the outside of the at least one planar radiating element 514.

The terms inside and outside refer to the opposing edges of the at least two planar conductive elements 518-1, 518-2 and the at least one planar radiating element 514, respectively. Hence, the current which flows on the outside of the at least one planar radiating element 514 also sees a short-circuited transmission line.

Since the at least two planar conductive elements 518-1, 518-2 of the at least one sleeve structure 516 have an electrical length which correspond to substantially a quarter of a wavelength ($\lambda/4$) of the frequency in the second frequency band, the impedance at the

frequency which the current sees that flows on the outside of the at least one planar radiating element 514 is infinity.

Hence, this configuration of the at least two planar conductive elements 518-1, 518-2 and of the at least one planar radiating element 514 to which both are electrically connected, the at least one sleeve structure 516 suppresses current from flowing at the frequency in the second frequency band.

Referring now to Figs. 7a and 7b, an exemplary schematic diagram of an antenna system 600 according to a sixth embodiment of the invention is shown together with a front view of the first antenna element comprised in the antenna system 600. The antenna system 600 is based on the antenna system 500 of Figs. 6a and 6b, where corresponding parts are given corresponding reference numerals and terms. The description of corresponding parts has been omitted for reasons of conciseness.

The antenna system 600 of Figs. 7a and 7b differs from the antenna system 500 in that the first antenna element 610 comprises three interconnected radiating structures 612-1, 612-2 each of which includes at least one sleeve structure 616-1, 616-2.

Further, each of the at least one sleeve structure 616-1, 616-2 is configured to attenuate a same frequency in the second frequency band and includes two planar conductive elements 618-1, 618-2, 618-3, 618-4. Additionally, each of the at least one sleeve structure 616-1, 616-2 is electrically connected to one planar radiating element 614 of a different of the three radiating structures 612-1, 612-2.

In summary, due to this configuration of the at least two planar conductive elements 618-1, 618-2, 618-3, 618-4 and of the at least one planar radiating element 614 to which both are electrically connected, the at least one sleeve structure 516 suppresses current from flowing at the frequency in the second frequency band, thereby attenuating – in the far-field – the radiation power in the second frequency band.

This advantageous effect is illustrated in connection with Figs. 7c, 7d, and 7e showing simulation results of the interference effect on the second antenna element, a filtering effect by the first antenna element, and a decoupling effect between the first and the second antenna element of the antenna system 600 according to the sixth embodiment of the invention.

Particularly, the results for the antenna system 600 are provided in form of a two-port scattering parameter (or s-parameter) simulation where the two port are connected to the feeding line of the second antenna element 120 (denoted P1E in the Figs. 7a and 7b) and to the feeding line of the first antenna element 610 (denoted P2E), respectively.

As can be appreciated from the simulation results, the reflection coefficient S11 shows the reduced interference effect where the attenuation corresponds to the frequency of the second frequency range for which each of the at least one sleeve structure is configured, the reflection coefficient S22 showing the filtering effect by the first antenna, and reverse gain coefficient S21 show a decoupling effect at the frequency of approximately 2.3 GHz. The reflection coefficients S11 and S22 show an inverse behavior.

Finally, each of the above discussed antenna systems of the various embodiments can be included in an antenna module for use on a vehicle rooftop. For this purpose, the antenna module, in addition to the antenna system, comprises a housing for protecting the antenna system from outside influences, a base for arranging the antenna system thereon, an antenna matching circuit, and an electrical connection for transmitting/receiving electrical signals from the outside to/from the first antenna element and the second antenna elements of the antenna system. Further, the vehicle rooftop provides for a ground plane to the first planar antenna element and the second antenna element of the antenna system.

References:

Reference Numeral(s)	Description
100, 200, 300, 500, 600	Antenna system
110, 210, 310, 410, 510, 610	First antenna element
112, 412, 512-1, 512-2, 612-1, 612-2	Radiating structure
114, 414, 514, 614	Planar radiating element
116, 216, 516, 616-1, 616-2	Band-stop filter structure; Sleeve structure
118, 218, 518-1, 518-2, 618-1, 618-2, 618-3, 618-4	Planar conductive element
120	Second antenna element

Claims:

1. Antenna system (100) comprising:

a first antenna element (110) adapted to a first frequency band;

a second antenna element (120) adapted to a second frequency band which is different from the first frequency band; wherein

the first antenna element (110) includes:

- a radiating structure (112) comprising at least one planar radiating element (114), the radiating structure being configured to radiate at a frequency in the first frequency band, and
- at least one band-stop filter structure (116) comprising at least one planar conductive element (118), the at least one band-stop filter structure (116) being configured to attenuate a current flow at a frequency in the second frequency band;

wherein the at least one planar conductive element (118) is arranged in form of a meander pattern, and is, at one end, electrically connected to the at least one planar radiating element (114);

the at least one planar conductive element (118) extends in a direction substantially in parallel to a direction of the at least one planar radiating element (114); and

the at least one planar conductive element (118) has an electrical length which corresponds to substantially a quarter of a wavelength of the frequency in the second frequency band.

2. Antenna system (200) comprising:

a first antenna element (210) adapted to a first frequency band;

a second antenna element (120) adapted to a second frequency band which is different from the first frequency band; wherein

the first antenna element (210) includes:

- a radiating structure (112) comprising at least one planar radiating element (114), the radiating structure being configured to radiate at a frequency in the first frequency band, and
- at least one band-stop filter structure (216) comprising at least one planar conductive element (218), the at least one band-stop filter structure (216) being configured to attenuate a current flow at a frequency in the second frequency band;

wherein the at least one planar conductive element (218) is arranged in form of a meander pattern, and is, at both ends, electrically connected to the at least one planar radiating element (114) such that it forms a parallel circuit therewith, and

the at least one planar conductive element (218) extends in a direction substantially in parallel to a direction of the at least one planar radiating element (214); and

the at least one planar conductive element (218) has an electrical length which exceeds the electrical length of the at least one planar radiating element (114) by a half of a wavelength of the frequency in the second frequency band.

3. The antenna system (100, 200) according to claim 1 or 2, wherein the second antenna element (120) is arranged within the near-field of the first antenna element (110, 210).
4. The antenna system (100, 200) according to one of claims 1 - 3, wherein:

the at least one planar conductive element (118, 218) of the at least one band-stop filter structure (116, 216) and the at least one planar radiating element (114) of the radiating structure are both arranged in a same or in two, substantially parallel planes such that the at least one planar conductive element (118, 218) is adjacent to or faces the at least one planar radiating element (114), respectively.
5. The antenna system (100, 200) according to any of claims 1 - 4, wherein:

the at least one planar conductive element (118, 218) of the at least one band-stop filter structure (116, 216) is shaped such that it covers the width of the at least one planar radiating element (114) of the radiating structure, and/or

the at least one planar conductive element (118, 218) of the at least one band-stop filter structure (116, 216) has dimensions such that it has a same width of the at least one planar radiating element (114) of the radiating structure.
6. The antenna system (100, 200) according to any of claims 1 - 5, wherein:

the at least one planar conductive element (118, 218) of the at least one band-stop filter structure (116, 216) and the at least one planar radiating element (114) of the radiating structure are both provided on two opposing surfaces of a dielectric substrate, or

the at least one planar conductive element (118, 218) of the at least one band-stop filter structure (116, 216) and the at least one planar radiating element (114) of the radiating structure are both provided on the same surface of a dielectric substrate.

7. The antenna system (100, 200) according to one of claims 1 – 6, wherein:
- the radiating structure of the first antenna element (110, 210) comprises a plurality of the planar radiating elements (114), each of which has an electrical length of less than or equal to three/eighth of the wavelength of the frequency in the second frequency band,
 - the first antenna element (110, 210) comprises a plurality of the band-stop filter structures, each of which includes the at least one planar conductive element (118, 218) arranged in form of a meander pattern, and electrically connected to a different one of the plurality of the planar radiating elements.
8. Antenna system (500) comprising:
- a first antenna element (510) adapted to a first frequency band;
- a second antenna element (120) adapted to a second frequency band which is different from the first frequency band; wherein
- the first antenna element (500) includes:
- a least one radiating structure (512-1, 512-2) comprising at least one planar radiating element (514), the radiating structure being configured to radiate at a frequency in the first frequency band, and
 - at least one sleeve structure (516) comprising at least two planar conductive elements (518-1, 518-2), the at least one sleeve structure (516) being configured to attenuate a current flow at a frequency in the second frequency band;
- wherein the at least two planar conductive elements (518-1, 518-2) are, at one end, electrically connected to the at least one planar radiating element (514);
- the at least two planar conductive elements (518-1, 518-2) extend in a direction substantially in parallel to a direction of the at least one planar radiating element (514); and
- the at least two planar conductive elements (518-1, 518-2) have an electrical length which corresponds to substantially quarter of a wavelength of the frequency in the second frequency band.

9. The antenna system (500) according to claim 8, wherein the second antenna element (120) is arranged within the near-field of the first antenna element (510).
10. The antenna system (500) according to claim 8 or 9, wherein:
the at least two planar conductive elements (518-1, 518-2) of the at least one sleeve structure (516) and the at least one planar radiating element (514) of the at least one radiating structure (512-1, 512-2) are both arranged in a same plane such that the at least two planar conductive element (518-1, 518-2) are adjacent to the at least one planar radiating element (514), respectively.
11. The antenna system (500) according to claim 8 – 10, wherein:
each of the at least two planar conductive elements (518-1, 518-2) of the at least one sleeve structure (516) is arranged equidistantly to the at least one planar radiating element (514) of the at least one radiating structure.
12. The antenna system (500) according to claims 8 – 11, wherein:
at least two slits are provided between each of the at least two planar conductive elements (518-1, 518-2) of the at least one sleeve structure (516) and the at least one planar radiating element (514) of the at least one radiating structure,
where each of the at least two slits extends laterally from the tip of the at least one planar radiating element (514) of the at least one radiating structure (512-1, 512-2) to the electrical connection between the respective one of the at least two planar conductive elements (518-1, 518-2) and the at least one planar radiating element (514).
13. The antenna system (500) according to one of claims 8 – 12, wherein the first planar antenna element (514) includes:
- a plurality of interconnected radiating structures each of which is configured to radiate at a different frequency in the first frequency band,
 - a plurality sleeve structures, each of which is configured to attenuate a current flow at a same frequency in the second frequency band,
- where each of the plurality of sleeve structures includes at least two planar conductive elements (518-1, 518-2) which are electrically connected to the at least one planar radiating element (514) of a different of the plurality of radiating structures.
14. The antenna system (100, 200, 500) according to one of claims 1 – 13, wherein:
the first planar antenna element (114, 514) is a multi-band planar inverted-F antenna element and/or

the second antenna element (120) is a corner-truncated rectangular patch antenna element.

15. An antenna module for use on a vehicle rooftop, comprising:

an antenna system (100, 200, 500) according to one of claims 1 – 14, wherein the vehicle rooftop provides for a ground plane to the first planar antenna element (114, 514) and the second antenna element (120).

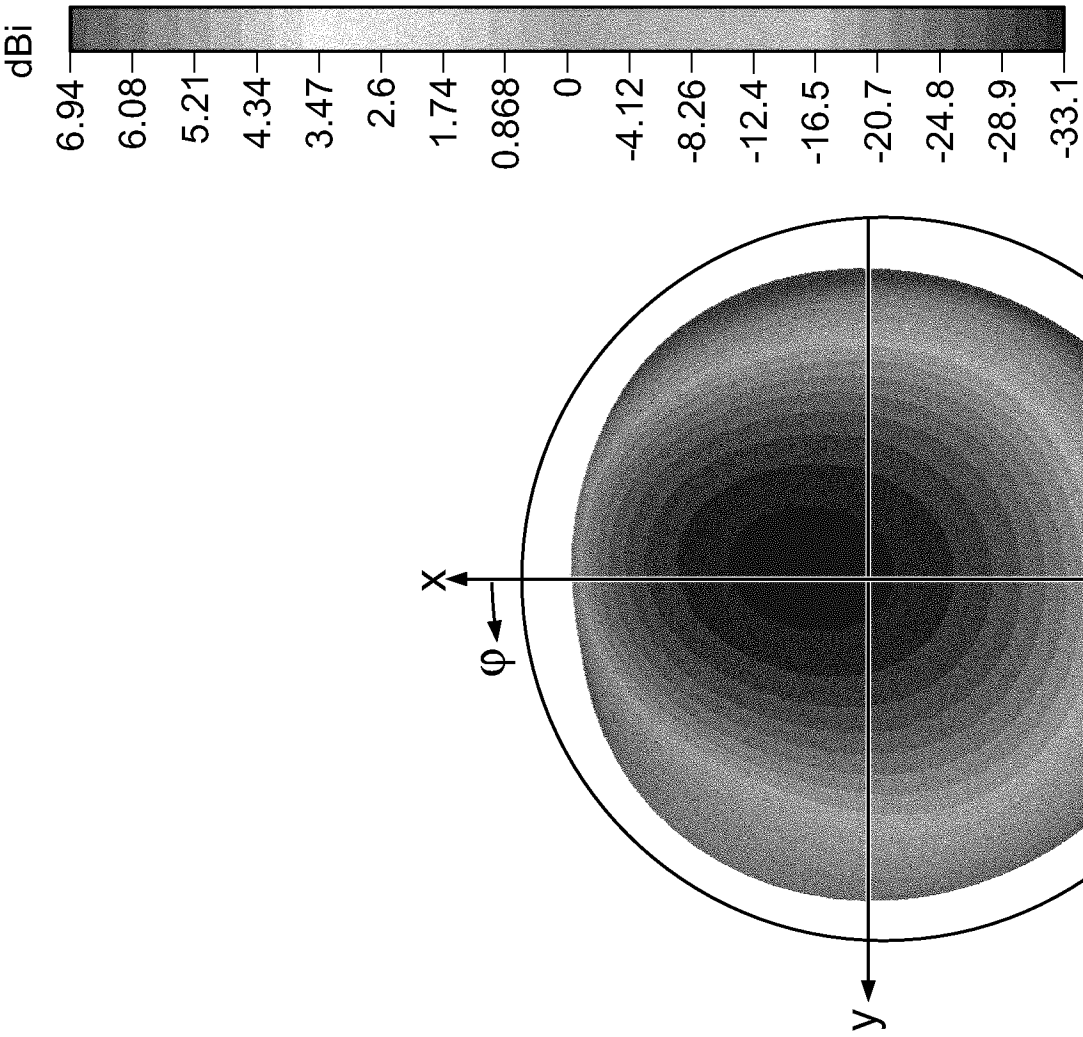


Fig. 1B

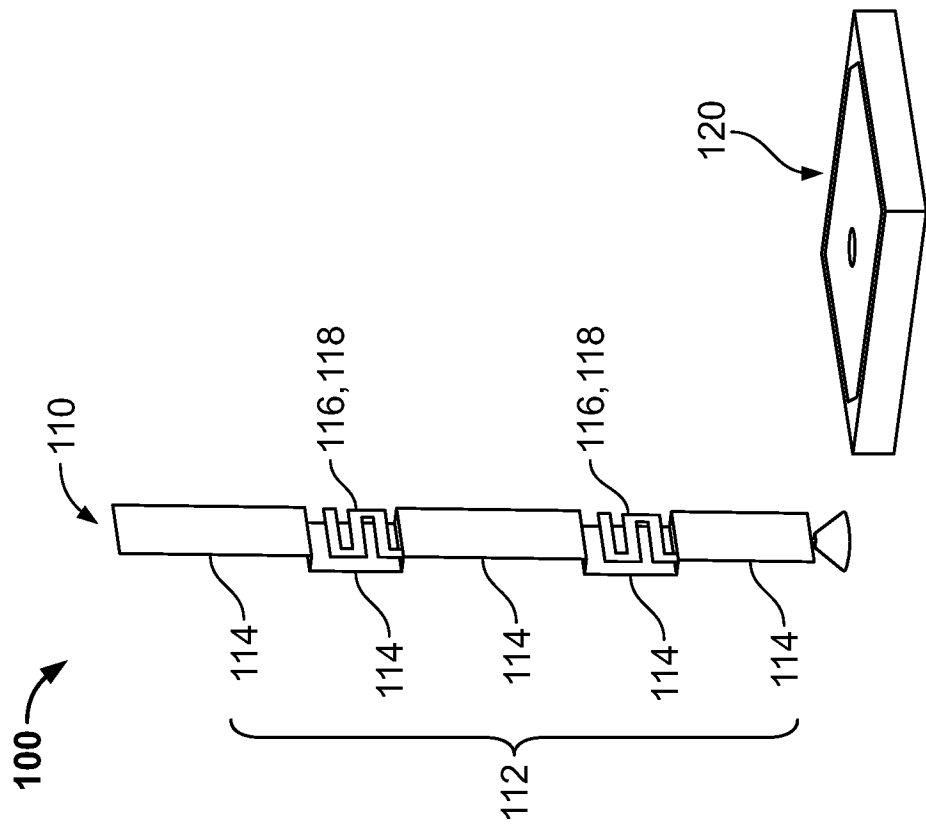
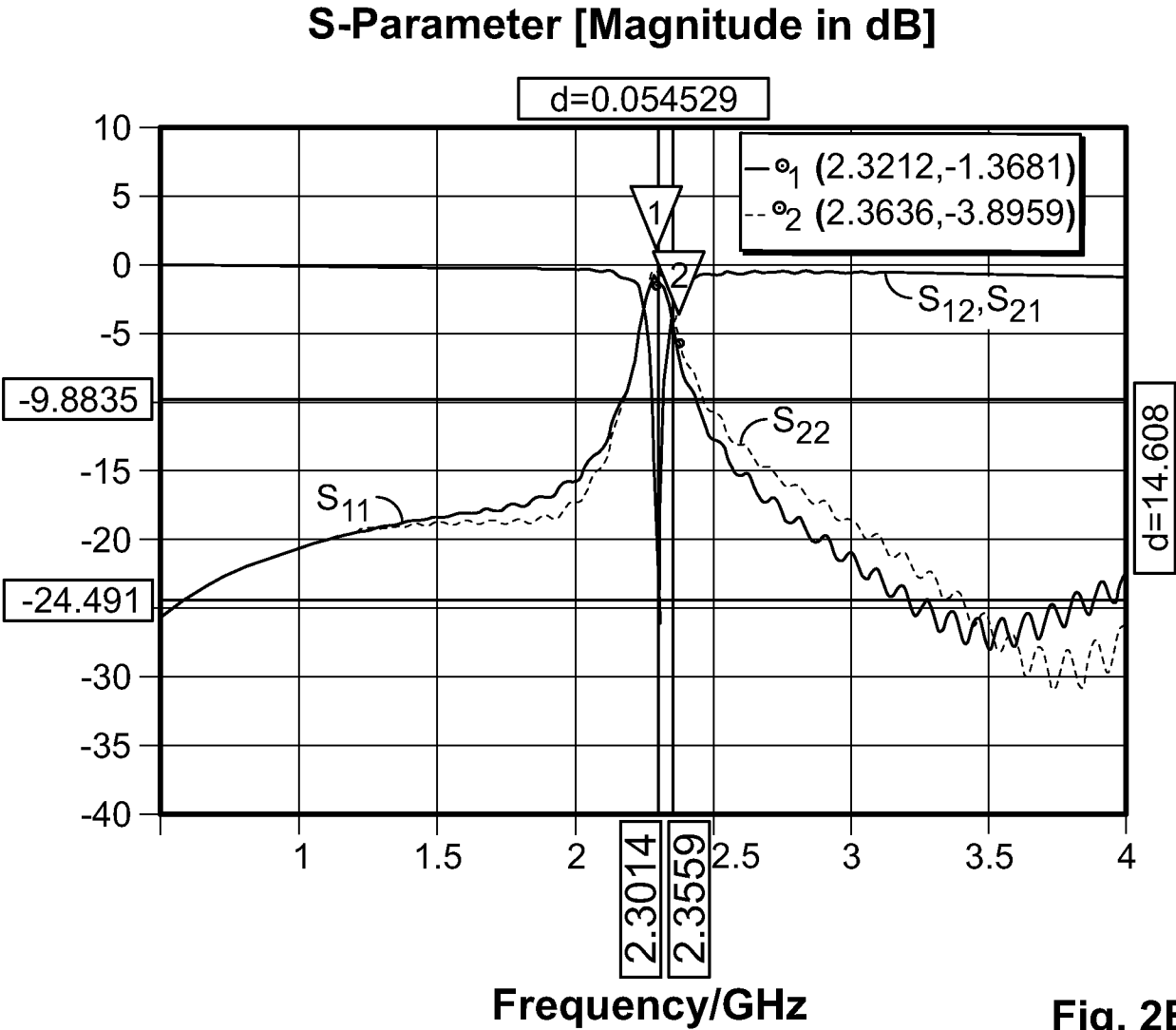
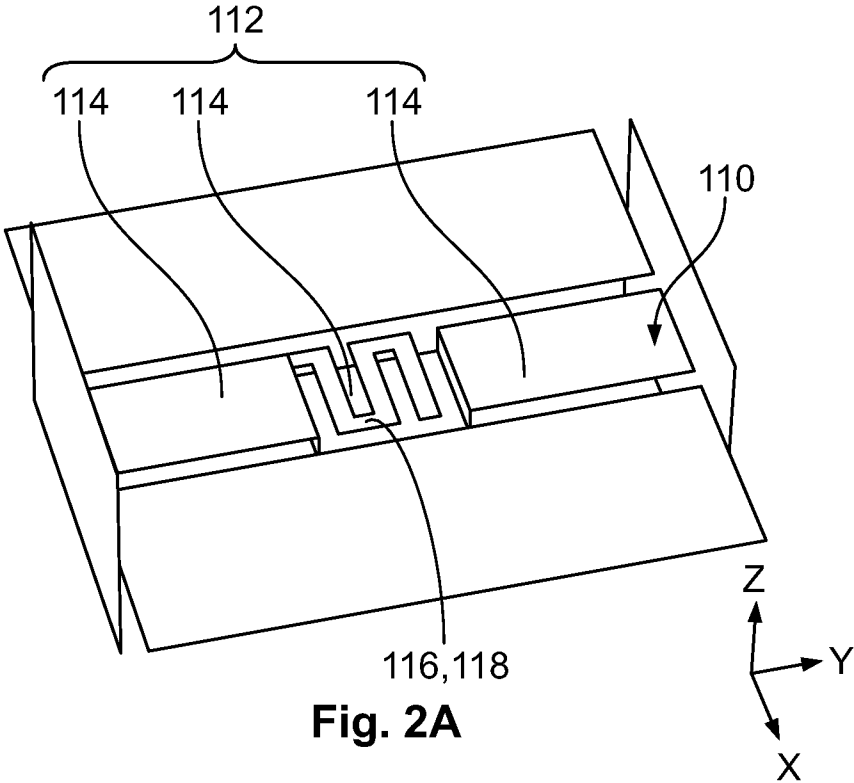


Fig. 1A



200

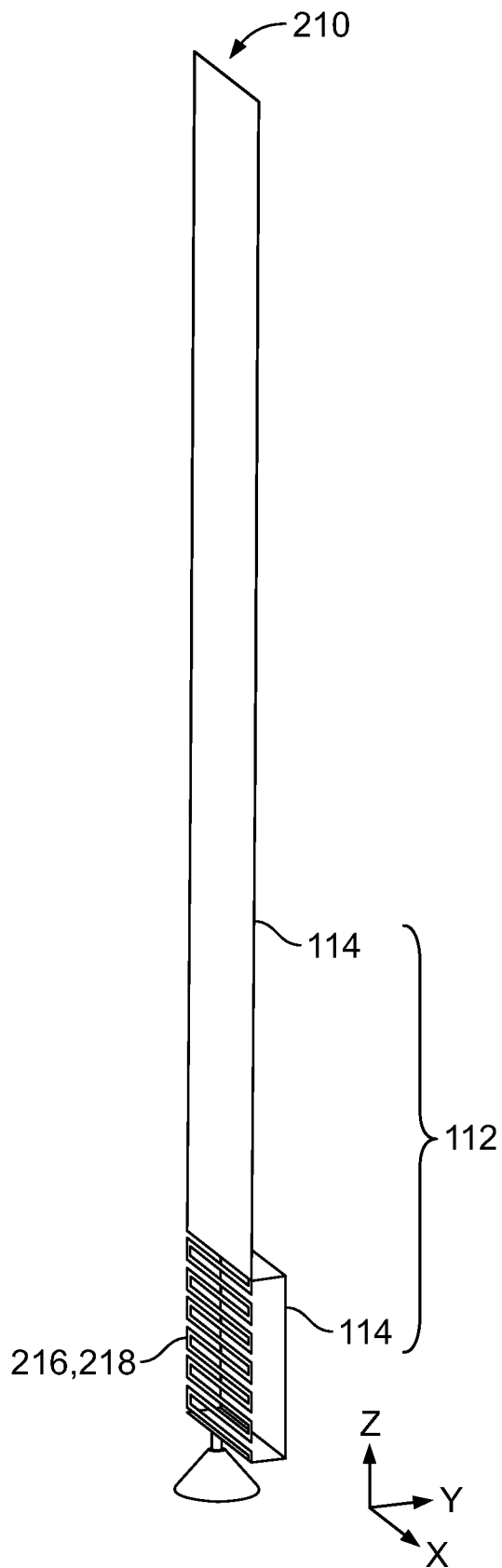


Fig. 3A

300

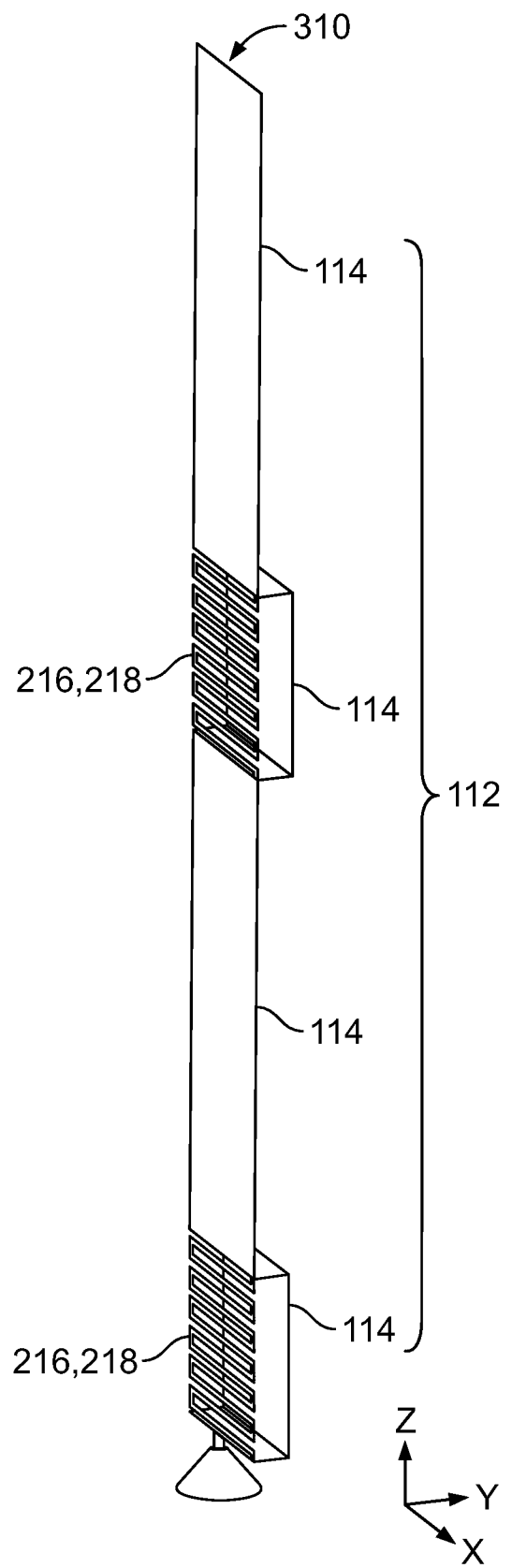
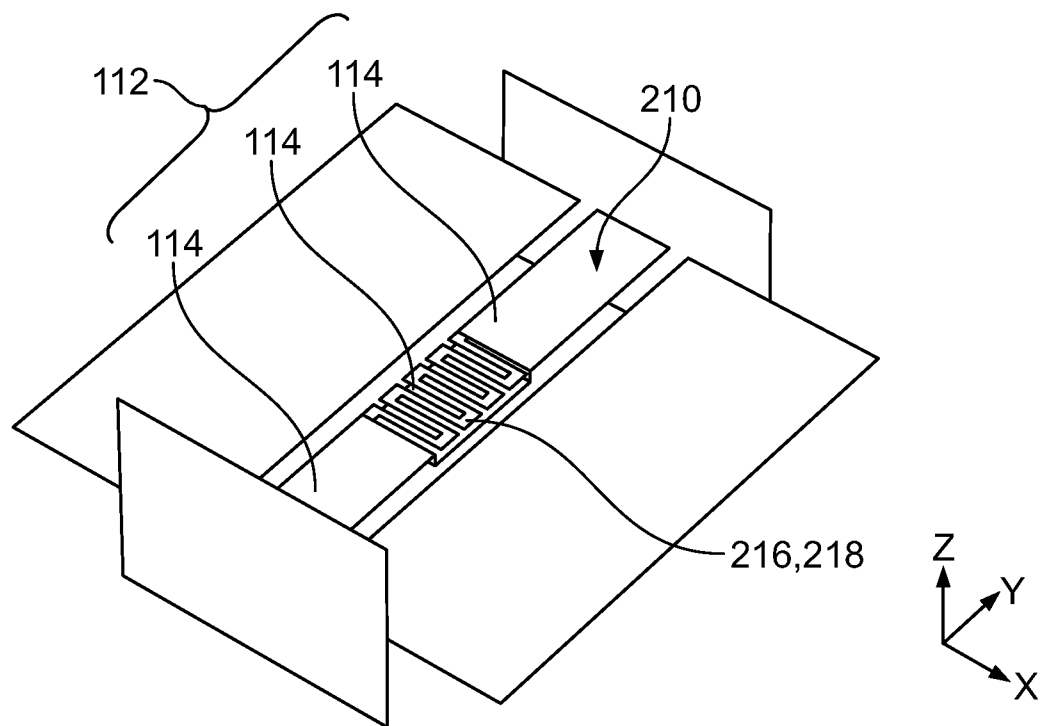
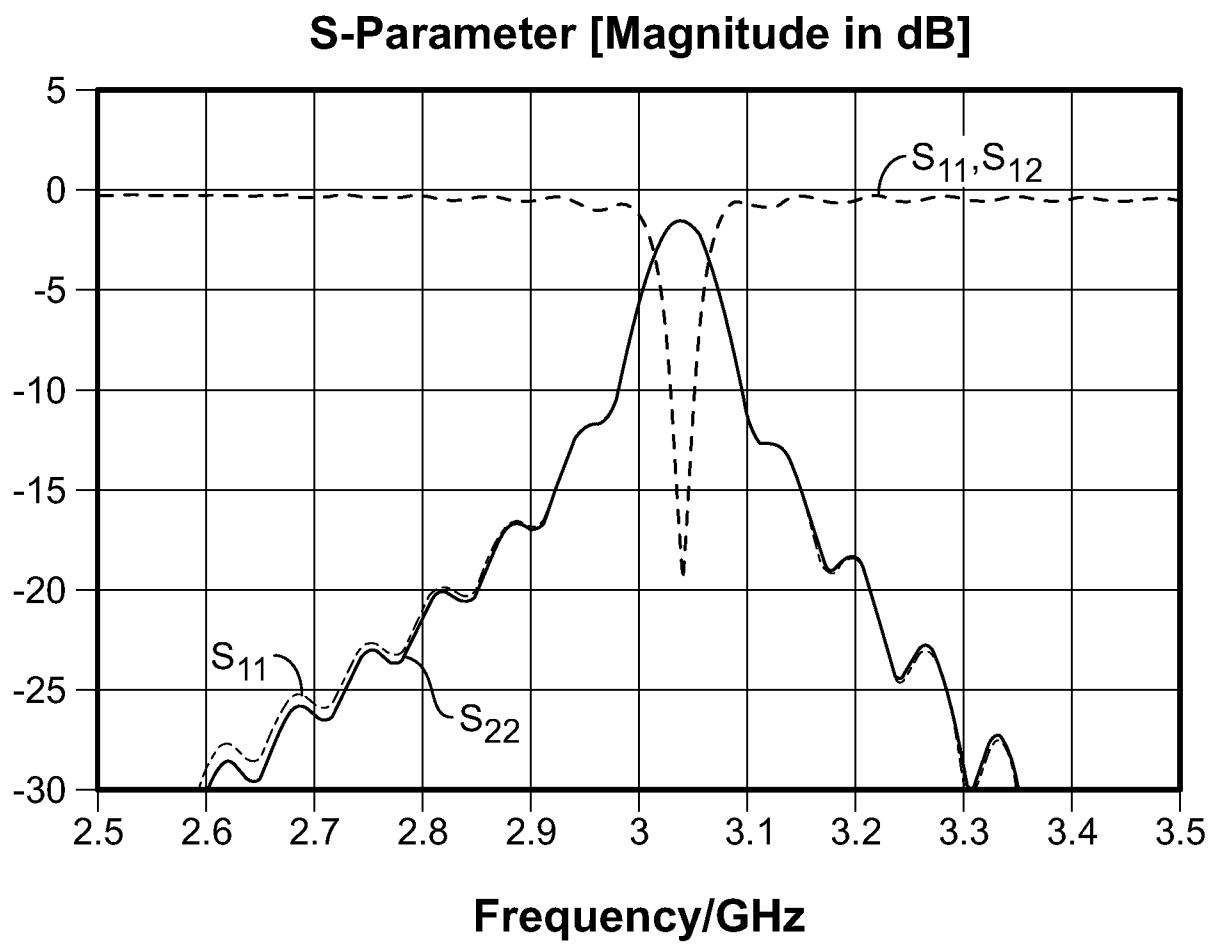
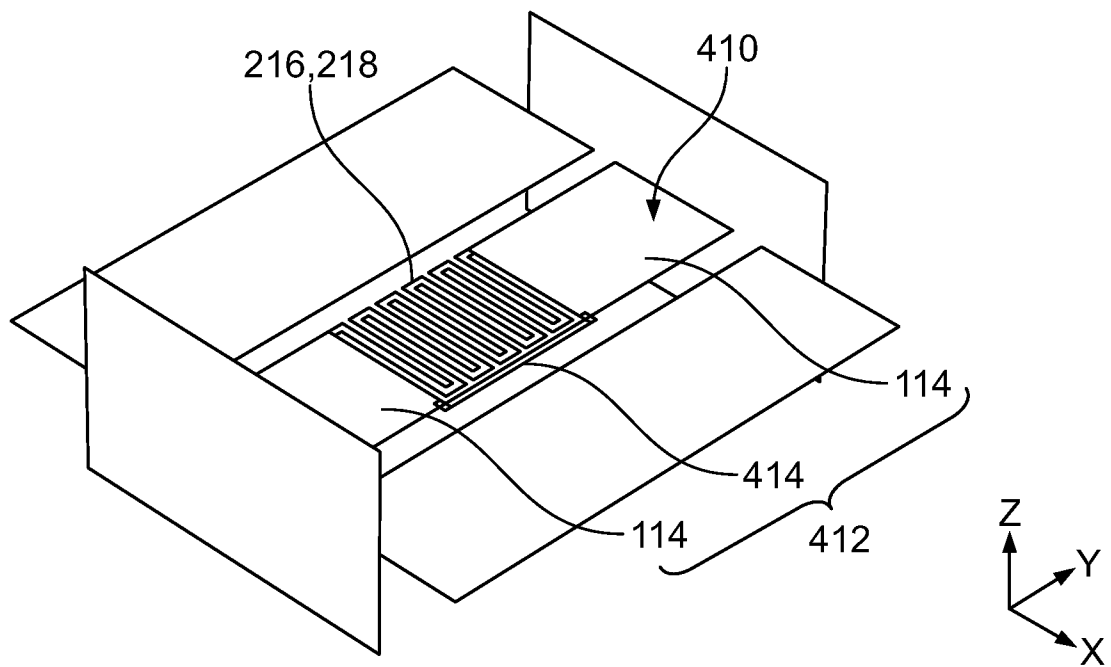
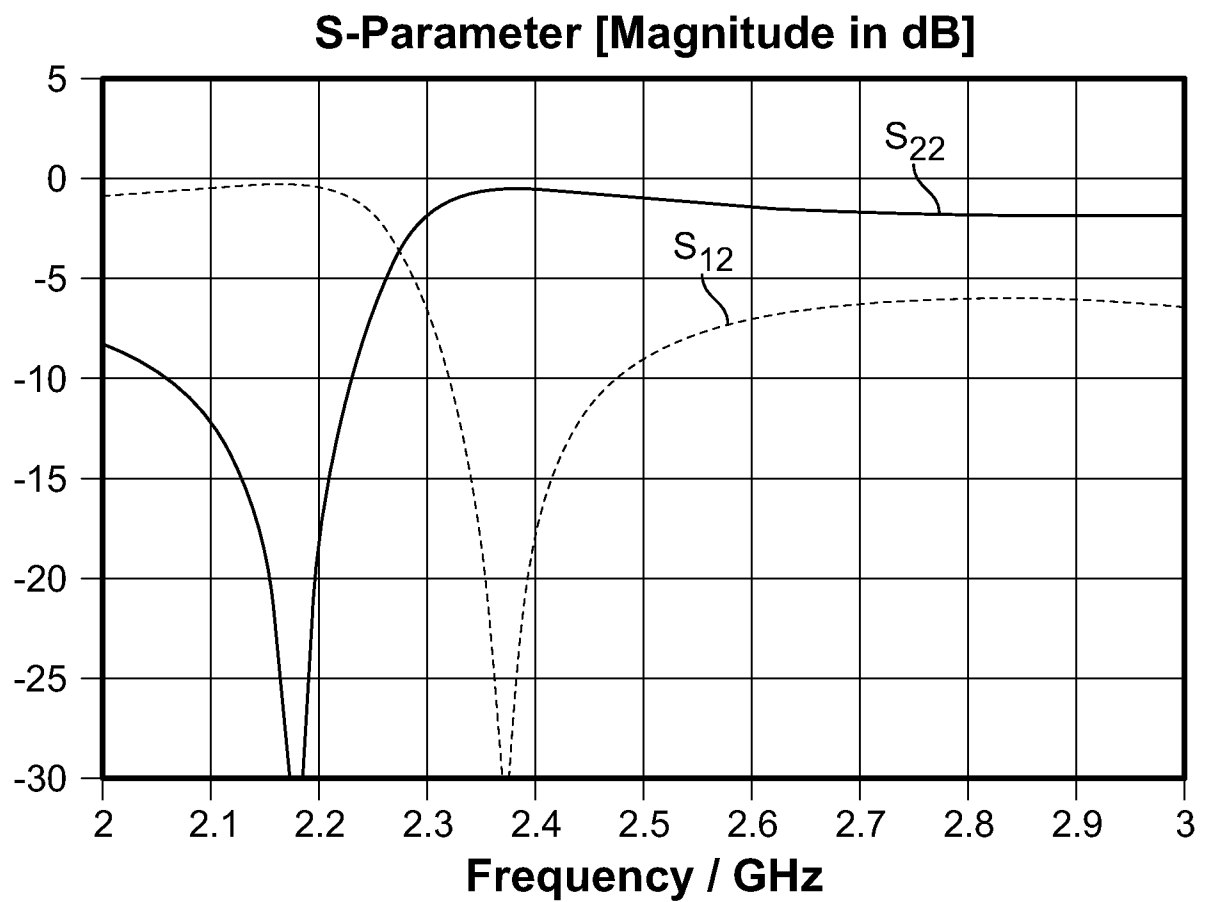
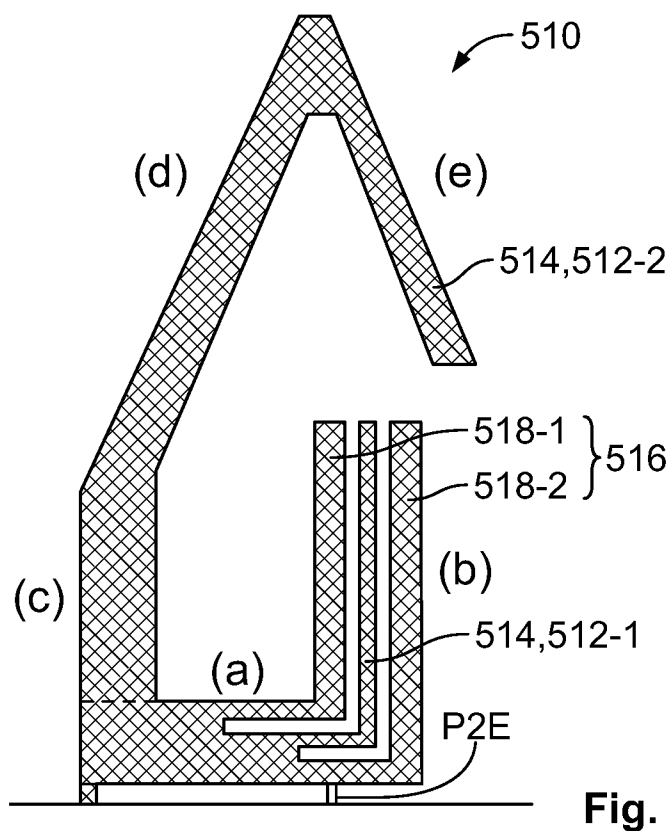
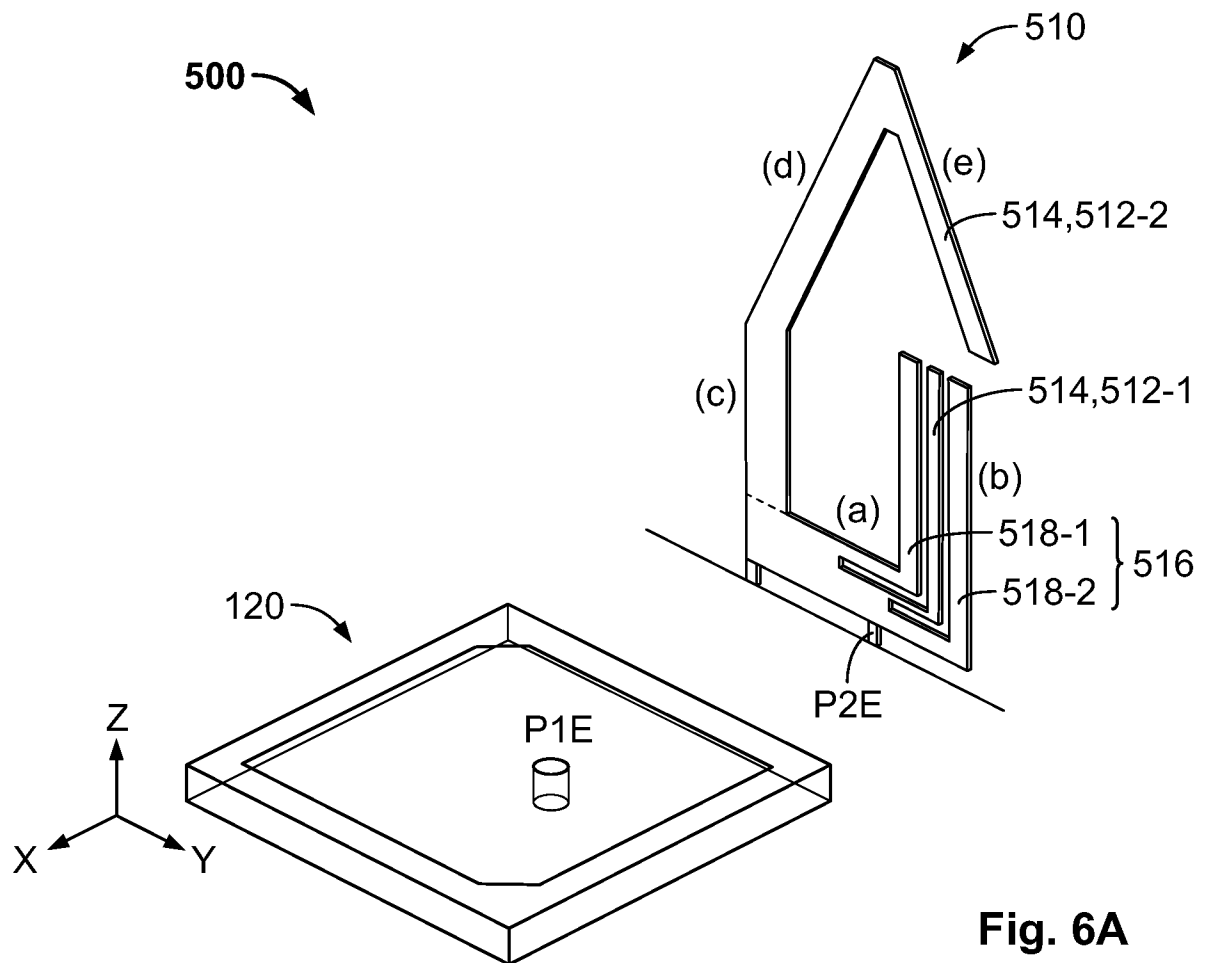


Fig. 3B

**Fig. 4A****Fig. 4B**

**Fig. 5A****Fig. 5B**



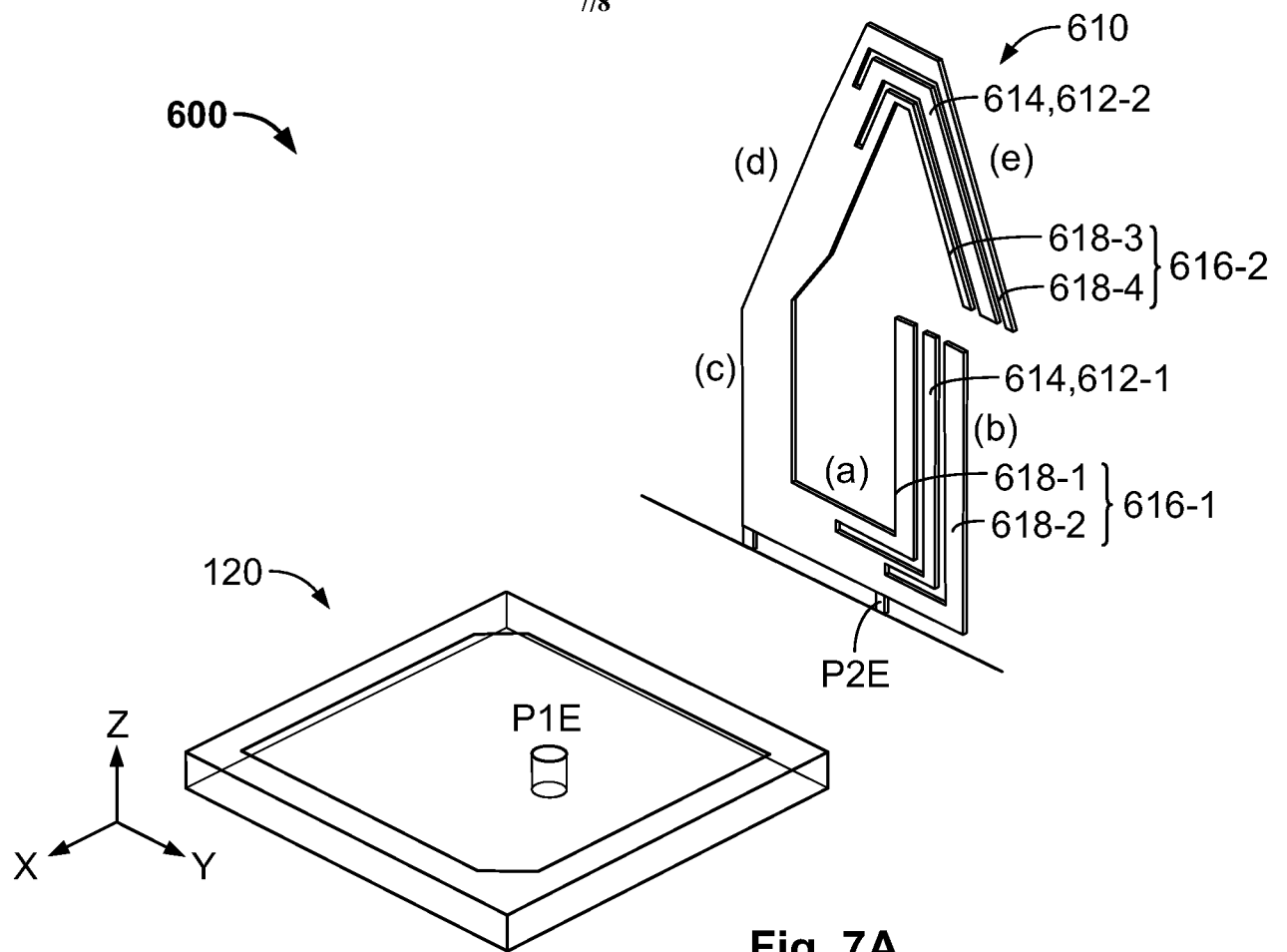


Fig. 7A

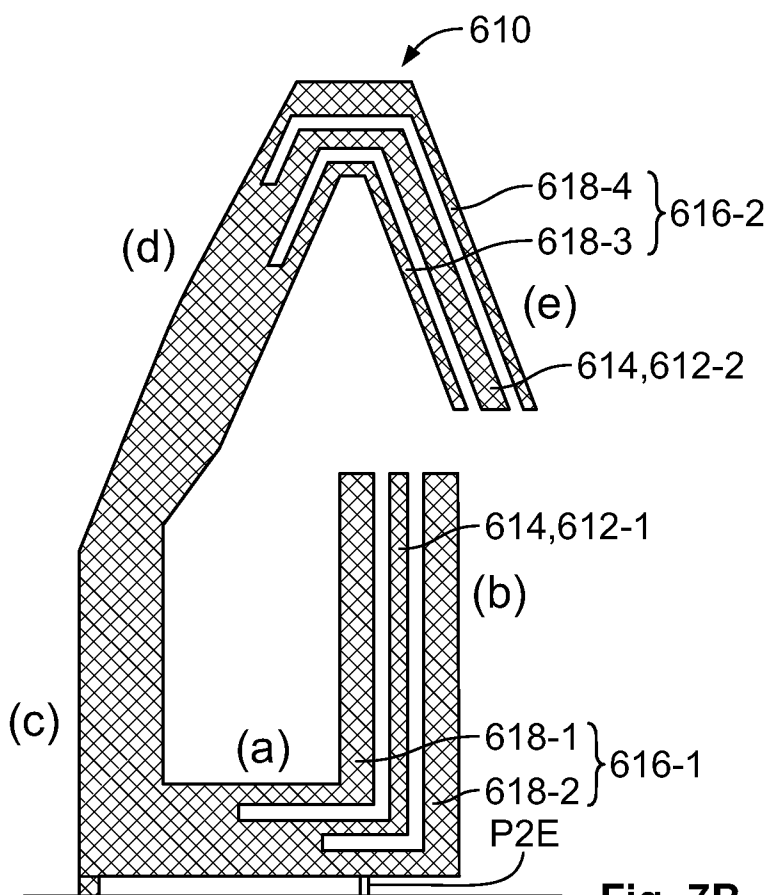


Fig. 7B

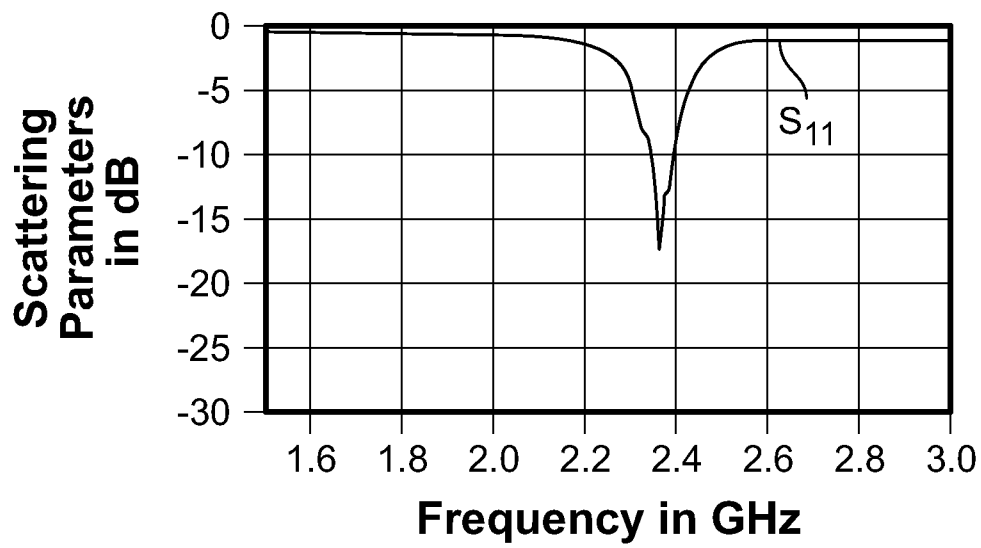


Fig. 7C

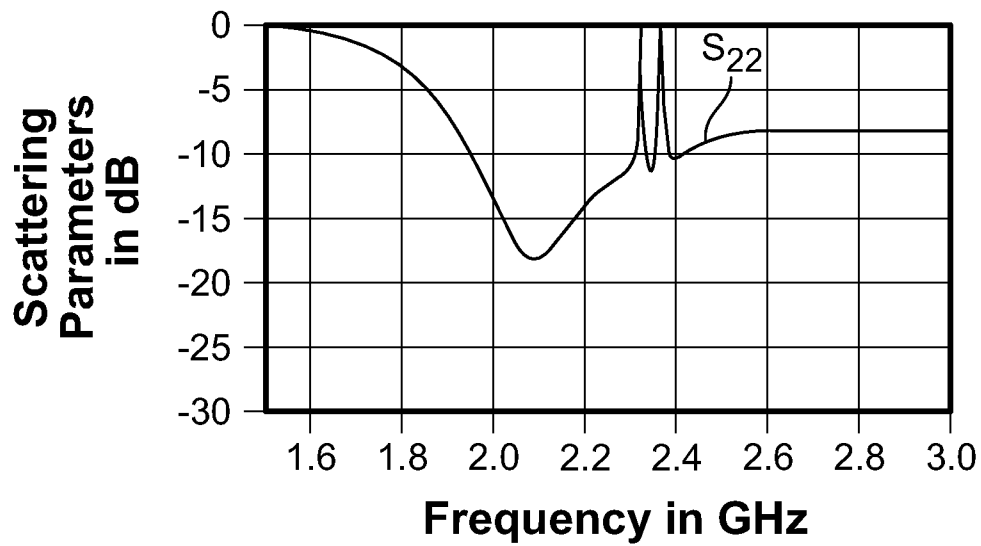


Fig. 7D

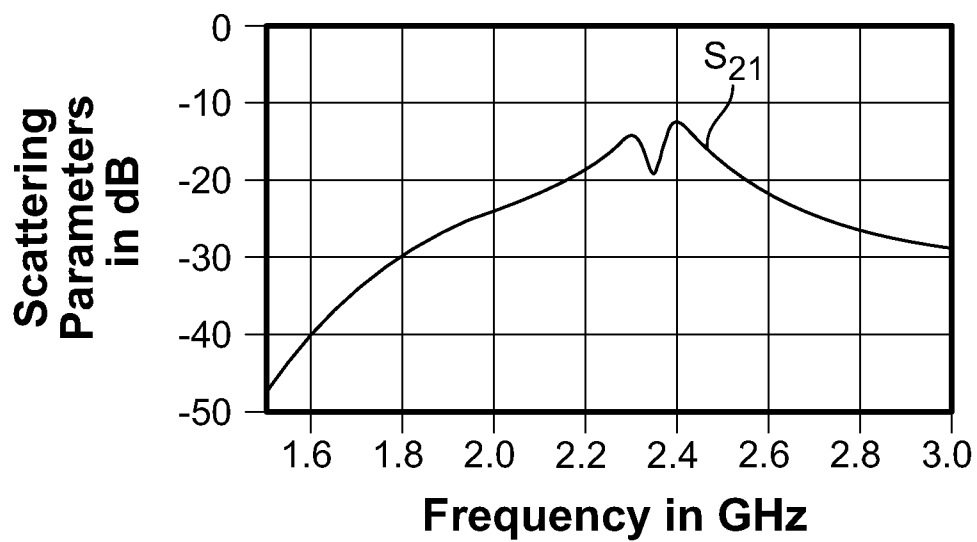


Fig. 7E

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2016/060211

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01Q1/52 H01Q21/30 H01Q21/28
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)

H01Q

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, 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 6 466 172 B1 (RYKEN MARVIN L [US] ET AL) 15 October 2002 (2002-10-15)	1,3-6, 8-12,14, 15
Y	column 2, line 51 - column 4, line 37 figures 1-5	2
A	----- JP H05 145324 A (MITSUBISHI ELECTRIC CORP) 11 June 1993 (1993-06-11) abstract figures 1-5	1,3-15
A	----- WO 2008/131157 A1 (SKYXROSS INC [US]; MONTGOMERY MARK T [US]; CAIMI FRANK M [US]; KISHLER) 30 October 2008 (2008-10-30) paragraphs [0141] - [0148] figures 27-29 ----- -/--	1,3-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

13 September 2016

Date of mailing of the international search report

04/10/2016

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

Kruck, Peter

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/060211

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2009 044206 A (YKC KK; CAMPUS CREATE CO LTD; UNIV ELECTRO COMMUNICATIONS) 26 February 2009 (2009-02-26) abstract figures 1-10 -----	2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/060211

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6466172 B1	15-10-2002	US 6466172 B1	15-10-2002
		US 2003076260 A1	24-04-2003
JP H05145324 A	11-06-1993	JP 2712991 B2	16-02-1998
		JP H05145324 A	11-06-1993
WO 2008131157 A1	30-10-2008	CN 101730957 A	09-06-2010
		CN 103474750 A	25-12-2013
		EP 2140516 A1	06-01-2010
		JP 5260633 B2	14-08-2013
		JP 5617005 B2	29-10-2014
		JP 2010525680 A	22-07-2010
		JP 2013176139 A	05-09-2013
		KR 20100017207 A	16-02-2010
		TW 200910688 A	01-03-2009
		US 2008278405 A1	13-11-2008
		US 2011080332 A1	07-04-2011
		US 2012299792 A1	29-11-2012
		US 2014062819 A1	06-03-2014
		US 2014340274 A1	20-11-2014
		US 2016190684 A1	30-06-2016
		WO 2008131157 A1	30-10-2008
JP 2009044206 A	26-02-2009	NONE	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2016/060211

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of Item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1, 3-15

defining an antenna system comprising a first antenna element operating at a first frequency band with high suppression of induced currents of a second antenna element operating at a second frequency band;

2. claim: 2

defining an antenna system with reduced interference between radiating patterns of plural antenna elements comprised therein;
