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(54) **A MULTI-BAND ANTENNA ARRANGEMENT**

(57) A multi-layer antenna arrangement having isolated first and second operational bandwidths, the antenna arrangement comprising, in order:
a first looped patch antenna element in a first layer;
a second looped patch antenna element in a second layer;
a third looped patch antenna element in a third layer;
a fourth looped patch antenna element in a fourth layer;
and
a conductive feed in a fifth layer,
wherein
the fourth looped patch antenna element in the fourth

layer and one of the second looped patch antenna element in the second layer and the first looped patch antenna element in the first layer are configured to form a first coupled pair of looped patch antennas that resonate within the first operational bandwidth and
the third looped patch antenna element in the third layer and the other of the second looped patch antenna element in the second layer and the first looped patch antenna element in the first layer are configured to form a second coupled pair of looped patch antennas that resonate within the second operational bandwidth.

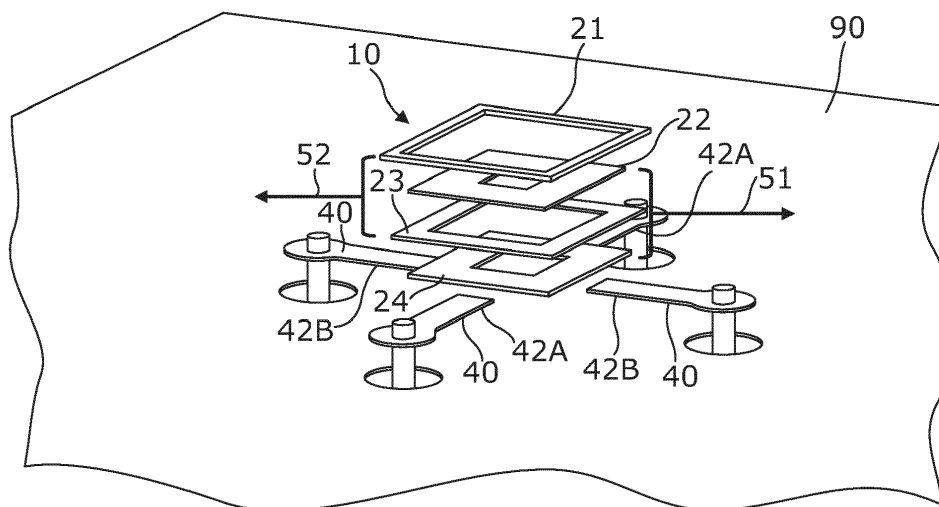


Fig. 2A

Description

TECHNOLOGICAL FIELD

[0001] Embodiments of the present invention relate to a multi-band antenna arrangement. Some embodiments of the present disclosure relate to a multi-band antenna arrangement suitable for use in 5G and other telecommunication systems.

BACKGROUND

[0002] Telecommunication standards specify operational frequency bands. It is therefore desirable for a transceiver to be multi-band and operate in multiple different operational frequency bands.

[0003] While, in some examples, it may be possible to use an antenna arrangement that has a single wide operational bandwidth that covers simultaneously multiple different operational frequency bands, this can be undesirable as there can then be insufficient isolation between communications in the different operational frequency bands causing interference.

BRIEF SUMMARY

[0004] According to various, but not necessarily all, embodiments there is provided a multi-layer antenna arrangement having isolated first and second operational bandwidths, the antenna arrangement comprising, in order:

- a first looped patch antenna element in a first layer;
- a second looped patch antenna element in a second layer;
- a third looped patch antenna element in a third layer;
- a fourth looped patch antenna element in a fourth layer; and
- a conductive feed arrangement in a fifth layer,

wherein

the fourth looped patch antenna element in the fourth layer and one of the second looped patch antenna element in the second layer and the first looped patch antenna element in the first layer are configured to form a first coupled pair of looped patch antennas that resonate within the first operational bandwidth and the third looped patch antenna element in the third layer and the other of the second looped patch antenna element in the second layer and the first looped patch antenna element in the first layer are configured to form a second coupled pair of looped patch antennas that resonate within the second operational bandwidth.

[0005] In some but not necessarily all examples, the first, second, third, fourth and fifth layers are integrated as a single component.

[0006] In some but not necessarily all examples, the first looped patch antenna element in the first layer is a

first printed conductive microstrip; the second looped patch antenna element in the second layer is a second printed conductive microstrip; the third looped patch antenna element in the third layer is a third printed conductive microstrip and the fourth looped patch antenna element in the fourth layer is a fourth printed conductive microstrip.

[0007] In some but not necessarily all examples, the first looped patch antenna element, the second looped patch antenna element, the third looped patch antenna element, and the fourth looped patch antenna element are integral components of a transceiver circuit board.

[0008] In some but not necessarily all examples, the first looped patch antenna element in the first layer and the third looped patch antenna element in the third layer are configured to form the first coupled pair of looped patch antennas that resonate within the first operational bandwidth and the second looped patch antenna element in the second layer and the fourth looped patch antenna element in the fourth layer are configured to form the second coupled pair of looped patch antennas that resonate within the second operational bandwidth.

[0009] In some but not necessarily all examples, the first coupled pair of looped patch antennas that resonate within the first operational bandwidth have relatively similar but not identical electrical lengths providing the first operational bandwidth and wherein the second coupled pair of looped patch antennas that resonate within the second operational bandwidth have relatively similar but not identical electrical lengths providing the second operational bandwidth and wherein the first coupled pair of looped patch antennas that resonate within the first operational bandwidth and the second coupled pair of looped patch antennas that resonate within the second operational bandwidth have relatively different electrical lengths providing isolation of the first and second operational bandwidths.

[0010] In some but not necessarily all examples, each looped patch antenna of the first coupled pair of looped patch antennas has a respective electrical length that defines a respective different resonant frequency that lies within the first operational bandwidth, and each looped patch antenna of the second coupled pair of looped patch antennas has a respective electrical length that defines a respective different resonant frequency that lies within the second operational bandwidth.

[0011] In some but not necessarily all examples, the looped patch antennas of the first coupled pair of looped patch antennas have axes of rotational symmetry that are aligned and the looped patch antennas of the second coupled pair of looped patch antennas have axes of rotational symmetry that are aligned.

[0012] In some but not necessarily all examples, each looped patch antenna element comprises a continuous conductor that forms a closed loop around an inner aperture.

[0013] In some but not necessarily all examples, the continuous conductor of each looped patch antenna has

a constant width.

[0014] In some but not necessarily all examples, a distance separating the first looped patch antenna element in the first layer and the second looped patch antenna element in the second layer is less than a distance separating the first coupled pair of looped patch antennas and less than a distance separating the second coupled pair of looped patch antennas.

[0015] In some but not necessarily all examples, the conductive feed arrangement is configured for dual polarization.

[0016] In some but not necessarily all examples, the first operational bandwidth and the second operational bandwidth are each a non-overlapping range starting at a frequency value greater than 24GHz.

[0017] In some but not necessarily all examples, an electronic communications device comprises the multi-layer antenna arrangement. In some but not necessarily all examples, the multi-layer antenna arrangement is directly connected to amplification circuitry without an intervening band stop filter component.

[0018] According to various, but not necessarily all, embodiments there is provided examples as claimed in the appended claims.

BRIEF DESCRIPTION

[0019] Some example embodiments will now be described with reference to the accompanying drawings in which:

FIG 1 shows an example of the subject-matter described herein;

FIG 2A shows an example of the subject-matter described herein;

FIG 2B shows an example of the subject-matter described herein;

FIG 2C shows an example of the subject-matter described herein;

FIG 3A shows an example of the subject-matter described herein;

FIG 3B shows an example of the subject-matter described herein;

FIG 4 shows an example of the subject-matter described herein;

FIG 5A shows an example of the subject-matter described herein;

FIG 5B shows an example of the subject-matter described herein;

FIG 6 shows an example of the subject-matter described herein; and

FIG 7 shows an example of the subject-matter described herein;

DETAILED DESCRIPTION

[0020] FIG 1 illustrates in side view, a cross-section through a generic example of multi-layer antenna ar-

range 10. Each of FIGs 2A, 2B, 2C illustrate, in perspective view, a particular example of a multi-layer antenna arrangement 10 as illustrated in FIG 1. The multi-layer antenna arrangement 10 has isolated first and second operational bandwidths 100_1 , 100_2 as illustrated in FIG 3A.

[0021] The multi-layer antenna arrangement 10 comprises, in order:

a first looped patch antenna element 21 in a first layer 31;

a second looped patch antenna element 22 in a second layer 32;

a third looped patch antenna element 23 in a third layer 33;

a fourth looped patch antenna element 24 in a fourth layer 34; and

one or more conductive feeds 40 in a fifth layer 35.

[0022] In at least some examples, the multi-layer antenna arrangement 10 uses a ground plane 90. The fourth looped patch antenna element 24 in the fourth layer 34 is the looped patch antenna element nearest the ground plane. In some but not necessarily all examples, for example as illustrated in FIGs 2A, 2B, 2C, the multi-layer antenna arrangement 10 comprises the ground plane 90 in a sixth layer 36 in the ordered stack of layers.

[0023] The fourth looped patch antenna element 24 in the fourth layer 34 and one of the second looped patch antenna element 22 in the second layer 32 and the first looped patch antenna element 21 in the first layer 31 are configured to form a first coupled pair 51 of looped patch antennas that resonate within the first operational bandwidth 100_1 .

[0024] The third looped patch antenna element 23 in the third layer 33 and the other of the second looped patch antenna element 22 in the second layer 32 and the first looped patch antenna element 21 in the first layer 31 are configured to form a second coupled pair 52 of looped patch antennas that resonate within the second operational bandwidth 100_2 .

[0025] In the example (i) in FIG 1, the fourth looped patch antenna element 24 in the fourth layer 34 and the second looped patch antenna element 22 in the second layer 32 are configured to form a first coupled pair 51 of looped patch antennas that resonate within the first operational bandwidth 100_1 . and the third looped patch antenna element 23 in the third layer 33 and the first looped patch antenna element 21 in the first layer 31 are configured to form a second coupled pair 52 of looped patch antennas that resonate within the second operational bandwidth 100_2 .

[0026] In the example (ii) in FIG 1, the fourth looped patch antenna element 24 in the fourth layer 34 and the first looped patch antenna element 21 in the first layer 31 are configured to form a first coupled pair 51 of looped patch antennas that resonate within the first operational bandwidth 100_1 and the third looped patch antenna ele-

ment 23 in the third layer 33 and the second looped patch antenna element 22 in the second layer are configured to form a second coupled pair 52 of looped patch antennas that resonate within the second operational bandwidth 100_2 .

[0027] In the examples (i) and (ii) in FIG 1, each of the looped patch antenna elements 21, 22, 23, 24 form a coupled pair 51, 52 of looped patch antennas. Not every pair 51, 52 are pairings of immediately physically adjacent looped patch antenna elements. There is at least one pair 51, 52 of looped patch antenna elements, where the looped patch antenna elements of the pair 51, 52 are separated by at least one other looped patch antenna element.

[0028] In other examples of the multi-layer antenna arrangement 10 there can be $2N$ looped patch antenna elements forming N coupled pairs of looped patch antennas. Not every pair 51, 52 are pairings of immediately adjacent looped patch antenna elements. There can be at least one pair 51, 52 of looped patch antenna elements, where the looped patch antenna elements of the pair 51, 52 are separated by one or more other looped patch antenna elements. Each pair of looped patch antennas provides a new operational bandwidth 100_n .

[0029] In some but not necessarily all examples, the first operational bandwidth 100_1 is at a higher frequency than the second operational bandwidth 100_2 .

[0030] In some but not necessarily all examples, the first operational bandwidth 100_1 is at a lower frequency than the second operational bandwidth 100_2 .

[0031] In the example of FIG 3A, the first operational bandwidth 100_1 is at a lower range of frequencies than the second operational bandwidth 100_2 .

[0032] FIG 3A illustrates a frequency response 70 of a reflection parameter S11 for the multi-layer antenna arrangement 10 when the first operational bandwidth 100_1 is at a lower frequency than the second operational bandwidth 100_2 .

[0033] The reflection parameter S11 is less than a threshold value T in the first operational band 72_1 and the second operational band 72_2 and is more than a threshold value T in a stop band S . The stop band S splits a frequency range F into two distinct operational frequency bands - the first operational bandwidth 100_1 ($F1$), and the second operational bandwidth 100_2 ($F2$). The stop band S reduces cross-talk (interference) between the operational frequency bands 72_1 , 72_2 .

[0034] The first operational bandwidth and the second operational bandwidth can both be a range that starts at a value greater than 24GHz. For example, if the operational bandwidths 100 are defined by a threshold -10 dB for the reflection parameter S11, then in some examples, the first operational band 72_1 has a first operational bandwidth 100_1 ($F1$) from 24.25 to 29.5 GHz and the second operational band 72_2 has a second operational bandwidth 100_2 ($F2$) from 37 to 40 GHz.

[0035] FIG 3B schematically illustrates a frequency response 50 of the reflection parameter S11 for each of

the looped patch antenna elements 21, 22, 23, 24 that combine to form the multi-layer antenna arrangement 10 whose overall frequency response 70 has been discussed with reference to FIG 3A.

[0036] For the purpose of the following example, the second looped patch antenna element 22 in the second layer 32 and the fourth looped patch antenna element 24 in the fourth layer 34 are configured to form the first coupled pair 51 of looped patch antennas that resonate within the first operational bandwidth 100_1 and the first looped patch antenna element 21 in the first layer 31 and the third looped patch antenna element 23 in the third layer 33 are configured to form the second coupled pair 52 of looped patch antennas that resonate within the second operational bandwidth 100_2 . This corresponds to example (i) in FIG 1.

[0037] Each looped patch antenna element 22, 24 of the first coupled pair 51 of looped patch antennas has a respective different electrical length that defines a respective different resonant frequency that lies within the first operational bandwidth 100_1 but outside the second operational bandwidth 100_2 .

[0038] Whereas physical length is a measurement of how long it takes electromagnetic waves to travel along a conductor that is resistive only; electrical length is a measurement of how long it takes electromagnetic waves to travel along a conductor that has resistance and reactance. The reactance may arise from capacitance and/or inductance and can be engineered.

[0039] The first coupled pair 51 of looped patch antennas 22, 24 that resonate within the first operational bandwidth 100_1 have relatively similar but not identical electrical lengths. The second looped patch antenna element 22 in the second layer 32 has a second electrical length $L2^*$ which is related to the physical length $L2$, as illustrated in FIG 1. The fourth looped patch antenna element 24 in the fourth layer 34 has a fourth electrical length $L4^*$ which is related to the physical length $L4$, as illustrated in FIG 1. In this example, $L2^* = L4^* + \delta 1$.

[0040] The second looped patch antenna element 22 has a frequency response 50_2 of the reflection parameter S11. A fundamental mode of the second looped patch antenna element 22 is responsible for a second resonance mode 52_2 that has a resonant wavelength that is dependent on the electrical length $L2^*$ of the second looped patch antenna element 22. The resonant frequency RF_2 illustrated in FIG 3B is determined by the resonant wavelength.

[0041] The fourth looped patch antenna element 24 has a frequency response 50_4 of the reflection parameter S11. A fundamental mode of the fourth looped patch antenna element 24 is responsible for a fourth resonance mode 52_4 that has a resonant wavelength that is dependent upon the electrical length $L4^*$ of the fourth looped patch antenna element 24. The resonant frequency RF_4 illustrated in FIG 3B is determined by the resonant wavelength.

[0042] Each of the resonant modes 52_2 , 52_4 for the

first coupled pair 51 of looped patch antennas 22, 24 has an associated operational frequency band. The associated operational frequency bands of the multiple resonant modes 52_2 , 52_4 overlap. The overlap is sufficient to define a combined operational frequency band 72_1 , as illustrated in FIG 3A, that has the first operational bandwidth 100_1 (F1).

[0043] Each looped patch antenna element 21, 23 of the second coupled pair 52 of looped patch antennas has a respective different electrical length that defines a respective different resonant frequency that lies within the second operational bandwidth 100_2 but outside the first operational bandwidth 100_1 .

[0044] The second coupled pair 52 of looped patch antennas 21, 23 that resonate within the second operational bandwidth 100_2 have relatively similar but not identical electrical lengths. The first looped patch antenna element 21 in the first layer 31 has a first electrical length $L1^*$ which is related to the physical length $L1$, as illustrated in FIG 1. The third looped patch antenna element 23 in the third layer 33 has a third electrical length $L3^*$ which is related to the physical length $L3$, as illustrated in FIG 1. In this example, $L1^* = L3^* + \delta_1$.

[0045] The first looped patch antenna element 21 has a frequency response 50_1 of the reflection parameter S_{11} . A fundamental mode of the first looped patch antenna element 21 is responsible for a first resonance mode 52_1 that has a resonant wavelength that is dependent upon the electrical length $L1^*$ of the first looped patch antenna element 21. The resonant frequency RF_1 illustrated in FIG 3B is determined by the resonant wavelength.

[0046] The third looped patch antenna element 23 has a frequency response 50_3 of the reflection parameter S_{11} . A fundamental mode of the third looped patch antenna element 23 is responsible for a third resonance mode 52_3 that has a resonant wavelength that is dependent upon the electrical length $L3^*$ of the third looped patch antenna element 23. The resonant frequency RF_3 illustrated in FIG 3B is determined by the resonant wavelength.

[0047] In the above examples, a fundamental mode, for example a dipole mode, of a looped patch antenna element is responsible for the resonance mode 52_n that has a resonant wavelength that is dependent upon, for example twice, the electrical length L_n^* of the looped patch antenna element.

[0048] The resonance of a looped patch antenna element when configured as a square ring patch antenna can, for example, be defined by the ratio of the physical length (L) of the ring and the equivalent physical length of the square central aperture 64. If one considers a virtual line passing through a center of the aperture 64, then the length of the looped patch antenna element is the distance along this line between the outer edges 68 and the length of the square central aperture 64 is the distance along this line between the inner edges 66. The distance between the inner edges 66 along the line is

equal to the physical length minus the widths of looped patch antenna element along the line, that is minus the sum of the distances along the line between adjacent inner and outer edges 66, 68. In this example, the resonant wavelength of the looped patch antenna element is dependent upon multiple dimensions (length and width; length and aperture size) of the looped patch antenna element.

[0049] In at least some examples the widths of the looped patch antenna element is constant. However, in other examples it may vary. In a dual polarized scenario the structure should be symmetric. In a single polarized structure width may change on different sides.

[0050] Each of the resonant modes 52_1 , 52_3 for the second coupled pair 52 of looped patch antennas 21, 23 has an associated operational frequency band. The associated operational frequency bands of the multiple resonant modes 52_1 , 52_3 overlap. The overlap is sufficient to define a combined operational frequency band 72_2 , as illustrated in FIG 3A, that has the second operational bandwidth 100_2 (F2).

[0051] In some but not necessarily all examples, the first coupled pair 51 of looped patch antennas 22, 24 that resonate within the first operational bandwidth 100_1 and second coupled pair 52 of looped patch antennas 21, 23 that resonate within the second operational bandwidth 100_2 have relatively different electrical lengths, sufficient to cause isolation between the first operational bandwidth 100_1 (F1) and the second operational bandwidth 100_2 (F2).

[0052] Where the first operational bandwidth 100_1 is at lower frequencies (longer wavelengths) than the second operational bandwidth 100_2 , then the difference between the electrical lengths $L2$, $L4$ of the first coupled pair 51 of looped patch antennas 22, 24 that resonate within the first operational bandwidth 100_1 is greater than the difference between the electrical lengths $L1$, $L3$ of the second coupled pair 52 of looped patch antennas 21, 23 that resonate within the second operational bandwidth 100_2 . This will be necessary, if for example, the first operational bandwidth 100_1 and the second operational bandwidth 100_2 are to have a similar frequency range.

[0053] Referring to FIGs 1, 2A, 2B, 2C and FIG 4 the looped patch antenna elements of the first coupled pair 51 of looped patch antennas have axes 60 of rotational symmetry that are aligned and the looped patch antenna elements of the second coupled pair 52 of looped patch antennas have axes 60 of rotational symmetry that are aligned.

[0054] As illustrated in FIGs 1, 2A, 2B, 2C in at least some examples, the looped patch antenna elements of the first coupled pair 51 of looped patch antennas and the looped patch antenna elements of the second coupled pair 52 of looped patch antennas have a common shared axis 60 of rotational symmetry. In this example, but not necessarily all examples, the rotational symmetry is 90° rotational symmetry.

[0055] An axes of n-fold rotational symmetry is a vector

about which a looped patch antenna can be rotated by $360^\circ/n$, without any apparent change to the orientation of the looped patch antenna.

[0056] Although in these FIGs, the looped patch antenna elements are square and have 4-fold rotational symmetry in other examples they may be triangular (3-fold rotational symmetry) or rectangular (2-fold rotational symmetry).

[0057] FIG 4 illustrates an example of a looped patch antenna element. In the example it is labelled as the first looped patch antenna element 21. However, it also illustrates features that are shared between the first, second, third, fourth looped patch antenna elements 21, 22, 23, 24. FIG 4 is a top plan view. FIGs 5A and 5B are cross-sectional views along the lines XX and YY of FIG 4, respectively.

[0058] The looped patch antenna 21 comprises a continuous conductor 62 that forms a closed planar loop around an inner aperture 64. The looped patch antenna 21 can also be called a ring patch, although this does not necessarily imply a particular shape.

[0059] In the example illustrated, the looped patch antennas of the first and second coupled pairs 51, 52 of looped patch antennas are each a loop of constant width W. The respective first, second, third, fourth looped patch antenna elements 21, 22, 23, 24 can each have a different respective width W1, W2, W3, W4.

[0060] In the example illustrated, the looped patch antennas of the first and second coupled pairs 51, 52 of looped patch antennas are each a loop of length dimension L. The respective first, second, third, fourth looped patch antenna elements 21, 22, 23, 24 can each have a different respective length L1, L2, L3, L4.

[0061] The looped patch antennas of the first and second coupled pairs 51, 52 of looped patch antennas can each be a square planar loop of conductive material 62 aligned on the same axis 60. The square has a side of length L.

[0062] The conductor 62 defining the looped patch antenna element has an inner edge 66 that circumscribes an aperture 64 and an exterior edge 68. The size of the aperture 64 can, in some examples, be several times wider than the width W.

[0063] As illustrated in FIG 5A and 5B, the looped patch antennas of the first and second coupled pairs 51, 52 of looped patch antennas are each at a height H above a ground plane 90. The respective first, second, third, fourth looped patch antenna elements 21, 22, 23, 24 can each have a different respective heights H1, H2, H3, H4.

[0064] In some examples, the distance separating the first looped patch antenna 21 and the second looped patch antenna 22 (H1-H2) is less than the distance separating the first coupled pair 51 of looped patch antennas and less than the distance separating the second coupled pair 52 of looped patch antennas.

[0065] Considering the example (i) in FIG 1, the distance separating the first looped patch antenna 21 and the second looped patch antenna 22 (H1-H2) is less than

the distance (H2-H4) separating the first coupled pair 51 of looped patch antennas 22, 24 and less than the distance (H1-H3) separating the second coupled pair 52 of looped patch antennas 21, 23.

[0066] Considering the example (ii) in FIG 1, the distance separating the first looped patch antenna 21 and the second looped patch antenna 22 (H1-H2) is less than the distance (H1-H4) separating the first coupled pair 51 of looped patch antennas 21, 24 and less than the distance (H2-H3) separating the second coupled pair 52 of looped patch antennas 22, 23.

[0067] The first, second, third, fourth looped patch antenna elements 21, 22, 23, 24 can be arranged to differ from each other in dimensional parameters, for example, one of more of: length L, width W, height H. The dimensional parameters (length Ln, width Wn, height Hn) of the first, second, third, fourth looped patch antenna elements 2n (n=1, 2, 3, 4) can be tuned to obtain a desired performance of the multi-layer antenna arrangement 10.

[0068] Referring back to the examples of FIGs 2A, 2B, 2C, each FIG illustrates a multi-layer antenna arrangement 10 that uses a different dual polarized feed arrangement 40.

[0069] In FIG 2A, the feed arrangement 40 is a differential feed arrangement. It comprises two pairs of differential feeds 42. There is a pair of microstrip feeds 42 for each one of two orthogonal polarizations. Each feed 42 can be a proximity coupled L probe. The pair of feeds 42A provide a first polarized, differential feed. The pair of feeds 42B provide a second polarized, differential feed.

[0070] In FIG 2B, the feed arrangement 40 is a single ended feed. It comprises two feeds 42. There is a microstrip feed 42 for each one of two orthogonal polarizations. Each feed 42 can be a proximity coupled L probe. The feed 42A provides a first polarized single ended feed. The feed 42B provides a second polarized, single ended feed.

[0071] In FIG 2C, the feed arrangement 40 is an aperture couple feed. Instead of providing a microstrip feed, an aperture 44 in a conductive ground plane is provided according in Babinet's principle.

[0072] Whereas FIGs 2A, 2B, 2C illustrate dual-polarized feeds, in other examples the feeds may be used as single polarization feeds or may be adapted to operate as single polarization feeds.

[0073] Fig 6 illustrates an example of the multi-layer antenna arrangement 10 as previously described. In this example, the first, second, third, fourth, fifth and sixth layers 31, 32, 33, 34, 35, 36 are integrated as a single component 120.

[0074] The single component 120 can, in some examples, be a substrate 122 where the first, second, third, fourth, fifth and sixth layers 31, 32, 33, 34, 35, 36 are stacked layers within a common substrate 122.

[0075] In some but not necessarily all examples, the substrate 122 is a substrate of a transceiver circuit board.

[0076] The looped patch antenna elements 21, 22, 23, 24 (not illustrated in FIG 6) can be printed conductive

strips.

[0077] Standard PCB manufacturing techniques can be used.

[0078] In some but not necessarily all examples, one or more but not all of the first, second, third, fourth, fifth and sixth layers 31, 32, 33, 34, 35, 36 are part of a first component, for example an antenna circuit board and the other ones of the first, second, third, fourth, fifth and sixth layers 31, 32, 33, 34, 35, 36 are part of a second component, for example a transceiver circuit board.

[0079] Different materials with different dielectric constant (ϵ_r) values can be used between the first, second, third, fourth, fifth and sixth layers 31, 32, 33, 34, 35, 36. For example, if higher ϵ_r is used, then the stacked structure of one or more but not all of the first, second, third, fourth looped patch antenna elements 21, 22, 23, 24 is more compact compared with a lower ϵ_r stack.

[0080] In the preceding examples, four patch antenna elements 21, 22, 23, 24 are paired to create two pairs that have respective different operational bandwidths. In other examples, 2M patch antenna elements can be paired to create M pairs that have respective M different operational bandwidths.

[0081] The antenna arrangement 10 can be configured as a filtenna. The antenna structure provides not just antenna functionality but also filtering functionality.

FIG 7 illustrates an example of an electronic communications device 200, for example, a transceiver system 200, comprising the multi-layer antenna arrangement 10. The communications device 200 comprises a receiver system and a transmitter system. In this example, the multi-layer antenna arrangement 10 is directly connected to amplification circuitry 202 without an intervening band stop filter component. The absence of the band stop filter component is indicated by reference 206 in the receiver system and the transmitter system.

[0082] The communication device 200 may, for example, be used in a base station or a mobile station. It may, for example, be suitable for, and not limited to, use in 5G telecommunications.

[0083] In a receiver only implementation, the receiver system is present but the transmitter system is not. In a transmitter only implementation, the transmitter system is present but the receiver system is not.

[0084] The communication device 200 and/or the multi-layer antenna arrangement 10 have several advantages including compact size, good inter-band rejection, a constant radiation pattern shape for dual band and dual polarization, ease of fabrication and freedom of resonator design by adjusting the geometry of four individual looped patch antenna elements 21, 22, 23, 24.

[0085] A radio module and/or a complete radio unit can comprise the multi-layer antenna arrangement 10 and associated transmitter and/or receiver circuitry.

[0086] The multi-layer antenna arrangement 10 can be used to form an antenna array. Multiple ones of the multi-layer antenna arrangement 10 can be used to form an antenna array.

[0087] Where a structural feature has been described, it may be replaced by means for performing one or more of the functions of the structural feature whether that function or those functions are explicitly or implicitly described.

[0088] An operational resonant mode (operational band or bandwidth) is a frequency range over which an antenna can efficiently operate. An operational resonant mode (operational band) may be defined as where the absolute value of the return loss S11 of the antenna arrangement is greater than an operational threshold T.

[0089] The antenna arrangement 10 may be configured to operate in a plurality of operational resonant frequency bands. For example, the operational frequency bands may include (but are not limited to) Long Term Evolution (LTE) (US) (734 to 746 MHz and 869 to 894 MHz), Long Term Evolution (LTE) (rest of the world) (791 to 821 MHz and 925 to 960 MHz), amplitude modulation (AM) radio (0.535-1.705 MHz); frequency modulation (FM) radio (76-108 MHz); Bluetooth (2400-2483.5 MHz); wireless local area network (WLAN) (2400-2483.5 MHz); hiper local area network (HiperLAN) (5150-5850 MHz); global positioning system (GPS) (1570.42-1580.42 MHz); US - Global system for mobile communications (US-GSM) 850 (824-894 MHz) and 1900 (1850 - 1990 MHz); European global system for mobile communications (EGSM) 900 (880-960 MHz) and 1800 (1710 - 1880 MHz); European wideband code division multiple access (EU-WCDMA) 900 (880-960 MHz); personal communications network (PCN/DCS) 1800 (1710-1880 MHz); US wideband code division multiple access (US-WCDMA) 1700 (transmit: 1710 to 1755 MHz, receive: 2110 to 2155 MHz) and 1900 (1850-1990 MHz); wideband code division multiple access (WCDMA) 2100 (transmit: 1920-1980 MHz, receive: 2110-2180 MHz); personal communications service (PCS) 1900 (1850-1990 MHz); time division synchronous code division multiple access (TD-SCDMA) (1900 MHz to 1920 MHz, 2010 MHz to 2025 MHz), ultra wideband (UWB) Lower (3100-4900 MHz); UWB Upper (6000-10600 MHz); digital video broadcasting - handheld (DVB-H) (470-702 MHz); DVB-H US (1670-1675 MHz); digital radio mondiale (DRM) (0.15-30 MHz); worldwide interoperability for microwave access (WiMax) (2300-2400 MHz, 2305-2360 MHz, 2496-2690 MHz, 3300-3400 MHz, 3400-3800 MHz, 5250-5875 MHz); digital audio broadcasting (DAB) (174.928-239.2 MHz, 1452.96- 1490.62 MHz); radio frequency identification low frequency (RFID LF) (0.125-0.134 MHz); radio frequency identification high frequency (RFID HF) (13.56-13.56 MHz); radio frequency identification ultra high frequency (RFID UHF) (433 MHz, 865-956 MHz, 2450 MHz); 5G communications (not yet finalized but may include e.g. 700MHz, 3.6-3.8GHz, 24.25-27.5GHz, 31.8-33.4GHz, 37.45-43.5, 66-71 GHz, mmWave, and > 24GHz).

[0090] As used here 'module' refers to a unit or apparatus that excludes certain parts/components that would be added by an end manufacturer or a user. The antenna

arrangement 10 can be a module.

[0091] The above described examples find application as enabling components of:

satellite communications and wireless industrial systems (industrial internet); automotive systems; telecommunication systems; electronic systems including consumer electronic products; distributed computing systems; media systems for generating or rendering media content including audio, visual and audio visual content and mixed, mediated, virtual and/or augmented reality; personal systems including personal health systems or personal fitness systems; navigation systems; user interfaces also known as human machine interfaces; networks including cellular, non-cellular, and optical networks; ad-hoc networks; the internet; the internet of things; virtualized networks; and related software and services.

[0092] The term 'comprise' is used in this document with an inclusive not an exclusive meaning. That is any reference to X comprising Y indicates that X may comprise only one Y or may comprise more than one Y. If it is intended to use 'comprise' with an exclusive meaning then it will be made clear in the context by referring to "comprising only one" or by using "consisting".

[0093] In this description, reference has been made to various examples. The description of features or functions in relation to an example indicates that those features or functions are present in that example. The use of the term 'example' or 'for example' or 'can' or 'may' in the text denotes, whether explicitly stated or not, that such features or functions are present in at least the described example, whether described as an example or not, and that they can be, but are not necessarily, present in some of or all other examples. Thus 'example', 'for example', 'can' or 'may' refers to a particular instance in a class of examples. A property of the instance can be a property of only that instance or a property of the class or a property of a sub-class of the class that includes some but not all of the instances in the class. It is therefore implicitly disclosed that a feature described with reference to one example but not with reference to another example, can where possible be used in that other example as part of a working combination but does not necessarily have to be used in that other example.

[0094] Although embodiments have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the claims.

[0095] Features described in the preceding description may be used in combinations other than the combinations explicitly described above.

[0096] Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

[0097] Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

[0098] The term 'a' or 'the' is used in this document with an inclusive not an exclusive meaning. That is any reference to X comprising a/the Y indicates that X may comprise only one Y or may comprise more than one Y unless the context clearly indicates the contrary. If it is intended to use 'a' or 'the' with an exclusive meaning then it will be made clear in the context. In some circumstances the use of 'at least one' or 'one or more' may be used to emphasize an inclusive meaning but the absence of these terms should not be taken to infer an exclusive meaning.

[0099] The presence of a feature (or combination of features) in a claim is a reference to that feature or (combination of features) itself and also to features that achieve substantially the same technical effect (equivalent features). The equivalent features include, for example, features that are variants and achieve substantially the same result in substantially the same way. The equivalent features include, for example, features that perform substantially the same function, in substantially the same way to achieve substantially the same result.

[0100] In this description, reference has been made to various examples using adjectives or adjectival phrases to describe characteristics of the examples. Such a description of a characteristic in relation to an example indicates that the characteristic is present in some examples exactly as described and is present in other examples substantially as described.

[0101] Whilst endeavoring in the foregoing specification to draw attention to those features believed to be of importance it should be understood that the Applicant may seek protection via the claims in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not emphasis has been placed thereon.

Claims

1. A multi-layer antenna arrangement having isolated first and second operational bandwidths, the antenna arrangement comprising, in order:

- a first looped patch antenna element in a first layer;
- a second looped patch antenna element in a second layer;
- a third looped patch antenna element in a third layer;
- a fourth looped patch antenna element in a fourth layer; and
- a conductive feed arrangement in a fifth layer,

wherein

the fourth looped patch antenna element in the fourth layer and one of the second looped patch antenna element in the second layer and the first looped patch antenna element in the first layer are configured to

form a first coupled pair of looped patch antennas that resonate within the first operational bandwidth and

the third looped patch antenna element in the third layer and the other of the second looped patch antenna element in the second layer and the first looped patch antenna element in the first layer are configured to form a second coupled pair of looped patch antennas that resonate within the second operational bandwidth.

2. A multi-layer antenna arrangement as claimed in claim 1, wherein the first, second, third, fourth and fifth layers are integrated as a single component.
3. A multi-layer antenna arrangement as claimed in any preceding claim, wherein the first looped patch antenna element in the first layer is a first printed conductive microstrip; the second looped patch antenna element in the second layer is a second printed conductive microstrip; the third looped patch antenna element in the third layer is a third printed conductive microstrip and the fourth looped patch antenna element in the fourth layer is a fourth printed conductive microstrip.
4. A multi-layer antenna arrangement as claimed in any preceding claim, wherein the first looped patch antenna element, the second looped patch antenna element, the third looped patch antenna element, and the fourth looped patch antenna element are integral components of a transceiver circuit board.
5. A multi-layer antenna arrangement as claimed in any preceding claim, wherein the first looped patch antenna element in the first layer and the third looped patch antenna element in the third layer are configured to form the first coupled pair of looped patch antennas that resonates within the first operational bandwidth and the second looped patch antenna element in the second layer and the fourth looped patch antenna element in the fourth layer are configured to form the second coupled pair of looped patch antennas that resonate within the second operational bandwidth.
6. A multi-layer antenna arrangement as claimed in any preceding claim, wherein the first coupled pair of looped patch antennas that resonate within the first operational bandwidth have relatively similar but not identical electrical lengths providing the first operational bandwidth and wherein the second coupled pair of looped patch antennas that resonate within the second operational bandwidth have relatively similar but not identical electrical lengths providing the second operational bandwidth and wherein the first coupled pair of looped patch antennas that resonate within the first operational bandwidth and the

second coupled pair of looped patch antennas that resonate within the second operational bandwidth have relatively different electrical lengths providing isolation of the first and second operational bandwidths.

7. A multi-layer antenna arrangement as claimed in any preceding claim, wherein each looped patch antenna of the first coupled pair of looped patch antennas has a respective electrical length that defines a respective different resonant frequency that lies within the first operational bandwidth, and each looped patch antenna of the second coupled pair of looped patch antennas has a respective electrical length that defines a respective different resonant frequency that lies within the second operational bandwidth.
8. A multi-layer antenna arrangement as claimed in any preceding claim, wherein the looped patch antennas of the first coupled pair of looped patch antennas have axes of rotational symmetry that are aligned and the looped patch antennas of the second coupled pair of looped patch antennas have axes of rotational symmetry that are aligned.
9. A multi-layer antenna arrangement as claimed in any preceding claim, wherein each looped patch antenna element comprises a continuous conductor that forms a closed loop around an inner aperture.
10. A multi-layer antenna arrangement as claimed in claim 9, wherein the continuous conductor of each looped patch antenna has a constant width.
11. A multi-layer antenna arrangement as claimed in any preceding claim, wherein a distance separating the first looped patch antenna element in the first layer and the second looped patch antenna element in the second layer is less than a distance separating the first coupled pair of looped patch antennas and less than a distance separating the second coupled pair of looped patch antennas.
12. A multi-layer antenna arrangement as claimed in any preceding claim, wherein the conductive feed arrangement is configured for dual polarization.
13. A multi-layer antenna arrangement as claimed in any preceding claim, wherein the first operational bandwidth and the second operational bandwidth are each a non-overlapping range starting at a frequency value greater than 24GHz.
14. An electronic communications device comprising the multi-layer antenna arrangement as claimed in any preceding claim.
15. An electronic communication device as claimed in

claim 14, wherein the multi-layer antenna arrangement is configured as a filtenna and is directly connected to amplification circuitry without an intervening band stop filter component.

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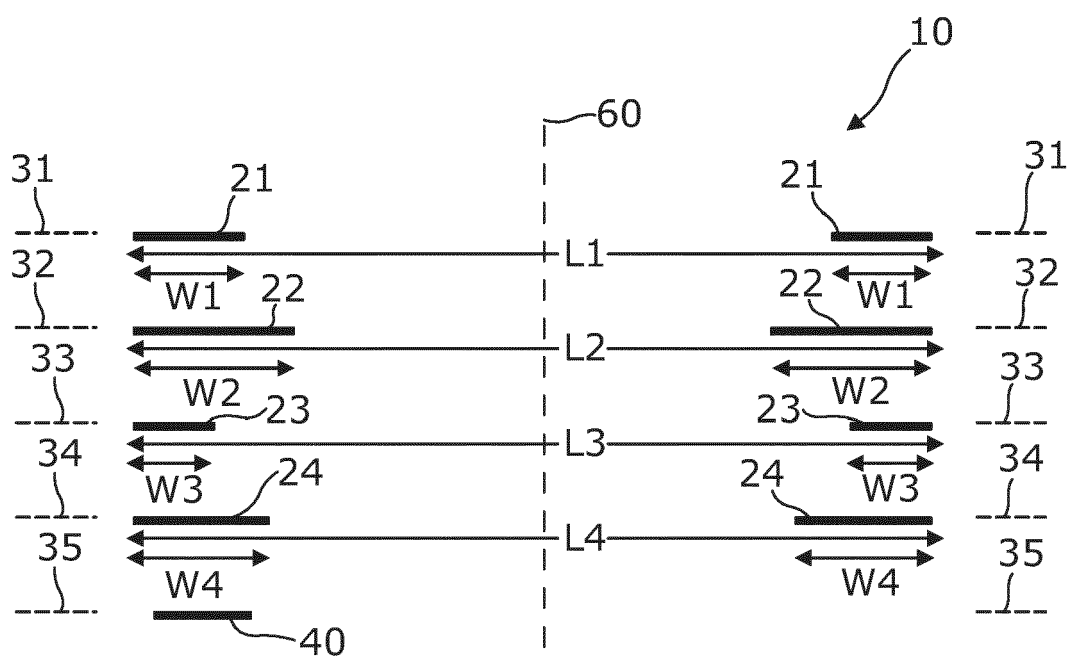


Fig. 1

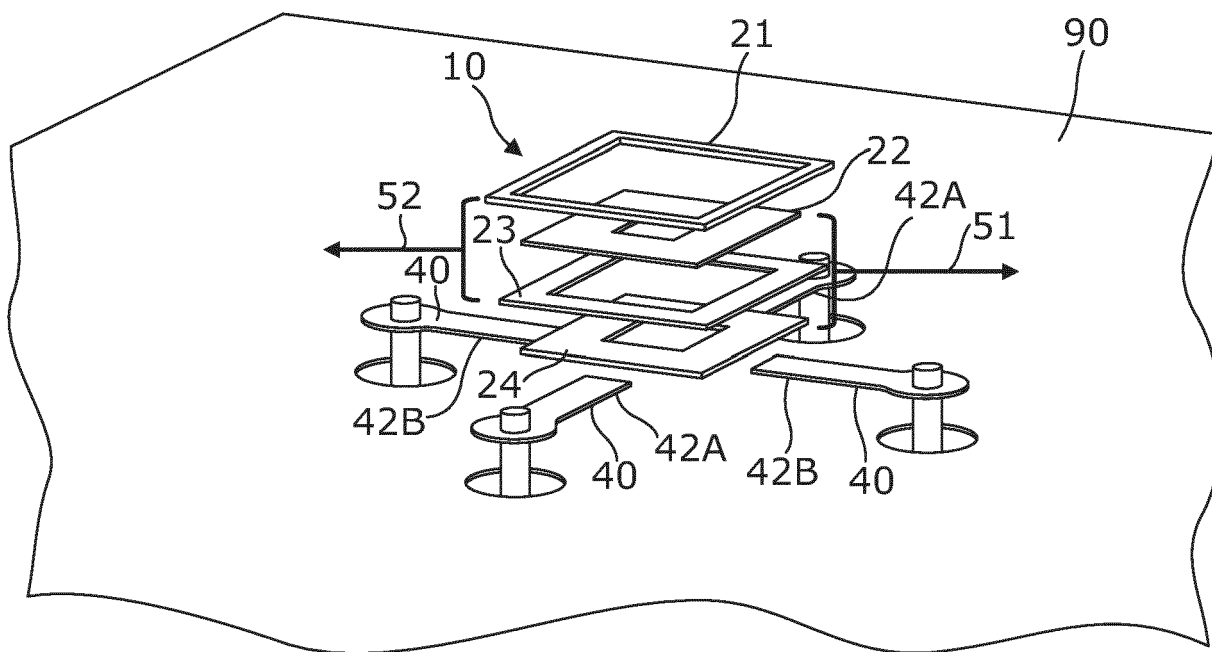


Fig. 2A

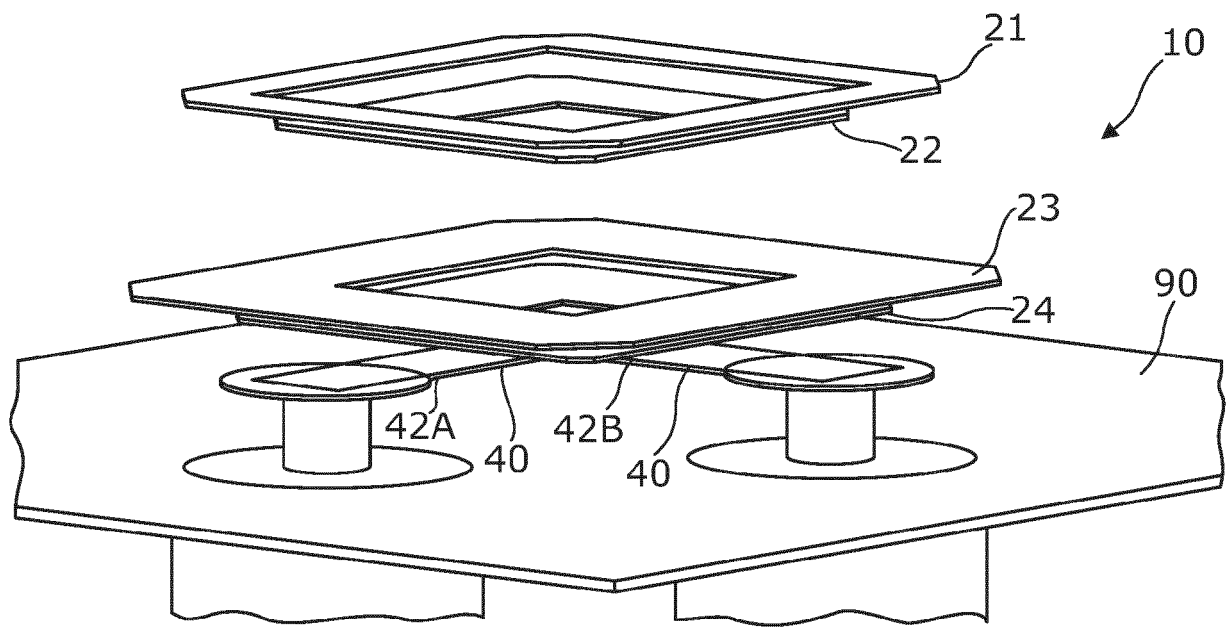


Fig. 2B

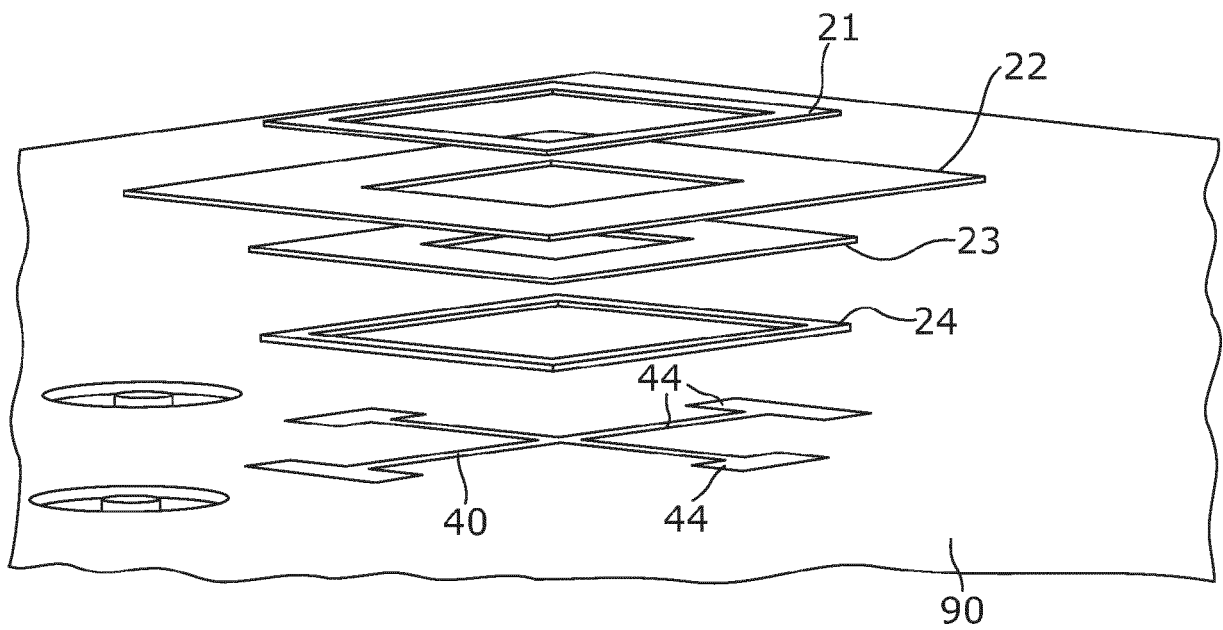


Fig. 2C

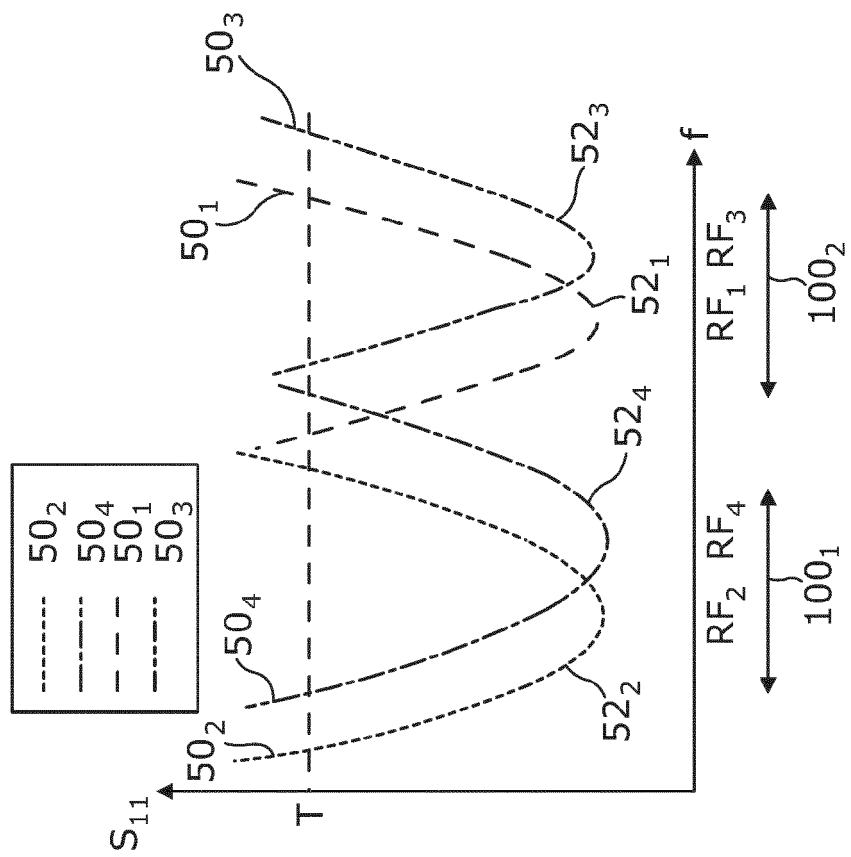


Fig. 3B

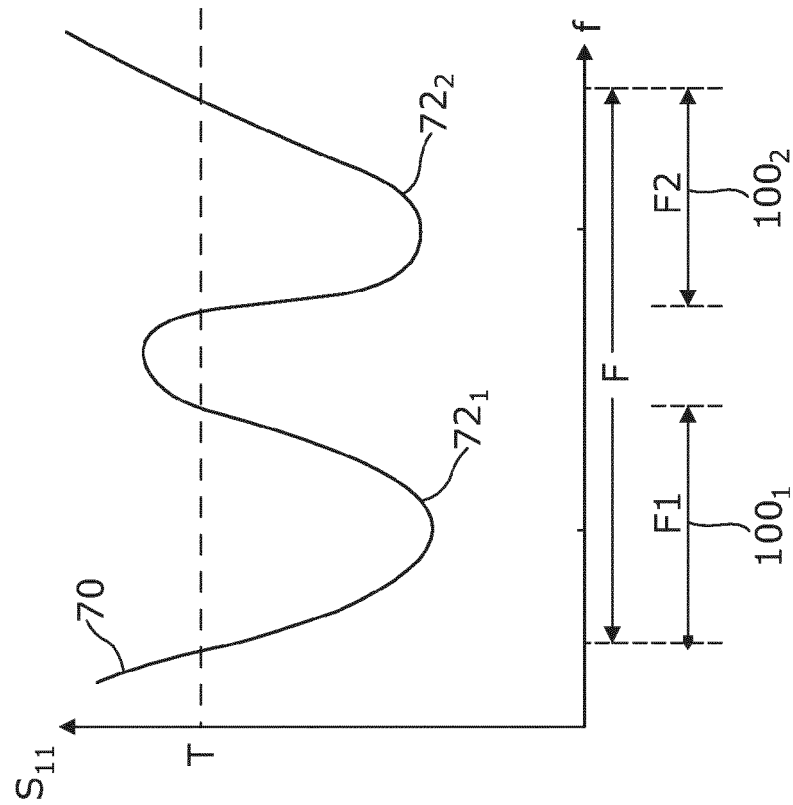


Fig. 3A

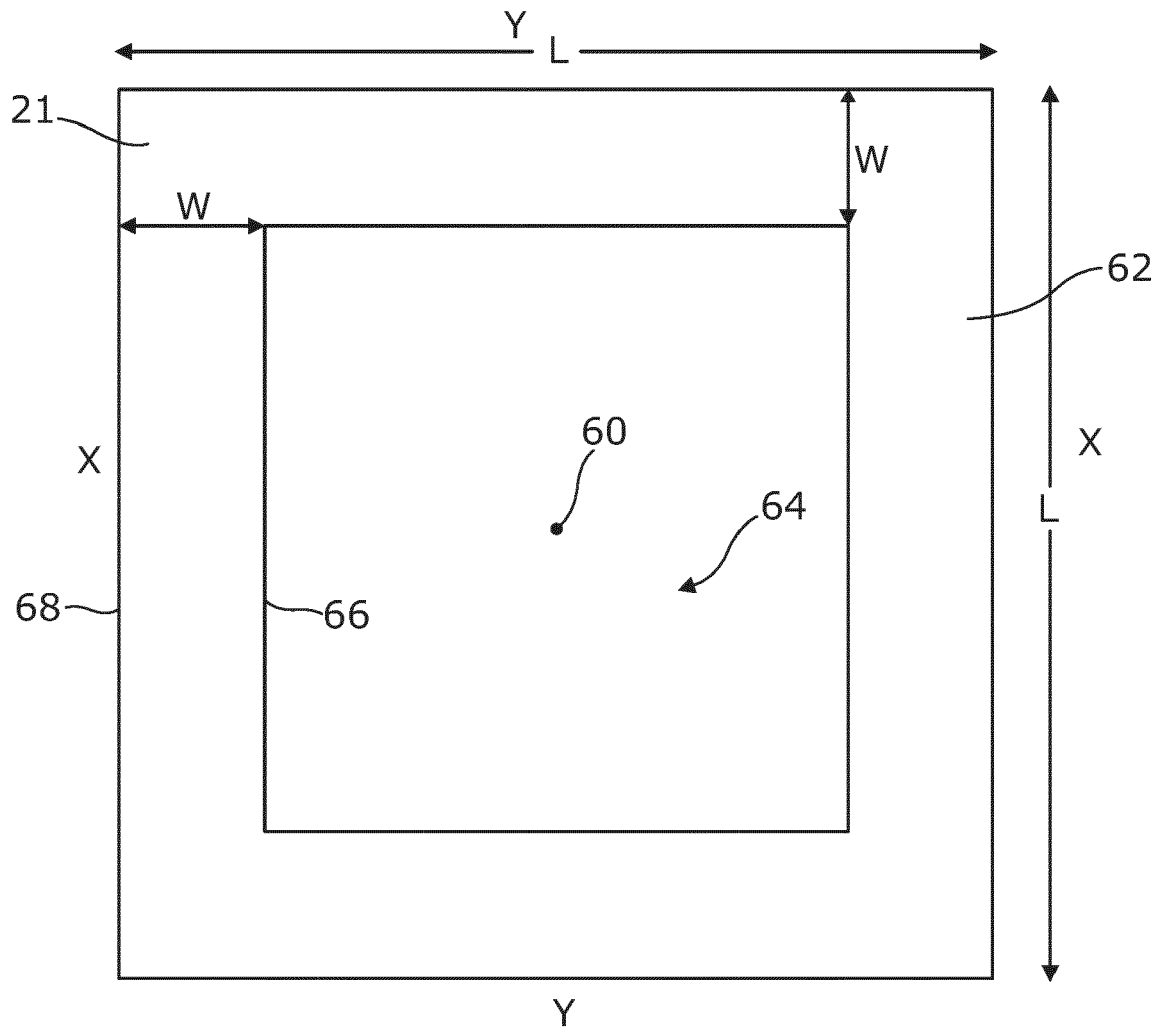


Fig. 4

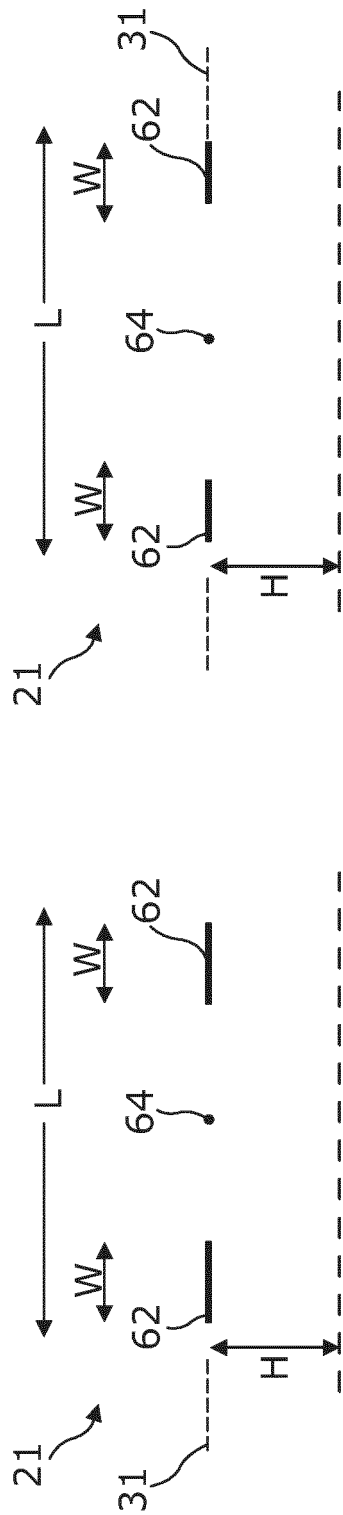


Fig. 5A

Fig. 5B

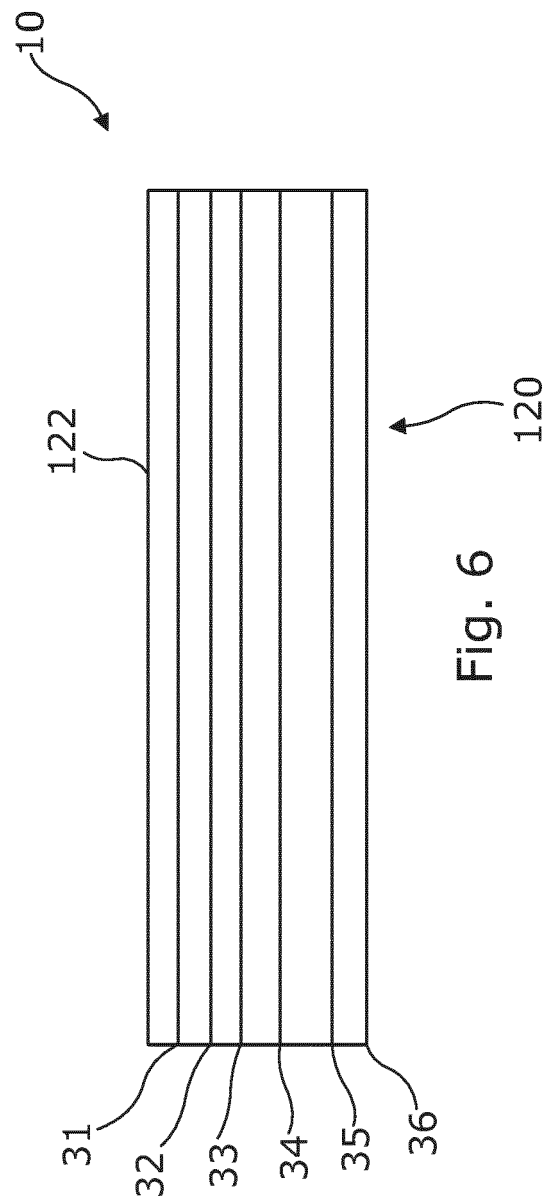


Fig. 6

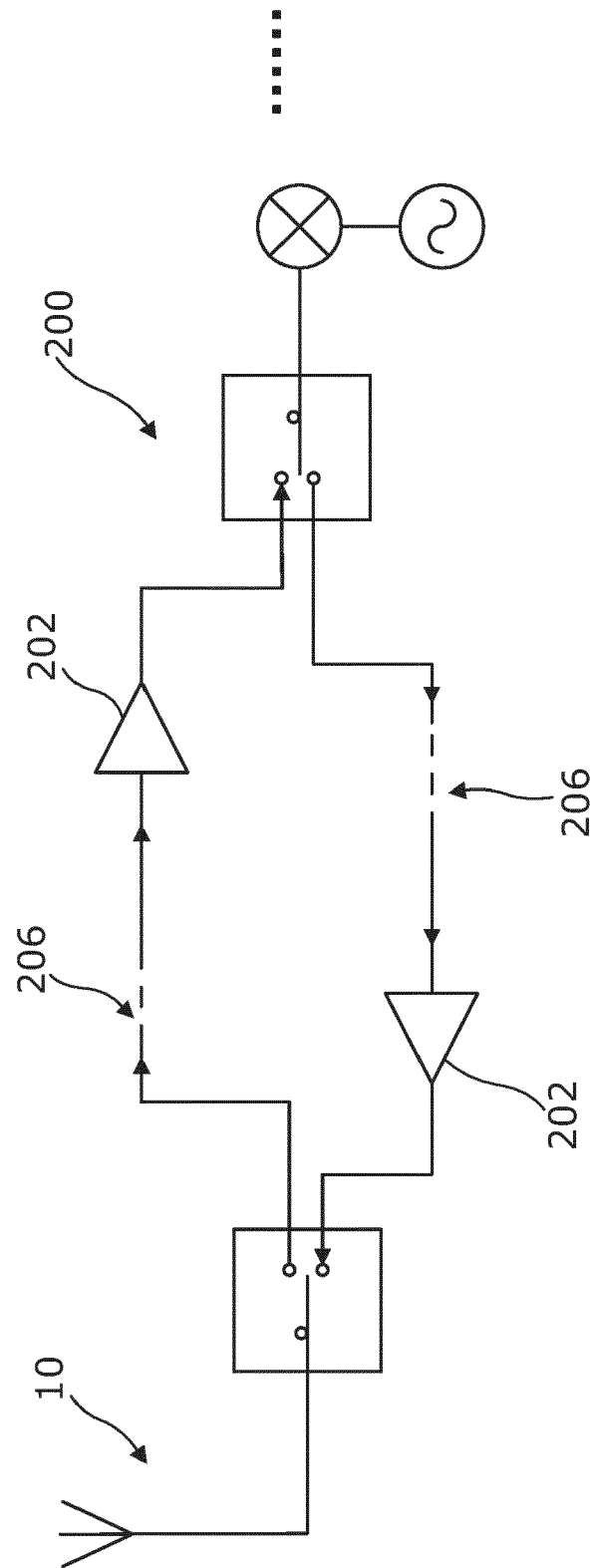


Fig. 7



EUROPEAN SEARCH REPORT

 Application Number
 EP 19 17 6293

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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	WO 2019/070509 A1 (INTEL IP CORP [US]; INTEL CORP [US]; ASAF OMER [IL]) 11 April 2019 (2019-04-11)	1-5, 8-10, 12-15	INV. H01Q5/35 H01Q5/378
Y	* paragraph [0040] - paragraph [0041]; figure 6A *	6,7,11	H01Q5/40 H01Q9/04
	* paragraph [0037] - paragraph [0038] *		
	* paragraph [0019] *		
Y	----- US 2018/358701 A1 (GIMERSKY MARTIN [CH]) 13 December 2018 (2018-12-13)	6,7,11	
A	* paragraph [0010] - paragraph [0011] *	1-5, 8-10, 12-15	

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The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
			H01Q
Place of search		Date of completion of the search	Examiner
The Hague		8 November 2019	Collado Garrido, Ana
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 19 17 6293

5 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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08-11-2019

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		WO 2017100126 A1	15-06-2017
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		WO 2018077611 A1	03-05-2018

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