

(19)



(11)

EP 2 963 736 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
06.01.2016 Bulletin 2016/01

(51) Int Cl.:
H01Q 5/00 (2015.01) **H01Q 9/04 (2006.01)**
H01Q 9/26 (2006.01) **H01Q 21/24 (2006.01)**

(21) Application number: **14306083.8**

(22) Date of filing: **03.07.2014**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**
Designated Extension States:
BA ME

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Remarks:

Amended claims in accordance with Rule 137(2)
EPC.

(54) Multi-band antenna element and antenna

(57) An antenna and antenna element are disclosed. The antenna element comprises: a conductive radiating surface mounted at a distance from a surface plane of a ground plate; at least one feed probe for feeding an input signal to the conductive radiating surface; at least one frequency selective component mounted on or close to the conductive radiating surface. The at least one fre-

quency selective component is configured to impede the flow of electric current within a first frequency band and to allow the flow of electric current within a second frequency band, such that a portion of the conductive radiating surface carries electric current of all of the frequency bands of the input signal and a further portion carries electric current of a subset of the frequency bands.

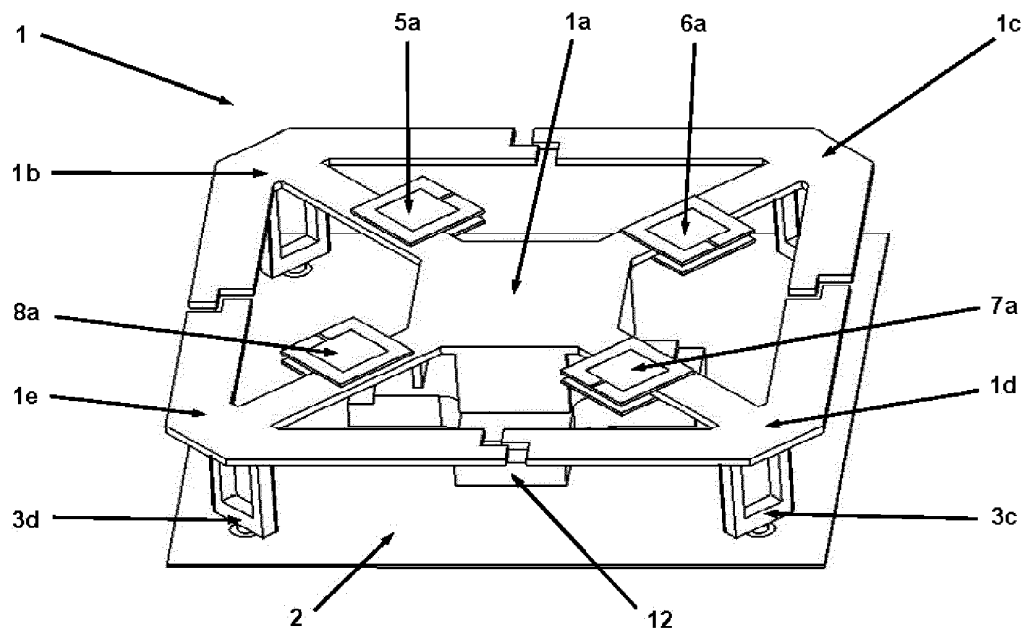


Figure 1: Isometric view of an exemplary radiating antenna element

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DescriptionFIELD OF THE INVENTION

[0001] The present invention relates to the field of antennas and antenna elements and in particular, to multi-band antennas and antenna elements operable to radiate within multiple frequency bands.

BACKGROUND

[0002] As the bandwidth requirements on antennas for mobile wireless communications increase, it becomes difficult for traditional antenna constructs to meet these increasing requirements. One potential way of addressing this is to move from radiating elements supporting all required frequency bands to hybrid radiating elements consisting of two or more constituting component radiators, whereby each component radiator supports only a subset of the required operating frequency bands, yet the hybrid radiating element in totality provides all required frequency bands. This allows the constituting component radiators making up the hybrid radiating element to be simpler and cheaper to build, as each of them is asked to function in only a subset of the required frequency bands.

[0003] With such hybrid devices, there is a requirement to control electromagnetic interference among the constituting component radiators. This interference arises from proximity-induced coupling of electromagnetic energy among the component radiators. Although this can be addressed by spatial separation between the component radiators, often in combination with the introduction of an electromagnetic-shielding structure, this presents a waste of valuable real estate, which could otherwise be used for a more-productive purpose, such as enhancement of the radiating element's radio-frequency performance.

[0004] It would be desirable to provide an antenna of a limited size able to operate in multiple frequency bands.

[0005] Planar or low-profile antennas having a radiating surface mounted above a ground plate provide a space efficient antenna. One example of an antenna that operates at two frequencies, is disclosed in "Dual-Frequency Printed Dipole Loaded With Split Ring Resonators" by Herraiz-Martinez et al. IEEE Antennas and Wireless Propagation Letters, vol.8, 2009). This document discloses a dipole antenna which lacks the low profile of a planar or low profile antenna. This dipole antenna is configured to operate at two frequencies and has four sets of nested split-ring resonators giving a total of eight resonators on each dipole arm. Each resonator is configured to resonate at the same frequency. The resonators are mounted symmetrically on the two arms such that there is a resonant frequency due to the whole dipole and a further resonant frequency due to the dipole electrically shortened by the resonance of the split-ring resonators.

SUMMARY

[0006] A first aspect of the present invention provides an antenna element comprising:

a conductive radiating surface mounted at a distance from a surface plane of a ground plate; at least one feed probe for feeding an input signal to said conductive radiating surface; at least one frequency-selective component mounted on or close to said conductive radiating surface, said at least one frequency-selective component being configured to impede the flow of electric current within a first frequency band and to allow the flow of electric current within a second frequency band, such that a portion of said conductive radiating surface carries electric current of all of said frequencies of said input signal and a further portion carries electric current of a subset of said frequencies.

[0007] As noted previously, hybrid antennas are often formed by using multiple elements. These multiple elements comprise lower- and higher-frequency component radiators which in some cases are arranged side by side. This arrangement offers ease of construction and the advantage of using essentially the same radiator design for all frequency bands, just scaled differently for the different frequencies. However, when such hybrid radiating elements are utilized to form an antenna array, array synthesis tends to yield suboptimal antenna performance due to the fact that the constituting component radiators do not have a common phase centre.

[0008] In terms of planar (2D) or low-profile (2.5D) antennas, the requirement of a common phase centre translates into the requirement of the lower-frequency component radiator, which generally has larger dimensions than radiating antenna structures operating at higher frequencies, being located around the higher-frequency component radiator in an onion-like fashion. Moreover, this nested arrangement reduces the required antenna footprint and therefore has advantages over the side-by-side arrangement. Since the higher-frequency component radiator is surrounded by the lower-frequency component radiator, the requirement to reduce the electromagnetic interference between the component radiators is even more pronounced than in the side-by-side arrangement, i.e., the higher-frequency component radiator should not be allowed to appreciably degrade the performance of the encompassing lower-frequency component radiator, and vice versa. The concern of electromagnetic interference is typically addressed by means of a fence-like metallic enclosure placed to encircle the higher-frequency component radiator, in-between the higher-frequency component radiator and its lower-frequency counterpart. A way to increase the utility of the enclosure is to make the enclosure an integral part of either, or both, component radiators for enhancement of the radiators' radiation properties, e.g., the higher-frequency com-

ponent radiator can be designed for ultra-wideband performance, and the enclosure - in addition to reducing the electromagnetic interference between the higher- and lower-frequency component radiators - suppresses unwanted higher-order modes that would otherwise prevent ultra-wideband performance. In this way the enclosure can perform double duty. Co-pending European application EP14205603.4 to Alcatel Lucent discloses such a low profile wideband radiating antenna with such circumferential topology.

[0009] Nonetheless, in applications which require enhanced performance of the lower-frequency component radiator, the enclosure between the component radiators decreases the portion of the hybrid radiating element's allocated footprint that can be used for improving the performance of the lower-frequency component radiator.

[0010] The present invention recognises that the spatial separation of antenna elements operating at different frequencies and the provision of shielding between them can lead to antenna elements that have a relatively large size, much of which is not used for active radiating components. It also recognised that frequency-selective components could be used to control the flow of electric currents on a radiating surface of an antenna element and this could allow certain portions of the element to carry a subset of frequencies while other portions could carry all frequencies. In this way certain frequencies could make use of the whole radiating surface while others could use just a portion. This would allow different frequency bands to be supported, with in some cases one of the bands making use of the entire radiating surface. In this regard, generally the lowest frequency band supported requires the largest radiating element. Allowing portions of a radiating element whose size is selected for the lowest frequency band to support other higher frequency bands makes efficient use of the radiating surface and provides a compact and efficient antenna element supporting more than one frequency band of operation.

[0011] In this way frequency-selective components serve to manipulate the way the electric currents of different frequencies flow on the radiating surface.. One or more frequency-selective components tuned to one or more different frequency bands and placed in the proximity of, or on the contiguous radiating surface, control the distribution of electric currents of different frequency bands to different sections of the radiating surface. Such a system increases the utilization of the footprint available for the antenna and, at the same time, offers ample versatility to allow performance optimization for various requirements in various application scenarios.

[0012] In effect a radiator that uses frequency-selective components, either in the proximity of the radiator or directly integrated into the radiator, to manipulate the way the electric currents of different frequencies flow on the radiator surface is used to provide an antenna element that supports more than one frequency band of operation.

[0013] The frequency-selective component(s) may be

mounted on the antenna element or close to the radiating surface. In this regard it may be mounted between the radiating surface and the ground plate, or it may be mounted on the other side of the radiating surface to the ground plate. The frequency-selective component(s) is mounted close enough to the radiating surface such that there is electromagnetic coupling between the radiating surface and the frequency-selective component.

[0014] The ground plate may be a metallic plate or a plate with a conductive layer. It may have a number of forms, it may have a continuous planar form or it may form a plane with some portions being absent, such that a circumferential hollow shape is provided. Furthermore, where the ground plate consists of a conductive layer on a surface of another material such as a substrate, the conductive layer may cover the whole of the surface of the other material or it may just cover a portion of the surface.

[0015] Although the radiating surface may in preferred embodiments be substantially parallel to the ground plate it may also lie at an angle to it. In this regard the radiating surface is preferably at an angle of less than 10° to the surface of the ground plate, although an angle of up to 40° would provide an antenna element with suitable properties, however, its profile would be larger than were the surface parallel to the ground plate, thus in preferred embodiments the radiating surface is substantially parallel to the ground plate.

[0016] In some embodiments, said at least one frequency-selective component is configured to impede a flow of electric current within said first frequency band to an area of said conductive radiating surface.

[0017] The frequency-selective component maybe arranged to impede the flow of electric current within a first frequency band to an area of the conductive radiating surface such that this area is free or virtually of electric current within the first frequency band. This area of the antenna element does therefore not radiate at this frequency band.

[0018] In some embodiments, said conductive radiating surface comprises a substantially planar surface and said at least one frequency-selective component is configured to impede a flow of electric current flowing on said planar surface by deflecting said electric current such that it does not flow through a portion of said radiating surface.

[0019] The frequency-selective component may act to deflect the electric current and in this way may cause an area of the planar surface to be substantially free from electric current in this frequency band.

[0020] Although, the frequency-selective component can have a number of forms, in some embodiments it comprises at least one of a band-stop, high-pass, band-pass or low-pass frequency-selective component.

[0021] Such components may impede either a particular frequency band or all low frequencies, or high frequencies or it may allow a frequency band to pass while impeding other frequencies. Suitable selection of such

components allows the electric current flowing on the radiating surface to be manipulated such that electric current in particular frequency band(s) are restricted from flowing in certain areas, producing an antenna element with different portions that radiate at different frequency bands.

[0022] In some embodiments, said at least one frequency-selective component comprises a band stop or band pass frequency-selective component configured such that said component has a relative impedance frequency band of at least 5% at an impedance match level of 10dB.

[0023] Where the frequency-selective component is a band-stop or band-pass frequency-selective component then it is configured to respectively impede or allow electric current across a relatively wide bandwidth, i.e. at least 5% of a relative impedance bandwidth at an impedance match level of 10 dB. This differentiates the component from a notch filter, for example, which only acts to impede a very narrow frequency range, providing a low-performance antenna element.

[0024] In some embodiments, the antenna element comprises at least two feed probes, at least one first feed probe for feeding a first input signal within a first lower frequency band and at least one second feed probe for feeding a second input signal within a second higher frequency band, said first feed probe feeding said first input signal to a location closer to a circumferential edge of said radiating surface than said second feed probe; and said at least one frequency-selective component being located between said first and second feed probe and being configured to impede an electric current from said second input signal and to allow an electric current from said first input signal, such that an inner portion of said radiating surface is configured to carry both said first and second input signals and said outer portion is configured not to carry said second input signal.

[0025] An antenna element that is configured to radiate a low-frequency signal generally needs to have a larger size than one that is configured to radiate a higher-frequency signal, owing to the longer wavelengths of the lower-frequency signal. Embodiments of the present invention can radiate at higher and lower frequency bands by feeding the higher-frequency signal to an inner portion of the radiating surface and using frequency-selective components to confine this signal to the inner area of the radiating surface while allowing the lower-frequency signal to use the whole radiating surface. In this way, the radiating surface is used efficiently and radiates effectively at both the higher and lower frequencies.

[0026] Although the frequency-selective component can have a number of forms provided that it can act to impede electric current in certain frequency bands while allowing electric current in other frequency bands to flow, in some embodiments it comprises an inductor-capacitor (LC) circuit operable to resonate at a predetermined frequency.

[0027] In this regard, the inductor-capacitor circuit will

be mounted close enough to the radiating surface to be electromagnetically coupled to it, so that electric current of the frequency close to the resonant frequency of the inductor-capacitor circuit is impeded as it causes resonance within this circuit causing a high-resistance path for current on the radiating surface at this frequency.

[0028] In some embodiments, said at least one frequency-selective component comprises two of said inductor-capacitor circuits mounted close to each other, such that they are electromagnetically coupled to each other and to said radiating surface, mutual electromagnetic couplings among said two inductor-capacitor circuits and said radiating surface providing a plurality of resonant frequencies within said two inductor-capacitor circuits and generating a stop band comprising said frequencies.

[0029] Although, the frequency-selective component maybe a single inductor-capacitor circuit mounted on its own and acting to impede electric current on the radiating surface at a frequency band close to the resonant frequency of the inductor-capacitor circuit when it is electromagnetically coupled to the radiating surface, in other embodiments there may be two frequency-selective components mounted close to each other such that they are electromagnetically coupled to each other and to the radiating surface.

[0030] Advantageously the two frequency-selective components are configured to resonate at different frequencies, such that mutual couplings among the two inductor-capacitor circuits and the radiating surface provide for a plurality of resonant frequencies and generate a stop band comprising these frequencies. In this way, the stop bandwidth is increased, allowing the frequency-selective components to impede electric current in a relatively wide frequency band, making it an efficient multiple-band antenna element.

[0031] In some embodiments, said frequency-selective component comprises at least one split-ring resonator.

[0032] Although the frequency-selective component may have a number of forms, in some embodiments it comprises one or more split-ring resonators. In this regard, in some embodiments two split-ring resonators are mounted on either side of the radiating surface and act to generate a stop band that is dependent on the resonant frequency of each of the resonators and the resonant frequency that is generated by them being electromagnetically coupled with each other and with the radiating surface. Where they have different resonant frequencies then a relatively wide frequency stop band comprising the different resonant frequencies can be generated.

[0033] In some embodiments, the antenna element comprises, an antenna element comprising a plurality of frequency selective components mounted on or in proximity to said radiating surface, at least some of said frequency selective components being configured to impede electric current of different frequency bands, such that different portions of said radiating surface carry cur-

rents of different frequency bands.

[0034] The antenna element may act as a multi-band antenna element having multiple frequency-selective components, at least some of them being configured to impede electric currents in different frequency bands. In this way, different portions of the radiating surface carry currents of different frequency bands, producing an antenna element operable to radiate these different frequency bands.

[0035] In some embodiments, said antenna element comprises, a multi-band antenna element comprising a plurality of feed probes for feeding input signals within a plurality of different frequency bands to said radiating surface, at least some of said plurality of frequency-selective components being configured to impede electric currents within at least some of said plurality of different frequency bands.

[0036] In some cases the multi-band antenna element will have several feed probes feeding input signals of different frequency bands, the frequency-selective components being configured to impede electric currents within at least some of these different frequency bands such that different portions of the radiating surface carry electric currents in different frequency bands. Thus, some portions may just carry the low-frequency band signals while other portions may carry higher-frequency signals, and perhaps intermediate frequency signals. Generally there will be a portion that carries all of the bands, and a larger portion which carries all but the high-frequency band and an even larger portion that carries all but the two high-frequency bands and so on, until you have a portion that carries just the low-frequency band, the other portions also carrying the low-frequency band such that the low-frequency band will make use of the largest portion of the radiating surface of all of the frequency band signals.

[0037] It should be noted that in some embodiments the frequency-selective components are positioned asymmetrically at different points on the radiating surface. In this regard there is no requirement for them to be mounted symmetrically, each being able to act either independently or in concert to provide an area of radiation suitable for a particular frequency band.

[0038] In some embodiments, said radiating surface comprises a single contiguous radiating surface.

[0039] A single contiguous radiating surface maybe used with frequency-selective components defining portions which carry electric currents within particular frequency bands.

[0040] In some embodiments, said radiating surface comprises at least two portions, said at least one frequency-selective component being mounted at or close to a junction between said at least two portions, at least one of said portions comprising a substantially planar radiating surface area.

[0041] The different portions of the radiating surface which carry different frequency bands of electric current are separated by frequency-selective components which

impede currents of one frequency band from flowing into the other portion. In some embodiments, at least one of the portions comprises a planar radiating surface area, this implementation being particularly applicable to planar antenna elements.

[0042] In some embodiments, the antenna element comprises an inner portion comprising a continuous planar surface and an outer portion, said outer portion comprising at least two arms extending away from said continuous planar surface.

[0043] In some cases, the inner portion may be a continuous planar surface and the outer portions may have different forms such as arms extending away. The two portions will be separated by the frequency-selective components such that the lower-frequency band will have signals running along the arms and across the inner continuous planar surface while the higher-frequency signals will only operate in the continuous planar surface, the frequency-selective components confining them to this portion.

[0044] A second aspect of the present invention provides a planar or low-profile antenna comprising at least one antenna element according to the first aspect of the present invention.

[0045] In some embodiments, the antenna comprises a plurality of antenna elements arranged in an array of antenna elements.

[0046] An antenna may be formed in an array of these antenna elements, each configured to support multi-band operation and in this way an antenna that can support multiple frequency bands can be provided in a cost-effective and space-efficient manner. Further particular and preferred aspects are set out in the accompanying independent and dependent claims. Features of the dependent claims may be combined with features of the independent claims as appropriate, and in combinations other than those explicitly set out in the claims.

[0047] Where an apparatus feature is described as being operable to provide a function, it will be appreciated that this includes an apparatus feature which provides that function or which is adapted or configured to provide that function.

BRIEF DESCRIPTION OF THE DRAWINGS

[0048] Embodiments of the present invention will now be described further, with reference to the accompanying drawings, in which:

Figure 1 illustrates an isometric view of an exemplary radiating antenna element according to an embodiment of the present invention;
Figure 2 shows an exploded isometric view of an exemplary radiating antenna element according to an embodiment of the present invention;
Figure 3 shows an exploded isometric view of an exemplary radiating antenna element according to an embodiment of the present invention;

Figure 4 shows an isometric view of an exemplary contiguous radiator, with feed probes according to an embodiment of the present invention;

Figure 5 shows a lumped-element equivalent circuit model of a portion of the radiator loaded with one split-ring resonator;

Figure 6 shows a frequency-dependence plot of the magnitude of the input reflection coefficient, where vertical dotted lines delimit the design operating lower-frequency band;

Figure 7 shows a frequency-dependence plot of the magnitude of the input reflection coefficient, vertical dotted lines delimit the design operating higher-frequency band;

Figure 8 shows a plot of co-polarized far-field gain radiation pattern of an exemplary radiating antenna element in accordance with an embodiment of the present invention;

Figure 9 shows a plot of cross-polarized far-field gain radiation pattern of an exemplary radiating antenna element in accordance with an embodiment of the present invention;

Figure 10 shows a plot of co-polarized far-field gain radiation pattern of an exemplary radiating antenna element in accordance with an embodiment of the present invention;

Figure 11 shows a plot of cross-polarized far-field gain radiation pattern of an exemplary radiating antenna element in accordance with an embodiment of the present invention; and

Figure 12 shows an antenna element configured to operate in three frequency bands in accordance with an embodiment of the present invention.

DESCRIPTION OF THE EMBODIMENTS

[0049] Before discussing the embodiments in any more detail, first an overview will be provided.

[0050] Antenna elements according to embodiments of the present invention provide a single contiguous radiating surface of a radiator positioned above a ground plate or plane. The radiator may be ungrounded - i.e., electrically floating above the ground plane - or it may be electrically connected to the ground plane at one or more locations. One or more feed probes feeding a radio-frequency signal to the radiator are coupled to the radiator either by direct connection or proximity coupling. In addition, there are one or more frequency-selective components either in the proximity of the radiating surface or directly integrated into the radiator. The frequency-selective components are designed to control the flow of electric currents on the radiator surface; specifically, the frequency-selective components manipulate the way the electric currents of different frequencies flow on the radiator surface.

[0051] Consequently, in such an arrangement, not all sections of the radiator carry electric currents of all frequency bands fed to the radiator by the feeding probes

- e.g., some sections of the contiguous radiator may carry only a subset of the frequency bands, other sections may carry a different subset of the frequency bands (partially overlapping with the first subset or not), and yet other sections may carry all frequency bands supplied to the radiator. In this regard the frequency-selective components may confine signals of certain frequency bands to certain portions of the radiating surface, while allowing signals of other frequency bands to flow over further portions of the surface or over the whole surface.

[0052] Embodiments of the present invention seek to provide an alternative to the electromagnetic-shielding structure between the lower- and higher-frequency component radiators in a hybrid radiating element by building lower- and higher-frequency component radiators as a single contiguous radiator and limiting the electromagnetic interference between the radiators by means of a small number of frequency-selective components judiciously located on or proximate to the contiguous radiator. In such an arrangement, higher-frequency electric currents (signals) are restricted to only a portion of the contiguous radiator while lower-frequency electric currents (signals) use the entire contiguous radiator, i.e., a segment of the contiguous radiator carries both higher- and lower-frequency electric currents (signals). Since in some embodiments the full contiguous radiator carries lower-frequency electric currents, the entire structure of the radiating element can be applied to serve the lower-frequency functionality of the radiating element, thereby providing increased means for performance enhancement.

[0053] A single contiguous electrically-conducting radiator can be utilized to conduct electric currents of multiple frequency bands. Frequency-selective components tuned to a number of different frequency bands and placed in the proximity of the contiguous radiating surface control the distribution of electric currents of different frequency bands to different sections of the radiating surface. Such a system increases the utilization of the footprint available for the antenna and, at the same time, offers ample versatility to allow performance optimization for various requirements in various application scenarios.

[0054] In effect embodiments provide a multi-band radiating antenna element as a single contiguous radiator and use frequency-selective components, either in the proximity to the radiator or directly integrated in the radiator, to manipulate the way the electric currents of different frequencies flow on the radiator surface.

[0055] Figures 1-4 show an exemplary radiating antenna element according to an embodiment of the present invention. The antenna element comprises a single contiguous metallic radiator 1 elevated over a metallic ground plane 2. The ground plane 2 forms the top surface of a rectangular-shaped standard radio-frequency/ microwave substrate sheet material 9. The radiator 1 is formed by joining a central radiator 1a with four circumferentially-mounted, sequentially-rotated identical radiators 1b, 1c, 1d, 1e placed in the corners of the substrate

sheet material 9. The central radiator 1a comprises an inverted-cup patch elevated over a grounded pedestal 12.

[0056] The central radiator 1a is fed by means of two feed probes 4a, 4b, which provide for operation with dual linear ($\pm 45^\circ$ -slant) polarization. The radio-frequency signal is brought to the feed probes 4a, 4b by conventional metallic microstrip lines 11a, 11b on the lower surface of the substrate sheet material 9 (see Figure 3). The radiating element comprising the central radiator 1a, the feed probes 4a, 4b and the grounded pedestal 12 is designed to operate over the frequency band of 1.50-1.85 GHz.

[0057] The radiators 1b, 1c, 1d, 1e form two pairs of mutually-orthogonal arms: one pair is formed by radiators 1b and 1d, and the other pair is formed by radiators 1c and 1e. Feed probes 3a, 3b, 3c, 3d feed the respective radiators 1b, 1c, 1d, 1e. The radio-frequency signal is brought to the feed probes 3a, 3b, 3c, 3d by a conventional metallic microstripline signal-distribution network 10a, 10b on the lower surface of the substrate sheet material 9 (Figure 3).

[0058] The signal-distribution network 10a provides differential feeding to radiators 1b and 1d, while the signal-distribution network 10b provides differential feeding to radiators 1c and 1e. In this way each pair of radiators (1c/ 1e and 1b/ 1d) radiates electromagnetic waves of one linear ($+45^\circ$ - or -45° -slant) polarization. Differential feeding provides radio-frequency signals of equal amplitude and a 180° phase shift, compensating for the mutual 180° rotation of the radiators serving one polarization.

[0059] Furthermore, there are four frequency-selective components 5a/5b, 6a/ 6b, 7a/7b, 8a/ 8b mounted in proximity to the central radiator 1a, whereby each frequency-selective component consists of a pair of metallic split-ring resonators etched on a standard radio-frequency/microwave substrate sheet material. As long as the electrical size of the frequency-selective components is small, the function of the basic frequency-selective cell 5a, 5b, 6a, 6b, 7a, 7b, 8a, 8b can be described by means of a lumped-element model. Specifically, the equivalent model of a transmission line loaded by one split-ring resonator is depicted in Figure 5.

[0060] In the model, L and C are the per-section inductance and capacitance of the transmission line, while the split-ring resonator is modelled as a resonant circuit - with inductance L_{SRR} and capacitance C_{SRR} - electromagnetically coupled to the transmission line through the mutual inductance M. Consequently each frequency-selective cell acts as a notch filter. By coupling two cells - tuned to somewhat different resonant frequencies - to the same transmission line, thus forming a single frequency-selective component, a band-stop filter is formed that encompasses the frequencies of the individual notch filters. In the arrangement depicted in Figures 1-4, the design goal is to enlarge the filter's stopband to the extent that the stopband would ideally just about encompass the operating frequency band of the radiating element composed of the central radiator 1a, the feed probes 4a,

4b and the grounded pedestal 12. Hence the electric currents of the 1.50-1.85 GHz frequency band on the surface of the contiguous radiator 1 are confined to the central radiator 1a, while the electric currents of lower frequency bands are allowed to flow over the entire surface of the contiguous radiator 1.

[0061] In all of the above, the term "metallic" refers to parts with electrically conducting surfaces; as such, the parts can be manufactured in several ways, e.g., as solid or sheet metals, electrically conducting plastics or metallized plastics.

[0062] A full-wave software analysis has been utilized to calculate the scattering parameters and far-field gain radiation patterns of the radiating element depicted in Figures 1-4. Ohmic losses are included in the simulations; copper (Cu) has been considered for all metallic parts. Figure 6 is the frequency-dependence plot 21 of the magnitude of the input reflection coefficient 22 of the complete radiating element when radio-frequency signal is fed to the input port of either of the signal-distribution networks 10a, 10b. The radiating element has been designed for the operating frequency band of 650-870 MHz, which is delimited by the markers f_1 and f_2 in the plot 21.

[0063] Figure 7 shows the frequency-dependence plot 31 of the magnitude of the input reflection coefficient 32 of the complete radiating element when radio-frequency signal is fed to the input port of either of the microstrip lines 11a, 11b. The radiating element shows a usable operating frequency band of 1.58-1.74 GHz, delimited by the markers f_3 and f_4 in the plot 31. Four resonances are observed in that frequency band; they arise from a combination of three phenomena: (A) the fundamental resonance of the inverted-cup patch itself, (B) the electromagnetic coupling of energy from the transmission line to the two frequency-selective cells forming each frequency-selective component and (C) the electromagnetic coupling of energy between the two frequency-selective cells forming each frequency-selective component.

[0064] Figures 8 and 9 show the typical plots 41 and 51 of the respective co- and cross-polarized far-field gain radiation patterns in the frequency band of 650-870 MHz of the radiating element in the E-, mid- and H-planes, while Figures 10 and 11 show the typical plots 61 and 71 of the respective co- and cross-polarized far-field gain radiation patterns in the frequency band of 1.58-1.74 GHz of the radiating element in the E-, mid- and H-planes. Good peak gain, co-polarized beam integrity and good polarization purity are observed throughout the two operating frequency bands.

[0065] Figure 12 shows an alternative embodiment of the present invention comprising an antenna element configured to operate in 3 different frequency bands. The radiating surface 100 is formed of a contiguous surface having four outer fin type elements 101a, 101b, 101c and 101d, two of which are fed by feed probes 30, 32 which input a low frequency signal. These outer fins are joined to intermediate fins 102a, 102b, 102c and 102d via four regions of radiating surface on which are mounted re-

spectively low pass filters 20a, b, c, d. These low pass filters allow the low frequency band input signal of the feed probes 30 and 32 to pass into the intermediate fins 102 a, b, c, d. Since the two fins 101d, 101c that the corresponding two feed probes 30, 32 connect to, fill adjacent 90°-wide quadrants of the radiating surface 100 and the electric currents on the surfaces of fins 101d, 101c can only leave the fins through the low pass filters 20d, 20c positioned on the diagonals of the radiating surface 100, the signals fed to feed probes 30, 32 are radiated mutually orthogonal ($\pm 45^\circ$ -slant linear polarizations) signals.

[0066] The four intermediate fins are similar in shape to the outer fins and similarly have two input feed probes 40 and 42 which feed signals to two neighbouring intermediate fins. These signals are in an intermediate frequency band that is a higher frequency band than the signals input by feed probes 30 and 32 and they cannot pass through the low pass filters 20a, b, c, d and are thus, restricted from flowing to the outer fins.

[0067] Radiating surface 100 has a central region 103 with two input feed probes 50 and 52 for inputting a higher frequency signal. The central region 130 is joined to the intermediate fins via four regions of radiating surface on which are mounted respectively band stop filters 22a, 22b, 22c, 22d which stop the higher frequency signals input at the input feed probes 50 and 52 but allow the low frequency signals and intermediate frequency signals to pass.

[0068] In this way the radiating surface 100 has a central portion which carries signals of all input frequencies, an intermediate portion which carries low frequency and intermediate frequency signals and an outer portion which only carries the low frequency signals. Thus, the whole radiating surface acts as a radiating element for the low frequency signals input at probes 30 and 32, while the intermediate fins and central region act as a radiating element for the intermediate frequency signals input at probes 40 and 42, and the central region acts as a radiating element for the high frequency signals input at probes 50 and 52.

[0069] Although Figure 12 shows an example of an antenna element according to an embodiment of the present invention that is configured to operate at three different frequency bands, further frequency bands could be supported using additional feed probes and frequency selective components configured to limit electric current of particular frequency bands to particular portions of the radiating surface.

[0070] It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is ex-

plicitly shown.

[0071] The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

Claims

1. An antenna element comprising:

a conductive radiating surface mounted at a distance from a surface plane of a ground plate;
at least one feed probe for feeding an input signal to said conductive radiating surface;
at least one frequency selective component mounted on or close to said conductive radiating surface, said at least one frequency selective component being configured to impede the flow of electric current within a first frequency band and to allow the flow of electric current within a second frequency band, such that a portion of said conductive radiating surface carries electric current of all of said frequency bands of said input signal and a further portion carries electric current of a subset of said frequency bands.

2. An antenna element according to claim 1, wherein said at least one frequency selective component is configured to impede a flow of electric current within said first frequency band to an area of said conductive radiating surface.

3. An antenna element according to any preceding claim, wherein said conductive radiating surface comprises a substantially planar surface and said at least one frequency selective component is configured to impede a flow of electric current flowing on said planar surface by deflecting said electric current such that it does not flow through a portion of said radiating surface.

4. An antenna element according to any preceding claim, wherein said at least one frequency selective component comprises at least one of a band stop, high pass, band pass or low pass frequency selective

component.

5. An antenna element according to claim 4, wherein said at least one frequency selective component comprises a band stop or band pass frequency selective component configured such that said component has a relative impedance frequency band of at least 5% at an impedance match level of 10dB.
6. An antenna element according to any preceding claim, comprising at least two feed probes, at least one first feed probe for feeding a first input signal within a first lower frequency band and at least one second feed probe for feeding a second input signal within a second higher frequency band, said first feed probe feeding said first input signal to a location closer to a circumferential edge of said radiating surface than said second feed probe; and said at least one frequency selective component being located between said first and second feed probe and being configured to impede an electric current from said second input signal and to allow an electric current from said first input signal, such that an inner portion of said radiating surface is configured to carry both said first and second input signals and said outer portion is configured not to carry said second input signal.
7. An antenna element according to any preceding claim, wherein said at least one frequency selective component comprises an inductor-capacitor (LC) circuit operable to resonate at a predetermined frequency.
8. An antenna element according to claim 7, wherein said at least one frequency selective component comprises two of said inductor-capacitor circuits mounted close to each other, such that they are electromagnetically coupled to each other and to said radiating surface, mutual electromagnetic couplings among said two inductor-capacitor circuits and said radiating surface providing a plurality of resonant frequencies within said two inductor-capacitor circuits and generating a stop band comprising said frequencies.
9. An antenna element according to any preceding claim, wherein said frequency selective component comprises at least one split-ring resonator.
10. An antenna element according to any preceding claim, comprising a plurality of frequency selective components mounted on or in proximity to said radiating surface, at least some of said frequency selective components being configured to impede electric current of different frequency bands, such that different portions of said radiating surface carry currents of different frequency bands.

11. An antenna element according to claim 10, said antenna element comprising a multi-band antenna element comprising a plurality of feed probes for feeding input signals within a plurality of different frequency bands to said radiating surface, at least some of said plurality of frequency selective components being configured to impede electric currents within at least some of said plurality of different frequency bands.
12. An antenna element according to any preceding claim, wherein said radiating surface comprises a single contiguous radiating surface.
13. An antenna element according to claim 12, wherein said radiating surface comprises at least two portions, said at least one frequency selective component being mounted at or close to a junction between said at least two portions, at least one of said portions comprising a substantially planar radiating surface area.
14. A planar or low profile antenna comprising at least one antenna element according to any preceding claim.
15. A planar or low profile antenna according to claim 14, comprising a plurality of antenna elements according to any preceding claim arranged as an array of antenna elements.

Amended claims in accordance with Rule 137(2) EPC.

1. An antenna element comprising:
 - a contiguous substantially planar conductive radiating surface (1) mounted at a distance from a surface plane of a ground plate 2;
 - at least one feed probe (3a, 3b, 3c, 3d, 4a, 4b) for feeding an input signal to said conductive radiating surface (1);
 - at least one frequency selective component (5a, 6a, 7a, 8a) mounted on or close to said conductive contiguous radiating surface (1), said at least one frequency selective component being configured to impede the flow of electric current within a first frequency band and to allow the flow of electric current within a second frequency band, such that a portion of said conductive radiating surface (1a) carries electric current of all of said frequency bands of said input signal and a further portion carries electric current of a subset of said frequency bands (1b, 1c, 1d, 1e).
2. An antenna element according to claim 1, wherein said at least one frequency selective component (5a,

6a, 7a, 8a) is configured to impede a flow of electric current within said first frequency band to an area of said conductive radiating surface.

3. An antenna element according to any preceding claim, wherein said at least one frequency selective component (5a, 6a, 7a, 8a) is configured to impede a flow of electric current flowing on said planar surface by deflecting said electric current such that it does not flow through a portion of said radiating surface.
4. An antenna element according to any preceding claim, wherein said at least one frequency selective component (5a, 6a, 7a, 8a) comprises at least one of a band stop, high pass, band pass or low pass frequency selective component.
5. An antenna element according to claim 4, wherein said at least one frequency selective component comprises a band stop or band pass frequency selective component configured such that said component has a relative impedance frequency band of at least 5% at an impedance match level of 10dB.
6. An antenna element according to any preceding claim, comprising at least two feed probes, at least one first feed probe (3a, 3b, 3c, 3d) for feeding a first input signal within a first lower frequency band and at least one second feed probe (4a, 4b) for feeding a second input signal within a second higher frequency band, said first feed probe feeding said first input signal to a location closer to a circumferential edge of said radiating surface than said second feed probe; and said at least one frequency selective component being located between said first and second feed probe and being configured to impede an electric current from said second input signal and to allow an electric current from said first input signal, such that an inner portion of said radiating surface is configured to carry both said first and second input signals and said outer portion is configured not to carry said second input signal.
7. An antenna element according to any preceding claim, wherein said at least one frequency selective component comprises an inductor-capacitor (LC) circuit operable to resonate at a predetermined frequency.
8. An antenna element according to claim 7, wherein said at least one frequency selective component comprises two of said inductor-capacitor circuits mounted close to each other, such that they are electromagnetically coupled to each other and to said radiating surface, mutual electromagnetic couplings among said two inductor-capacitor circuits and said

radiating surface providing a plurality of resonant frequencies within said two inductor-capacitor circuits and generating a stop band comprising said frequencies.

9. An antenna element according to any preceding claim, wherein said frequency selective component comprises at least one split-ring resonator.
10. An antenna element according to any preceding claim, comprising a plurality of frequency selective components mounted on or in proximity to said radiating surface, at least some of said frequency selective components being configured to impede electric current of different frequency bands, such that different portions of said radiating surface carry currents of different frequency bands.
11. An antenna element according to claim 10, said antenna element comprising a multi-band antenna element comprising a plurality of feed probes for feeding input signals within a plurality of different frequency bands to said radiating surface, at least some of said plurality of frequency selective components being configured to impede electric currents within at least some of said plurality of different frequency bands.
12. An antenna element according to any preceding claim, wherein said radiating surface comprises at least two portions, said at least one frequency selective component being mounted at or close to a junction between said at least two portions, at least one of said portions comprising a substantially planar radiating surface area.
13. A planar or low profile antenna comprising at least one antenna element according to any preceding claim.
14. A planar or low profile antenna according to claim 13, comprising a plurality of antenna elements according to any preceding claim arranged as an array of antenna elements.

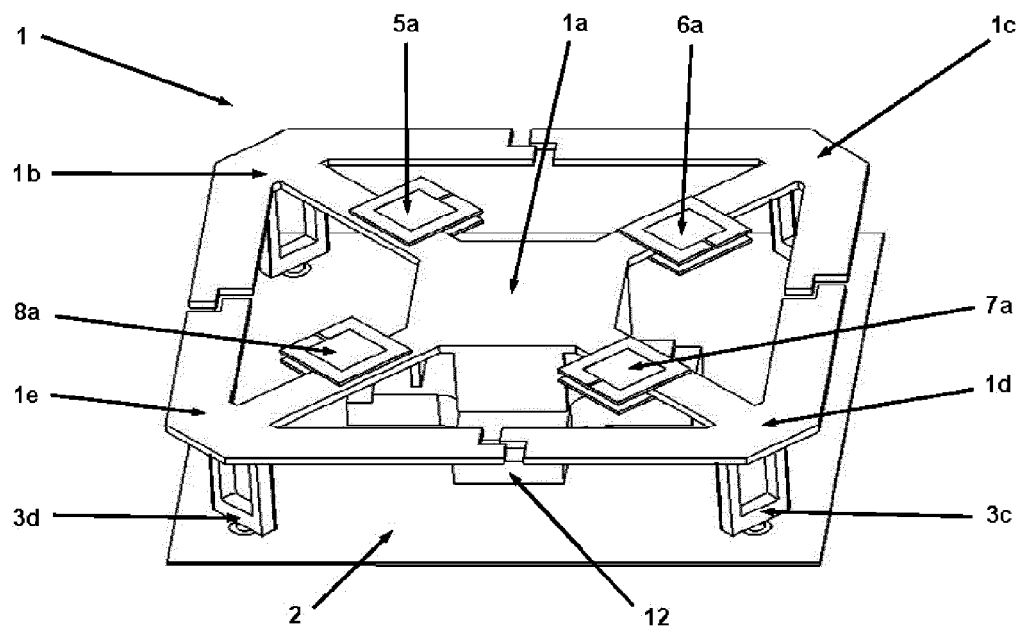


Figure 1: Isometric view of an exemplary radiating antenna element

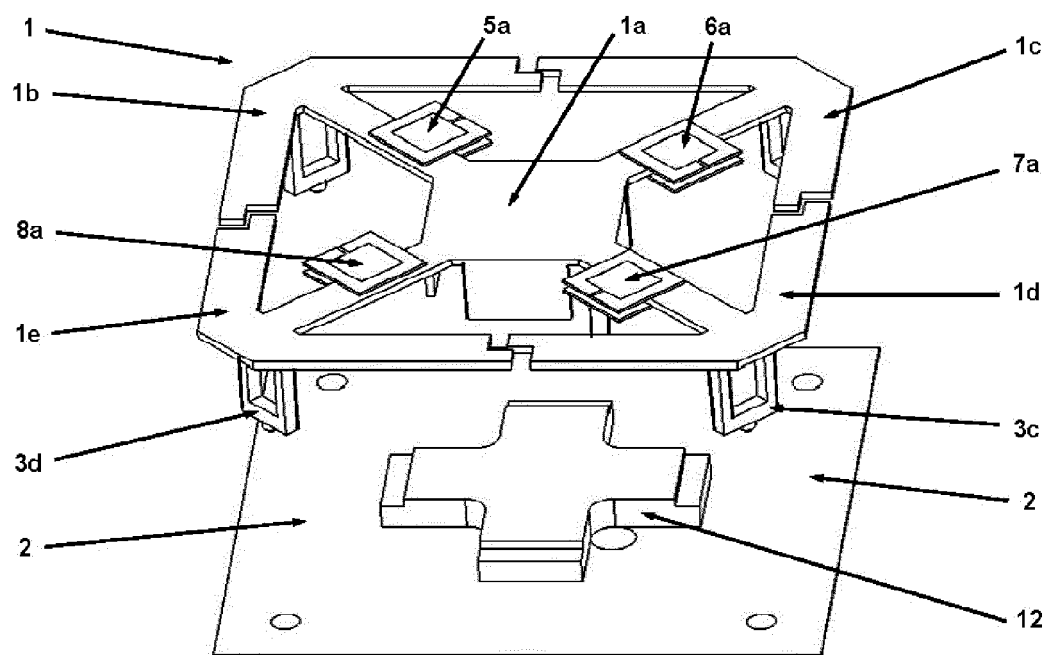


Figure 2: Exploded isometric view of an exemplary radiating antenna element

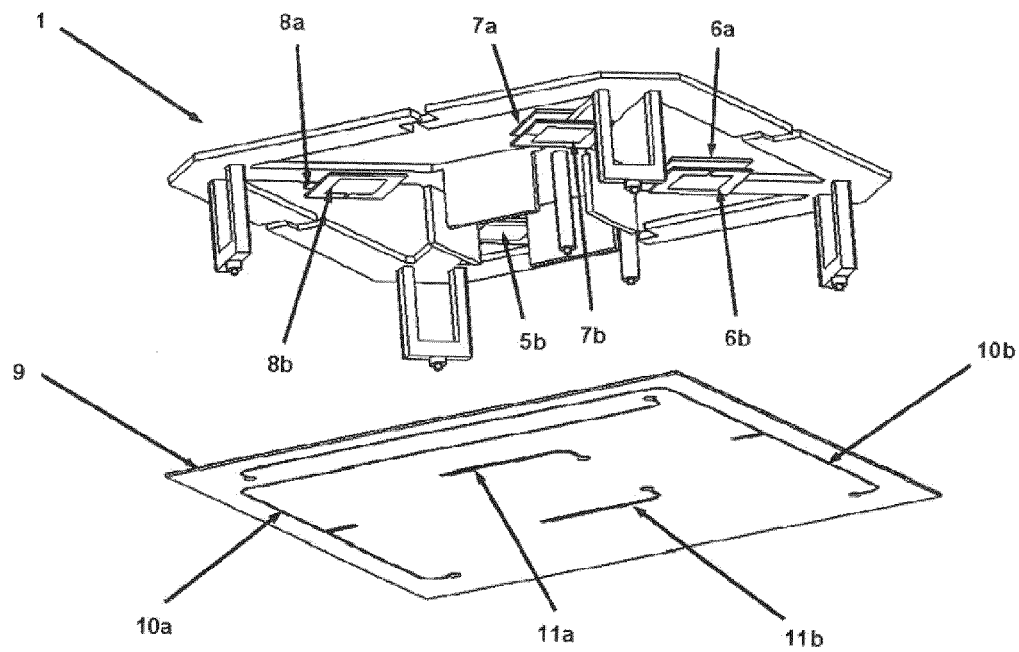


Figure 3: Exploded isometric view of an exemplary radiating antenna element

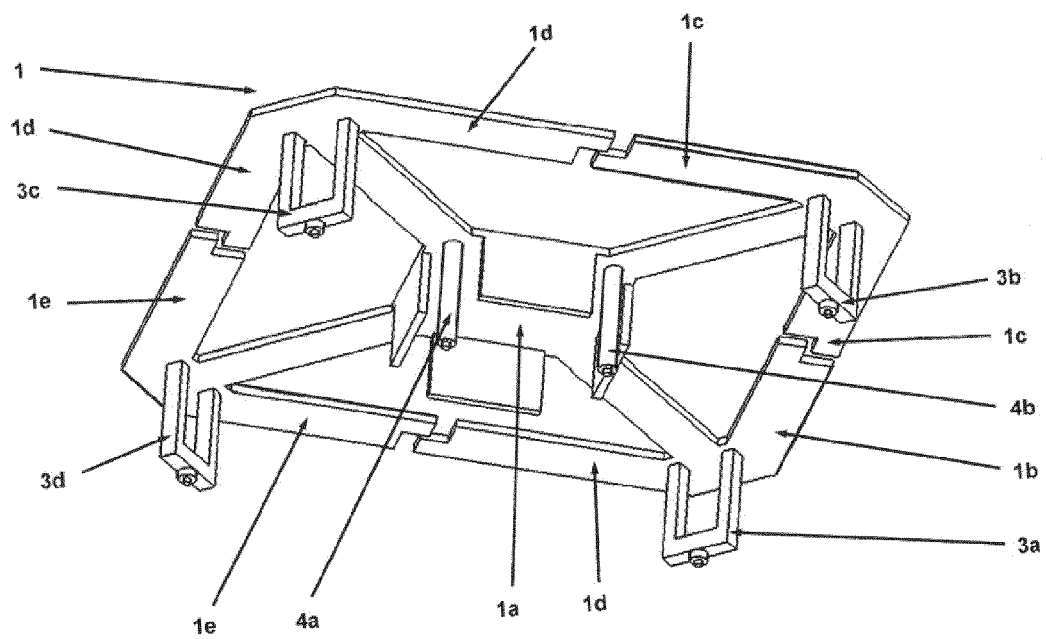


Figure 4: Isometric view of an exemplary contiguous radiator, with feed probes.

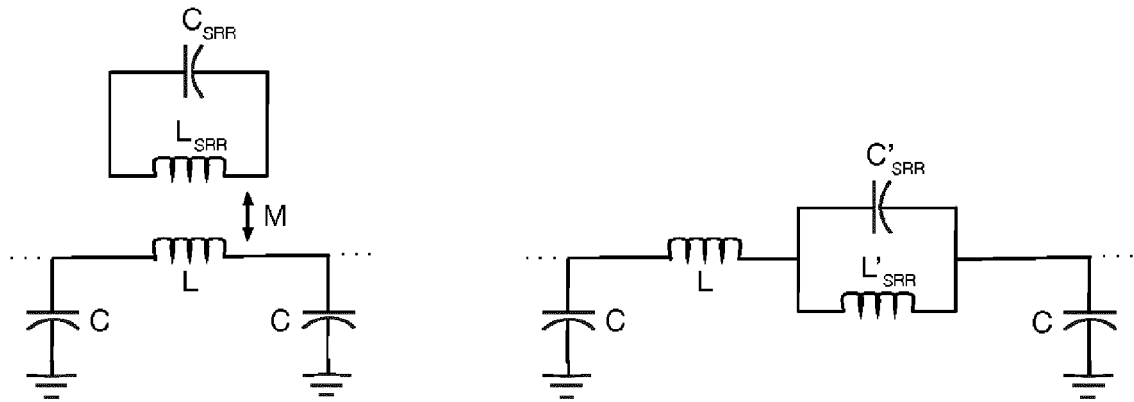


Figure 5: Lumped-element equivalent circuit model of transmission line loaded with one split-ring resonator (left) and circuit model that results after transformation of the series branch (right) [3].

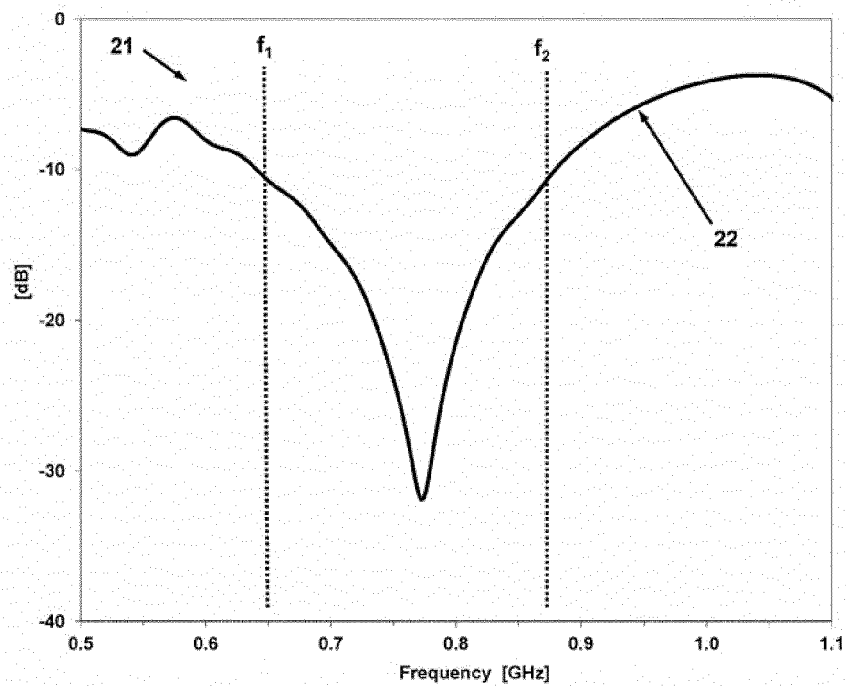


Figure 6: Frequency-dependence plot of the magnitude of the input reflection coefficient; vertical dotted lines delimit the design operating lower-frequency band.

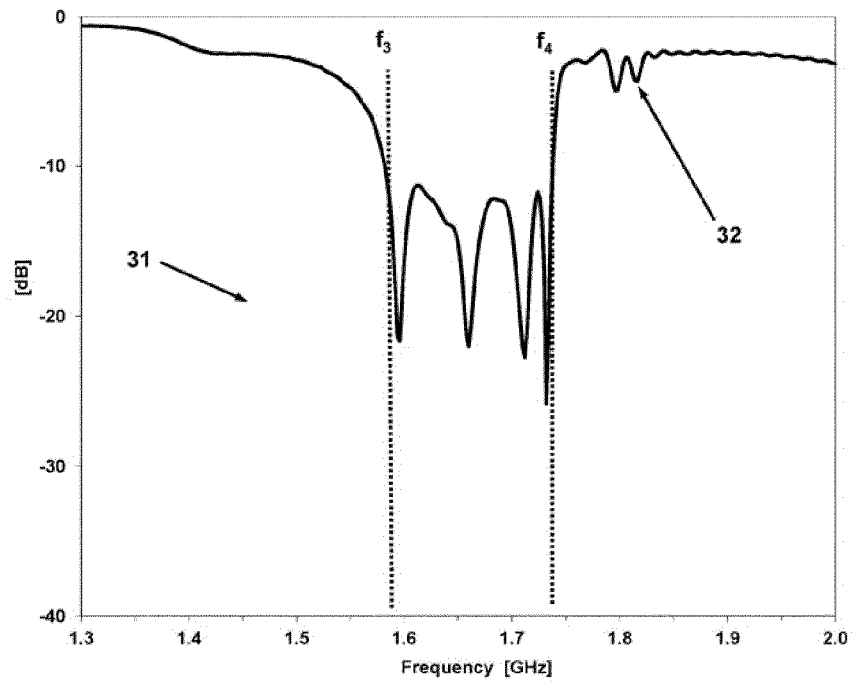


Figure 7: Frequency-dependence plot of the magnitude of the input reflection coefficient; vertical dotted lines delimit the design operating higher-frequency band.

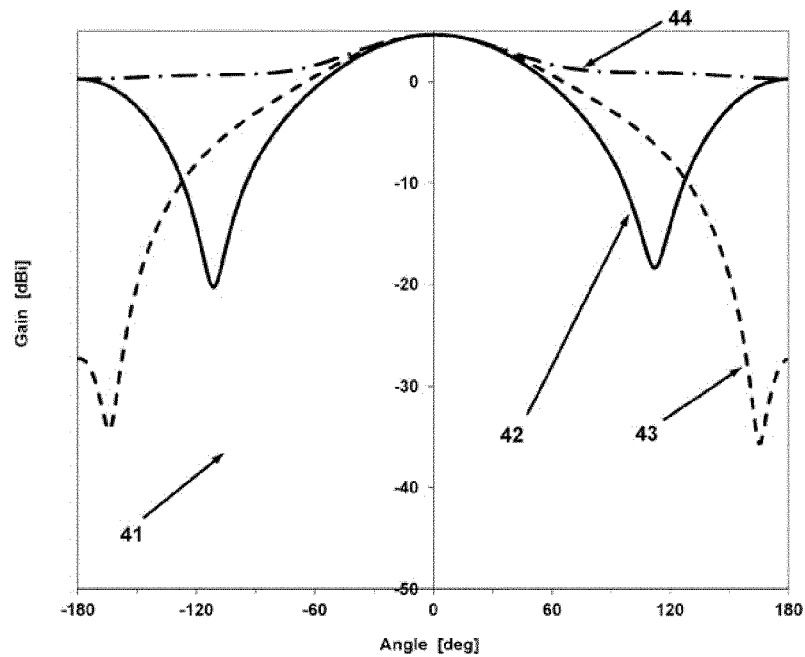


Figure 8: Plot of co-polarized far-field gain radiation pattern of an exemplary radiating antenna element at 800 MHz – solid line: E-plane cut; dashed line: mid-plane cut; dash-dotted line: H-plane cut.

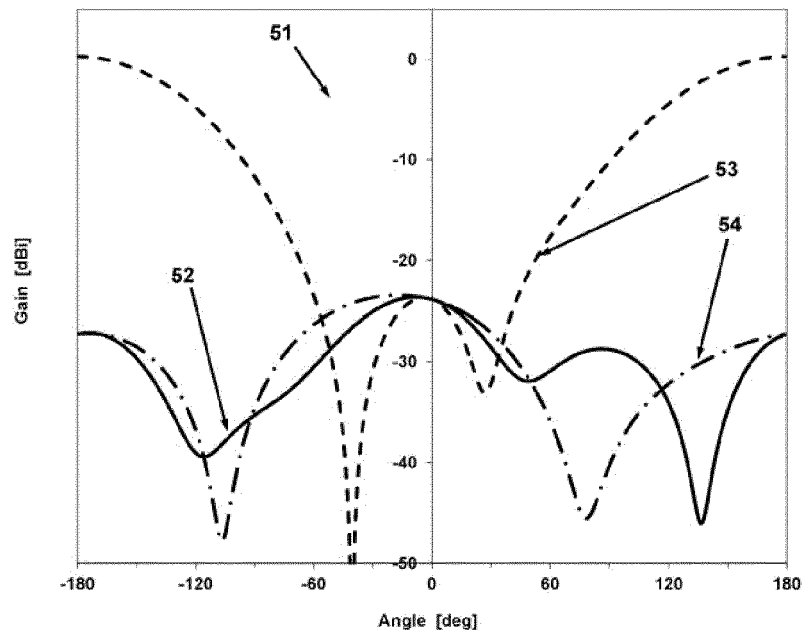


Figure 9: Plot of cross-polarized far-field gain radiation pattern of an exemplary radiating antenna element at 800 MHz – solid line: E-plane cut; dashed line: mid-plane cut; dash-dotted line: H-plane cut.

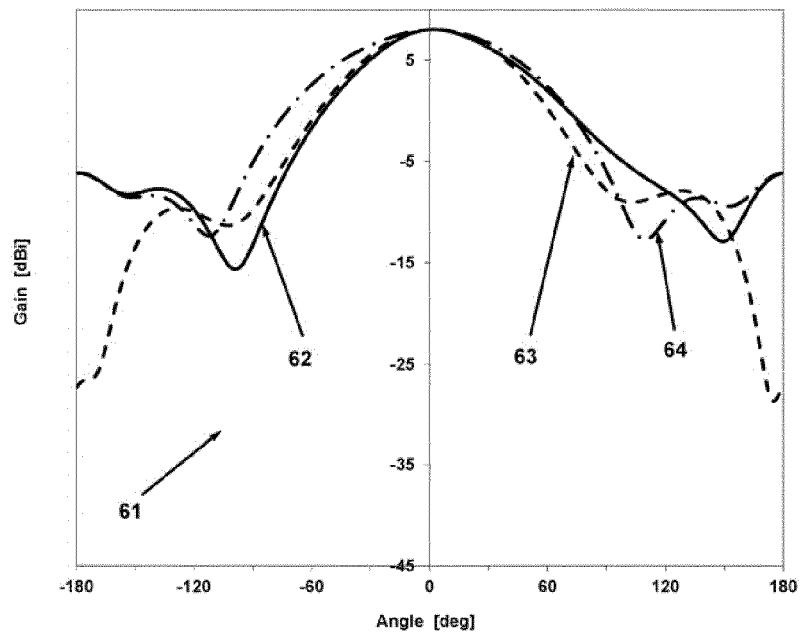


Figure 10: Plot of co-polarized far-field gain radiation pattern of an exemplary radiating antenna element at 1660 MHz – solid line: E-plane cut; dashed line: mid-plane cut; dash-dotted line: H-plane cut.

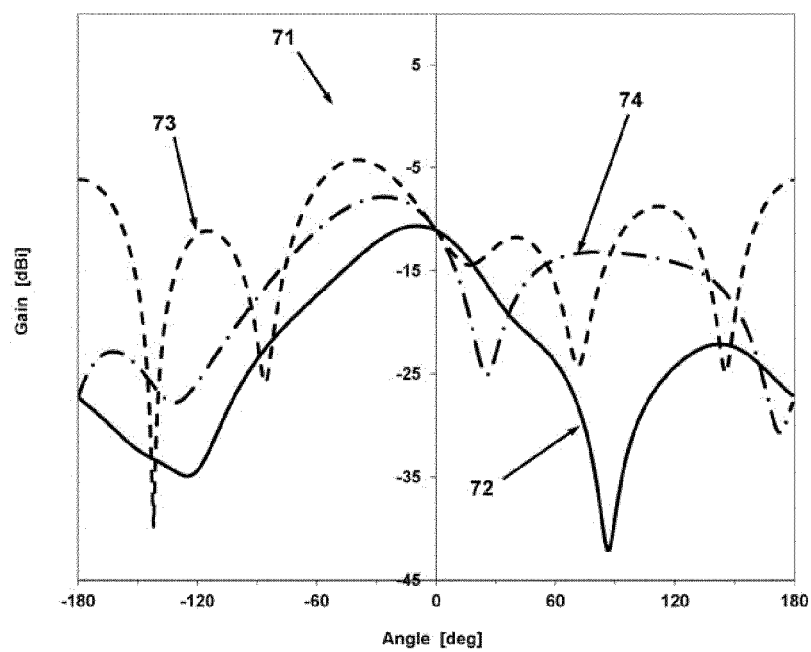


Figure 11: Plot of cross-polarized far-field gain radiation pattern of an exemplary radiating antenna element at 1660 MHz – solid line: E-plane cut; dashed line: mid-plane cut; dash-dotted line: H-plane cut.

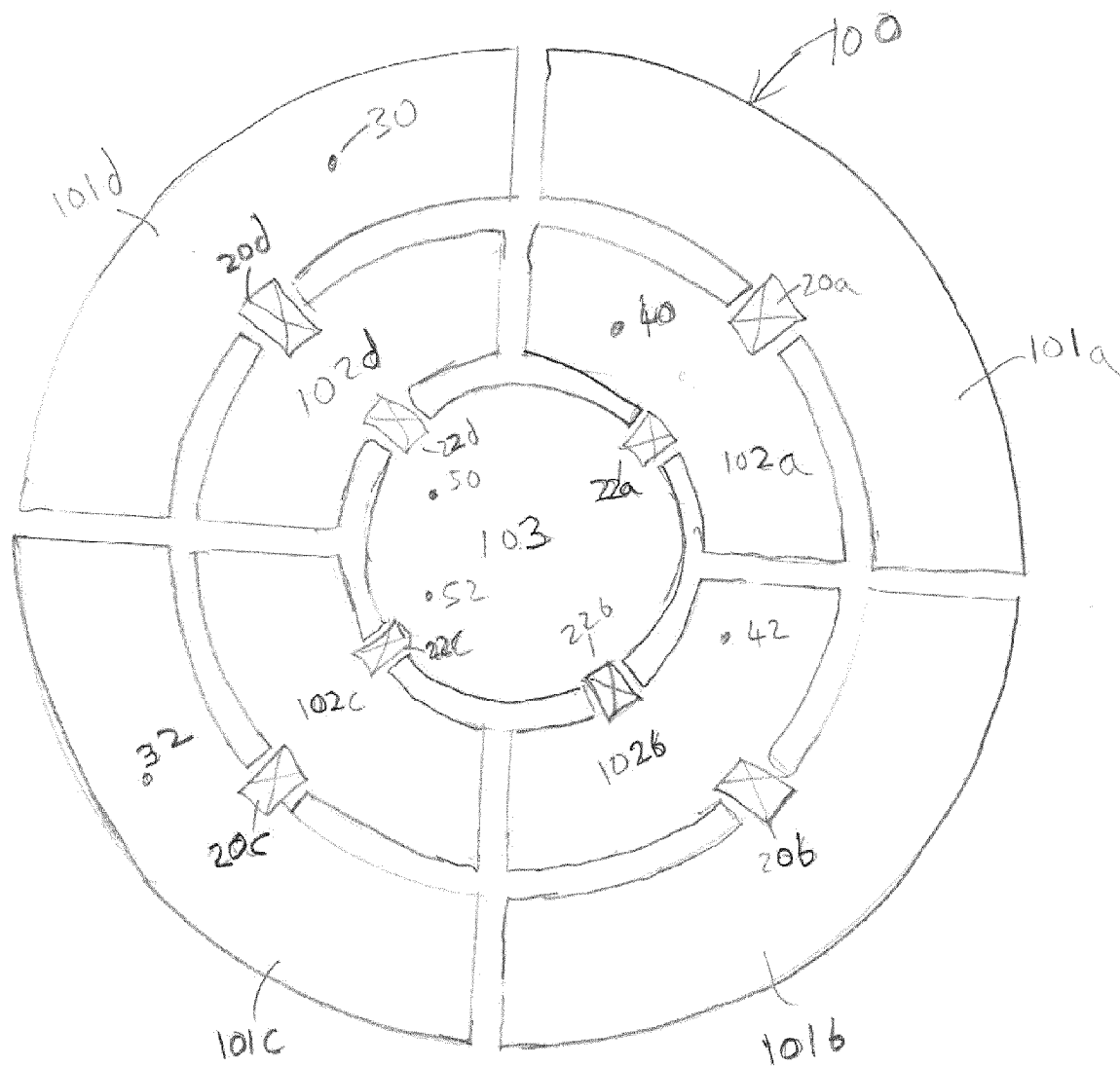


Figure 12



EUROPEAN SEARCH REPORT

Application Number
EP 14 30 6083

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 2 234 205 A1 (LAIRD TECHNOLOGIES AB [SE]) 29 September 2010 (2010-09-29) * abstract; figure 1 * * paragraphs [0030] - [0034] * -----	1-4,6,7,10-12,14	INV. H01Q5/00 H01Q9/04 H01Q9/26 H01Q21/24
X	US 2013/249753 A1 (ASANUMA KENICHI [JP] ET AL) 26 September 2013 (2013-09-26) * figures 1-5 * * paragraphs [0070] - [0077] * * paragraphs [0096], [0166] * -----	1-4,7,13-15	
X	WO 02/49151 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]) 20 June 2002 (2002-06-20) * abstract; figures 1,5 * * page 3, lines 10-29 * * page 5, line 26 - page 6, line 7 * -----	1	
X	US 2006/262028 A1 (TAKEI KEN [JP]) 23 November 2006 (2006-11-23) * abstract; figures 9,10 * * paragraphs [0074], [0075] * -----	1,4,7,8	TECHNICAL FIELDS SEARCHED (IPC)
X	HERRAIZ-MARTINEZ F J ET AL: "Dual-Frequency Printed Dipole Loaded With Split Ring Resonators", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, IEEE, PISCATAWAY, NJ, US, vol. 8, 1 January 2009 (2009-01-01), pages 137-140, XP011330909, ISSN: 1536-1225, DOI: 10.1109/LAWP.2009.2012402 * pages 137,138 * ----- -/--	1,9	H01Q
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 15 December 2014	Examiner Unterberger, Michael
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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EUROPEAN SEARCH REPORT

Application Number
EP 14 30 6083

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	DE 20 2004 021138 U1 (HIRSCHMANN ELECTRONICS GMBH [DE]) 22 February 2007 (2007-02-22) * figures 1,2 * * paragraphs [0014], [0015], [0017] * -----	1-15	
A	US 2010/302123 A1 (KNUDSEN MIKAEL BERGHOLZ [DK] ET AL) 2 December 2010 (2010-12-02) * figures 2-4 * * paragraphs [0036] - [0044] * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 15 December 2014	Examiner Unterberger, Michael
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 14 30 6083

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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15-12-2014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2234205 A1	29-09-2010	CN 101867085 A EP 2234205 A1	20-10-2010 29-09-2010
US 2013249753 A1	26-09-2013	CN 103229356 A US 2013249753 A1 WO 2013061502 A1	31-07-2013 26-09-2013 02-05-2013
WO 0249151 A1	20-06-2002	AT 333151 T CN 1401144 A DE 60121470 T2 EP 1346436 A1 JP 3978136 B2 JP 2004516700 A US 2002080088 A1 WO 0249151 A1	15-08-2006 05-03-2003 15-02-2007 24-09-2003 19-09-2007 03-06-2004 27-06-2002 20-06-2002
US 2006262028 A1	23-11-2006	CN 1650475 A EP 1553659 A1 JP 4101804 B2 US 2006262028 A1 WO 2004036687 A1	03-08-2005 13-07-2005 18-06-2008 23-11-2006 29-04-2004
DE 202004021138 U1	22-02-2007	NONE	
US 2010302123 A1	02-12-2010	DE 102010029265 A1 US 2010302123 A1	09-12-2010 02-12-2010

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 14205603 A [0008]

Non-patent literature cited in the description

- **HERRAIZ-MARTINEZ et al.** Dual-Frequency Printed Dipole Loaded With Split Ring Resonators. *IEEE Antennas and Wireless Propagation Letters*, 2009, vol. 8 [0005]