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(54) Title: PHASED ARRAY ANTENNA

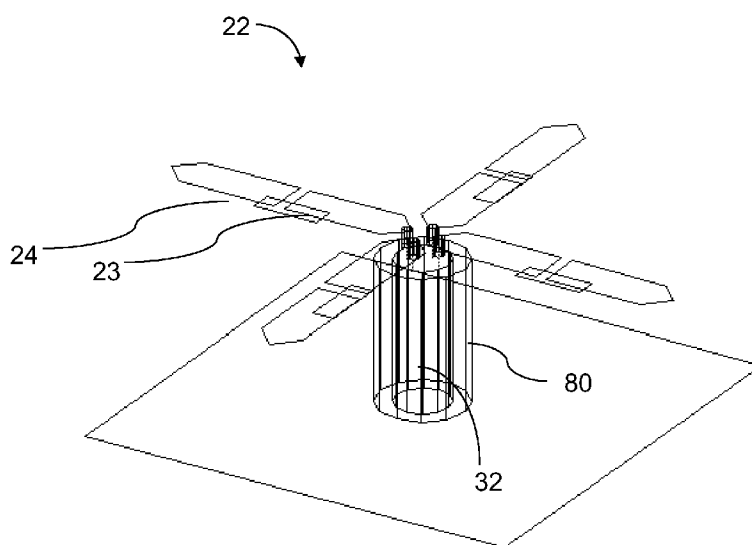


Fig. 10

(57) Abstract: The present invention relates to phased array antennas. The invention relates in particular to highly coupled arrays of dipoles having a vertical electrical feed structure. The invention provides a phased array antenna comprising a plurality of antenna elements a plurality of electrical feed structures each feed structure serving an antenna element; wherein each electrical feed structure is at least partially substantially surrounded by a ferrite element.

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PHASED ARRAY ANTENNA

BACKGROUND

a. Field of the Invention

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The present invention relates to phased array antennas. Phased array antenna systems are well known in the antenna art. Such antennas generally comprise a plurality of radiating elements that are individually controllable with regard to relative phase and amplitude. The antenna pattern of the array is selectively
10 determined by the geometry of the individual elements and the selected phase/amplitude relationships among the elements. Typical radiating elements for such antenna systems may comprise dipoles, slots or any other suitable arrangement.

15 Microwave antennas include a wide variety of designs for various applications, such as satellite reception, remote broadcasting, or military communication. For low profile applications printed circuit antennas may be used.

b. Related Art

20

A schematic diagram of a low profile, highly coupled dipole array is illustrated in Figure 1. Each dipole in this particular array has a span of around 10mm. The target bandwidth of the antenna array is approximately 2 GHz to 18 GHz. Dipoles are more attractive for use in a low profile antenna array than Vivaldi
25 elements, for example, which are much taller for a similar range of frequencies.

A typical dipole array forms part of a layered structure, including a substrate upon which the dipole array is printed and spacer material separating the dipole array from a ground plane. Dielectric layers may also be included to improve the
30 performance at wide scan angles.

However, there is a problem with using such a highly coupled dipole array for

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applications requiring a low profile antenna. Such antennas have a vertical feed structure which extends through the ground plane to connect the elements of the dipole array to a driving circuit.

- 5 A problem arises with feeding a planar array of dipoles, for example, because the vertical feed structure will support unwanted currents. In a scanned array, these unwanted currents are present even when using a balanced feed structure such as twin wire transmission line. These currents are excited at the frequencies and range of scan angles over which the antenna will work
10 effectively.

In order to avoid the problem of unwanted common-mode currents due to the feed structure it would be possible to feed an array of dipoles using an optical fibre feeding an active device. However, this solution would be expensive and
15 largely constrained to receive only applications due to the limited transmit power. Furthermore whilst an optical feed structure might be possible at lower frequencies which mean larger dipole structures due to larger wavelengths this will become less feasible for smaller dipole structures such as those working around 10 GHz.

20

It is desirable to produce a phased array antenna having high bandwidth and high scan range whilst also having a low profile and being lightweight. Of course, it is also desirable to produce such antenna at as low a cost as possible.

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SUMMARY OF THE INVENTION

According to the invention there is provided a phased array antenna comprising:
a plurality of antenna elements; a plurality of electrical feed structures each feed
5 structure serving an antenna element; wherein each electrical feed structure is
at least partially surrounded by a ferrite element for the suppression of
unwanted currents in the feed structure.

10 In the preferred embodiment, the antenna elements are printed on a substrate
each feed structure extends from a ground plane to the substrate to connect to
the antenna element served by said feed structure; and the ferrite element
comprises a cylinder surrounding at least part of the feed structure.

15 In one embodiment the ferrite element comprises a plurality of cylinders each
cylinder surrounding at least part of said feed structure. In another embodiment,
the ferrite element comprises a first ferrite ring disposed near the substrate and
a second ferrite ring disposed near the ground plane. In a further embodiment,
the ferrite element comprises a cylinder extending substantially from the ground
plane to the substrate.

20 Preferably, the antenna further comprises a dielectric layer supported on said
substrate.

25 Preferably an antenna element comprises a dipole and even more preferably an
antenna element comprises a pair of orthogonal dipoles.

In the preferred embodiment each antenna element is capacitively coupled with
at least one other antenna element.

30 In the preferred embodiment the feed structure is provided by coaxial cables.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of one example of a highly coupled dipole array for use in a phased array antenna;

5

Figure 2 is a second example of a highly coupled dipole array for use in a phased array antenna;

Figure 3 is an illustration of an antenna element showing various layers in an antenna structure.

10

Figures 4a to 4d are an illustration of a simulated performance of a highly coupled dipole array showing the voltage standing wave ratio in the E-plane and in the H-plane and illustrating thresholds of 2:1 and 2.5:1.

15

Figure 5a is an illustration of balanced currents in a feed structure;

Figure 5b is an example of an unbalanced current in a feed structure;

Figure 6 is an illustration of a first embodiment of the present invention;

20

Figures 7a to 7d are an illustration of a simulated performance of a highly coupled dipole array using elements as illustrated in Figure 6 showing the voltage standing wave ratio in the E-plane and in the H-plane and illustrating thresholds of 2:1 and 2.5:1.

25

Figure 8 is an illustration of a second embodiment of the present invention;

Figures 9a to 9d are an illustration of a simulated performance of a highly coupled dipole array using elements as illustrated in Figure 8 showing the voltage standing wave ratio in the E-plane and in the H-plane and illustrating thresholds of 2:1 and 2.5:1.

30

Figure 10 is an illustration of a third embodiment of the present invention;

Figures 11a to 11d are an illustration of a simulated performance of a highly
5 coupled dipole array using elements as illustrated in Figure 10 showing the
voltage standing wave ratio in the E-plane and in the H-plane and illustrating
thresholds of 2:1 and 2.5:1.

DETAILED DESCRIPTION

10

Figure 1 illustrates schematically a highly coupled dipole array 11. Each
antenna element 12 comprises four conducting arms 13 which form two
orthogonal dipole antennas and provide dual polarisation. T-shaped elements
14 at the end of each arm 13 increase the series capacitance between adjacent
15 antenna elements 12 in order to improve the antenna bandwidth. Each
conducting arm has a feed portion 15 located at the centre of the antenna
element 12 for receiving an electrical signal. A substrate for supporting the
dipole array 11 (as is conventional in printed circuit antennas) is not shown.

20 Figure 2 illustrates schematically a second example of a highly coupled dipole
array 21. Each antenna element 22 comprises four conducting arms 23 which
form two orthogonal dipole antennas and provide dual polarisation. Parallel line
coupling elements 24 which are provided on the opposite side to that of the
dipole elements on a double sided substrate serve to increase the series
25 capacitance between adjacent antenna elements 22 in order to improve the
antenna bandwidth. A section Z-Z of the antenna array is shown to illustrate a
side view of a coupling element 24.

It will be appreciated that the arrangement shown in Figure 2 is not as
30 convenient as the arrangement shown in Figure 1 if it is desired to produce a
dipole array spanning more than one substrate section as a coupling element
would have to span two substrate sections.

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Figure 3 is a perspective view of an antenna element 22 shown in Figure 2 illustrating the layers which were used in an antenna simulation. The antenna element 22 is fed by a feed structure 32 comprising a coaxial cable feeding each conducting arm 23. A spacer layer 34 separates the antenna element 22 from a ground plane (not shown). A substrate layer 36 supports the antenna elements 23, 24. Because the substrate layer 36 has a dielectric constant of 2.2 and air has a dielectric constant of approximately 1, the dielectric layers 38, 40 serve to smooth the differences in the dielectric properties between the substrate 36 and air and improves the scan angle of the antenna array 21. In this example, a first dielectric layer 38 having a dielectric constant of 2.0 supports a second dielectric layer 40 having a dielectric constant of 1.33 between the substrate layer 36 and air. In this description the feed structure is sometimes referred to as a vertical feed structure, although it will be appreciated that the dipole array 21 may be in any orientation when in use.

One method of illustrating the performance of an antenna is to plot a representation of the voltage standing wave ratio (VSWR) in the plane of the electric field (the E plane) and the plane of the magnetic field (the H plane) which are orthogonal to one another. Such plots can be generated using conventional antenna modelling software.

Figures 4a to 4d illustrate the simulated performance of a dipole array antenna with antenna elements as shown in Figure 2 with no measures to suppress any unwanted currents. The array scan angle considered varies from 0° to 70° and the frequency range is considered between $0.2f_0$ and $2f_0$, where f_0 is equal to 10 GHz.

Ideally the VSWR should be below 2:1 but a ratio of 2.5:1 can be tolerated for very wide bandwidth and scan angle operation. In Figures 4a to 4d a VSWR of below a chosen threshold is shown in white and a VSWR of above the chosen threshold is shown in black.

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Figure 4a illustrates a simulated scan in the E plane with a VSWR threshold of 2.5. Figure 4b illustrates a simulated scan in the E plane with a VSWR threshold of 2.0. Figure 4c illustrates a simulated scan in the H plane with a VSWR threshold of 2.5. Figure 4d illustrates a simulated scan in the H plane with a VSWR threshold of 2.0.

It can be seen from Figure 2 that in the E-plane the scan range is limited at around f_0 to between approximately 15° and 30° depending upon which VSWR threshold is acceptable.

This limited scan range is due to unwanted currents in the feed structure 32. Figures 5a and 5b show conductive arms 23 fed by the feed structure 32, each conductive arm being fed by a coaxial cable 50. Figure 5a illustrates balanced currents in the feed structure. Figure 5b on the other hand shows unbalanced currents.

In this invention the vertical feed structure of the phased array antenna is screened using an appropriately shaped ferrite element. The theoretical E and H plane scan characteristics are modelled including the electrical characteristic of such a ferrite element. One skilled in the art will understand that due to the electrical properties of ferrite, a ferrite element appears electrically very large. Small mechanical differences may mean very large electrical differences. Although the antenna dimensions are less than $\frac{1}{2}$ wavelength the ferrite element will appear to be several wavelengths. Therefore small mechanical differences in the ferrite element will potentially cause large electrical differences and a large difference to the performance of the antenna. Several shapes and configurations of ferrite elements have been considered and modelled to determine a preferred embodiment.

30

Figure 6 illustrates a first embodiment of the present invention. The antenna element 22 is fed by a feed structure 32 comprising four coaxial cables. The

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feed structure 32 has a ferrite ring 60 surrounding a portion of the feed structure 32.

The ferrite modelled for this example is a typical ferrite including magnesium
5 ferrites and nickel ferrites.

For the theoretical modelling the ferrite is assumed lossless and is assumed to have a relative dielectric constant $\epsilon_r = 13$ and a relative permeability of $\mu_r = 50$. Figures 7a to 7d show simulated scans modelling the antenna element shown
10 in Figure 6.

Figure 7a illustrates a simulated scan in the E plane with a VSWR threshold of 2.5. Figure 7b illustrates a simulated scan in the E plane with a VSWR threshold of 2.0. Figure 7c illustrates a simulated scan in the H plane with a VSWR
15 threshold of 2.5. Figure 7d illustrates a simulated scan in the H plane with a VSWR threshold of 2.0.

It can be seen from these simulations that the scan range in the E plane is improved, although when a VSWR threshold of 2 is considered there are still
20 some frequencies where the scan angle will be limited.

Figure 8 illustrates a second embodiment of the present invention. The antenna element 22 is fed by a feed structure 32 comprising four coaxial cables. The feed structure 32 has two ferrite rings 70 surrounding an upper portion and a
25 lower portion of the feed structure 32.

Figures 9a to 9d show simulated scans modelling the antenna element shown in Figure 8.

30 Figure 9a illustrates a simulated scan in the E plane with a VSWR threshold of 2.5. Figure 9b illustrates a simulated scan in the E plane with a VSWR threshold of 2.0. Figure 9c illustrates a simulated scan in the H plane with a VSWR

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threshold of 2.5. Figure 9d illustrates a simulated scan in the H plane with a VSWR threshold of 2.0.

Figure 10 illustrates a third embodiment of the present invention. The antenna
5 element 22 is fed by a feed structure 32 comprising four coaxial cables. The
feed structure 32 has a ferrite tube 80 surrounding substantially the full length of
the feed structure 32.

Figures 11a to 11d show simulated scans modelling the antenna element
10 shown in Figure 10.

Figure 11a illustrates a simulated scan in the E plane with a VSWR threshold of
2.5. Figure 11b illustrates a simulated scan in the E plane with a VSWR
threshold of 2.0. Figure 11c illustrates a simulated scan in the H plane with a
15 VSWR threshold of 2.5. Figure 11d illustrates a simulated scan in the H plane
with a VSWR threshold of 2.0.

Comparing the illustrations in Figures 4-4d, 7a-7d, 9a-9d and 11a-11d it is
apparent that the greatest benefit is achieved when the ferrite element
20 surrounds as much as the feed structure as is possible, and extends from as
close as the ground plane as possible to as close to the substrate as possible.
However, a ferrite element surrounding only certain portions of the feed
structure nevertheless provides some benefit.

25 It will be appreciated that various alterations, modifications, and/or additions
may be introduced into the constructions and arrangements of parts described
above without departing from the scope of the present invention as defined in
the appended claims.

30 Although the invention has been discussed specifically referring to co-axial
cables, any vertical feed structure, for example strip line or any other electrical
conductor feeding an antenna array in parallel will benefit from the use of ferrite

- 10 -

elements to suppress unwanted currents in the feed structure.

Although the invention has been described, and the simulations carried out using two dielectric layers between the antenna array and air, fewer, more or no
5 dielectric layers may be used. Furthermore one or more dielectric layers may be provided between the antenna array and the ground plane.

Although arrays of antenna elements having four conducting arms are used in the above simulations, the invention will also benefit arrays of antenna elements
10 having two conducting arms and will also benefit other types of antenna array structure where a parallel (or 'vertical') electrical feed structure is required

Various embodiments of the ferrite element have been simulated. However, a small gap in the structure whilst not a preferred embodiment will still provide a
15 reduction in unwanted currents, so any ferrite element substantially surrounding at least a portion of an electrical feed structure will shown some benefit.

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CLAIMS

1. A phased array antenna comprising:
 - a plurality of antenna elements;
 - 5 a plurality of electrical feed structures each feed structure serving an antenna element ;
 - wherein each electrical feed structure is at least partially surrounded by a ferrite element.
- 10 2. A phased array antenna according to claim 1, in which
 - the antenna elements are printed on a substrate
 - each feed structure extends from a ground plane to the substrate to connect to the antenna element served by said feed structure; and
 - the ferrite element comprises a cylinder surrounding at least part of said
 - 15 feed structure.
3. A phased array antenna according to claim 2, in which the ferrite element comprises a plurality of cylinders each cylinder surrounding at least part of said feed structure.
- 20 4. A phased array antenna according to claim 3, in which the ferrite element comprises a first ring near the substrate and an second ring near the ground plane.
- 25 5. A phased array antenna according to claim 2, in which the ferrite element comprises a cylinder extending substantially from the ground plane to the substrate.
6. A phased array antenna according to any one of claims 2 to 5, in which
- 30 the antenna further comprises a dielectric layer supported on said substrate.

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7. A phased array antenna according to any one of the preceding claims, in which an antenna element comprises a dipole.

8. A phased array antenna according claim 7, in which an antenna element
5 comprises a pair of orthogonal dipoles.

9. A phased array antenna according to any one of the preceding claims, in which each antenna element is capacitively coupled with at least one other antenna element.

10

10. A phased array antenna according to any one of the preceding claims in which the feed structure is provided by coaxial cables.

11. A phased array antenna, substantially as herein described, with
15 reference to and as shown in the accompanying drawings.

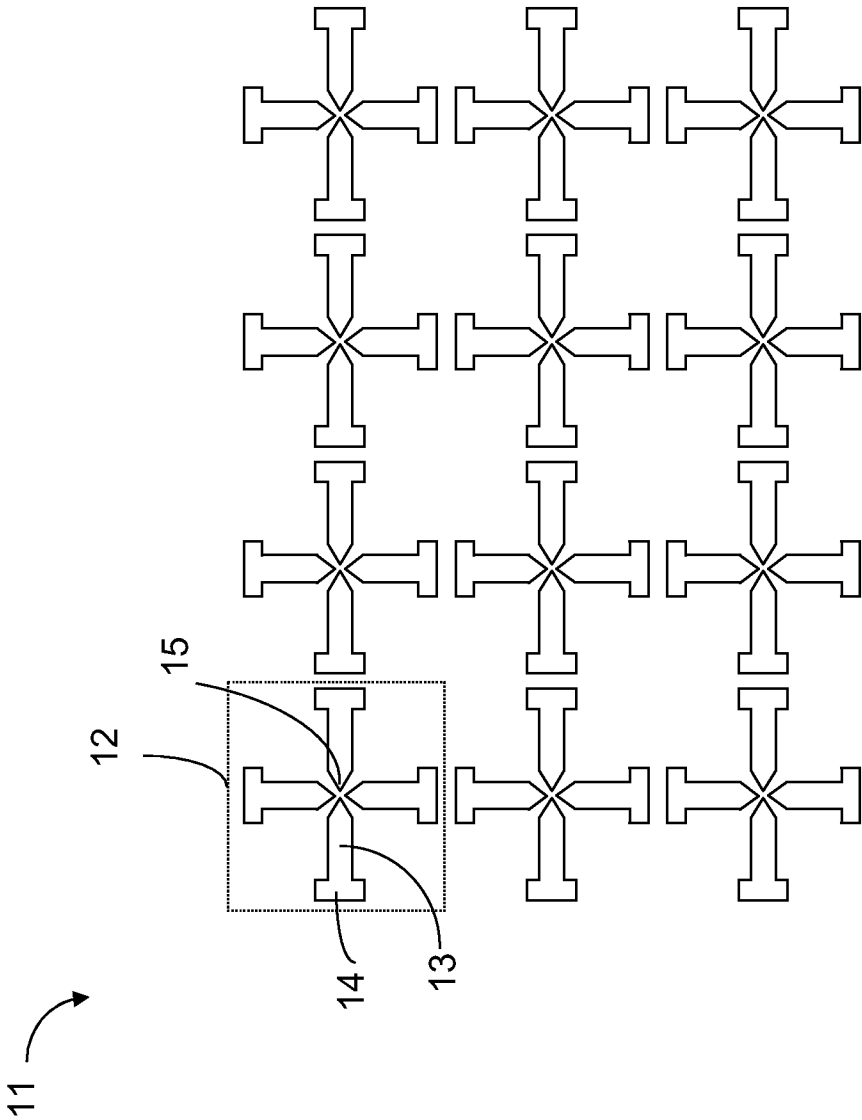
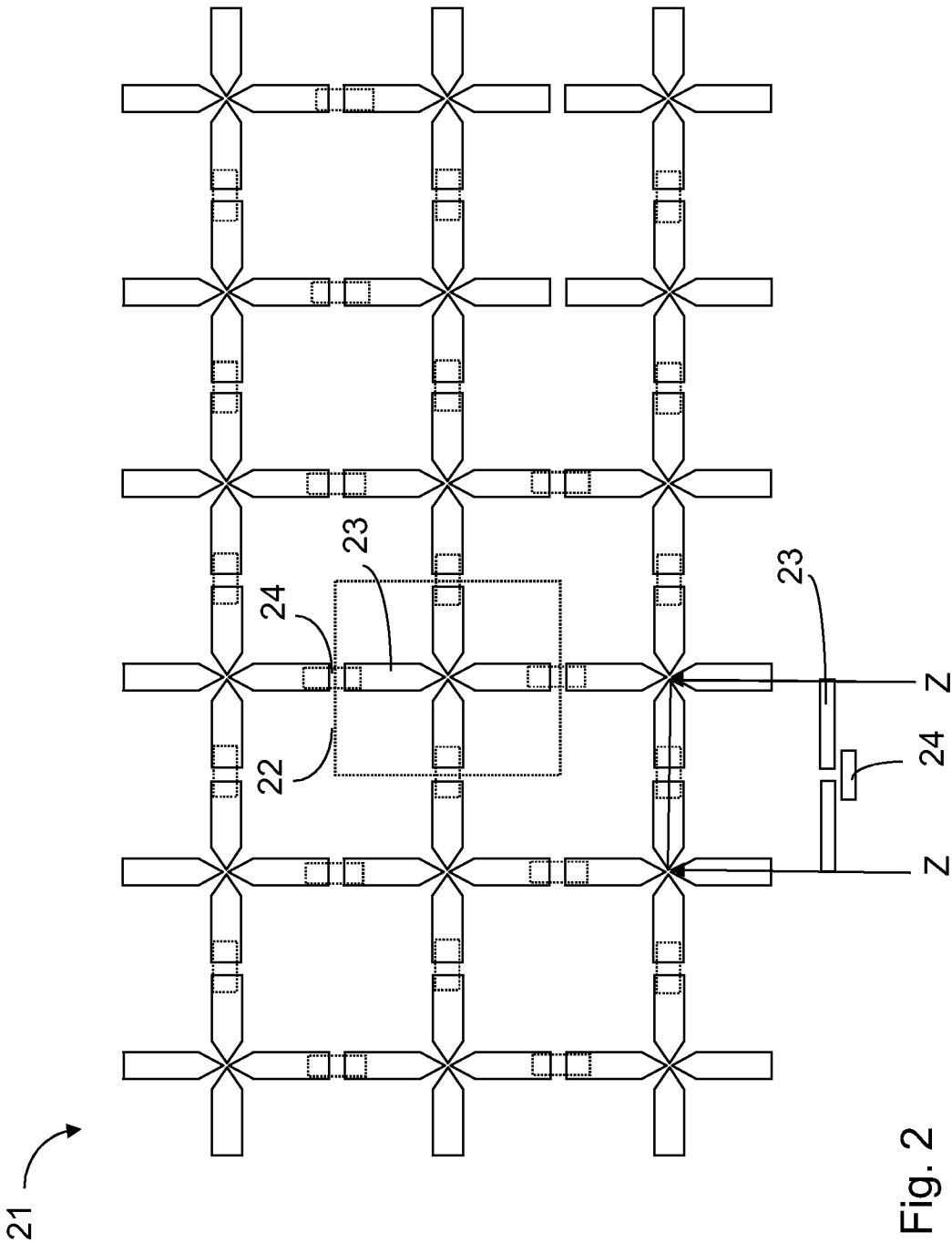


Fig. 1



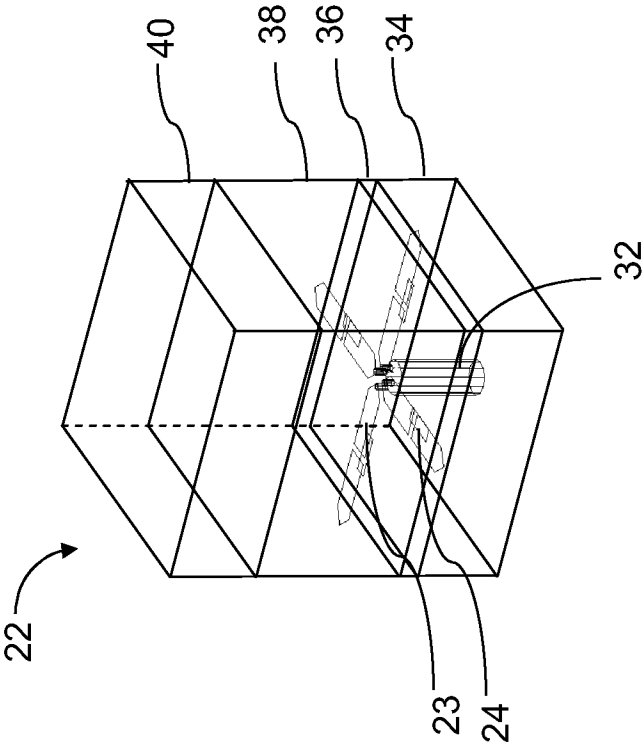


Fig. 3

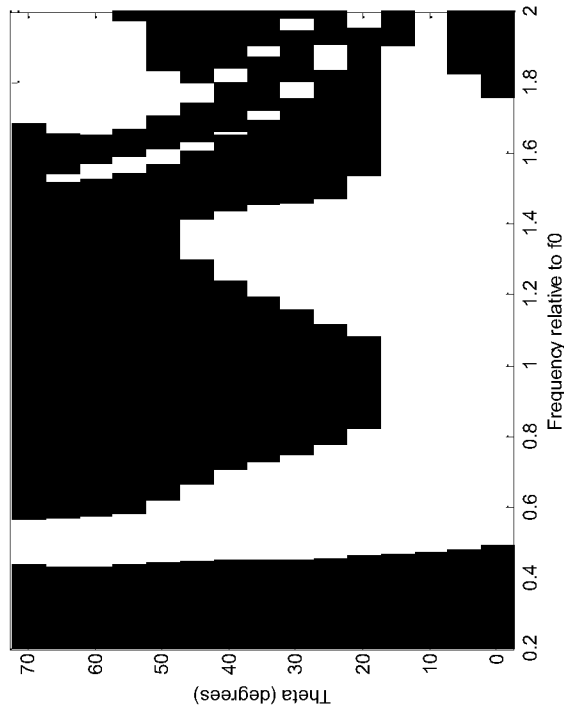


Fig. 4a E plane VSWR threshold 2.5

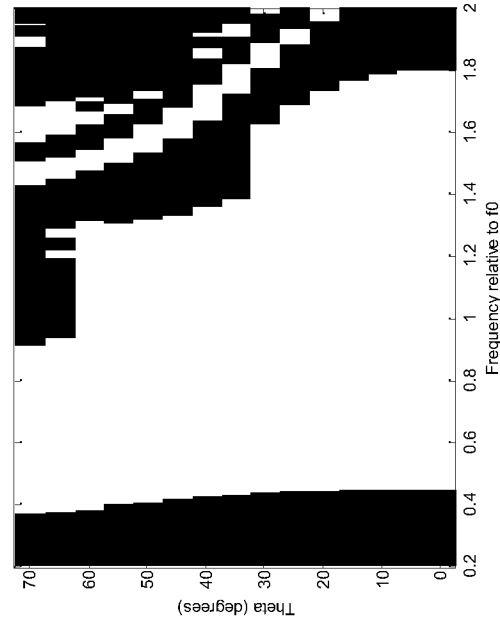


Fig. 4b E plane VSWR threshold 2

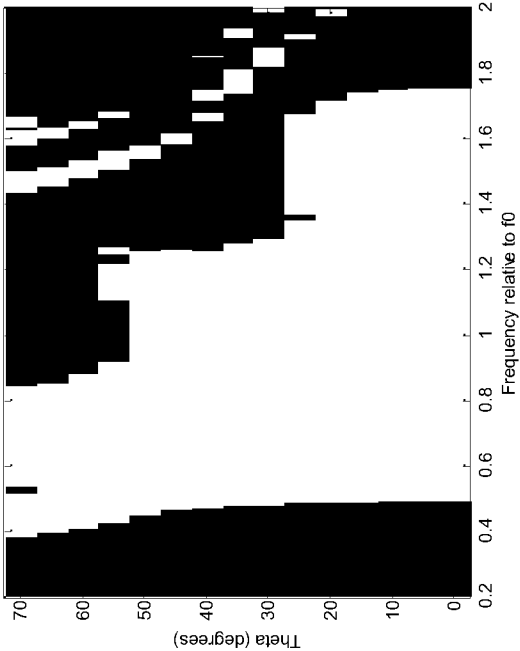
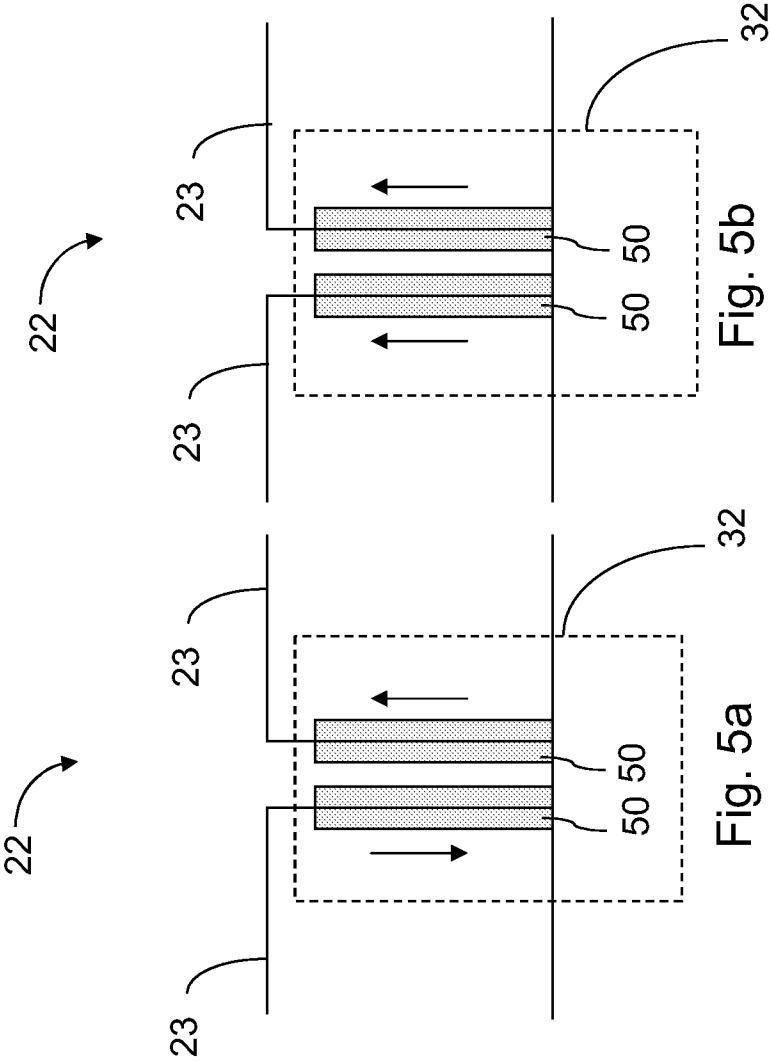


Fig. 4c H plane VSWR threshold 2.5

Fig. 4d H plane VSWR threshold 2



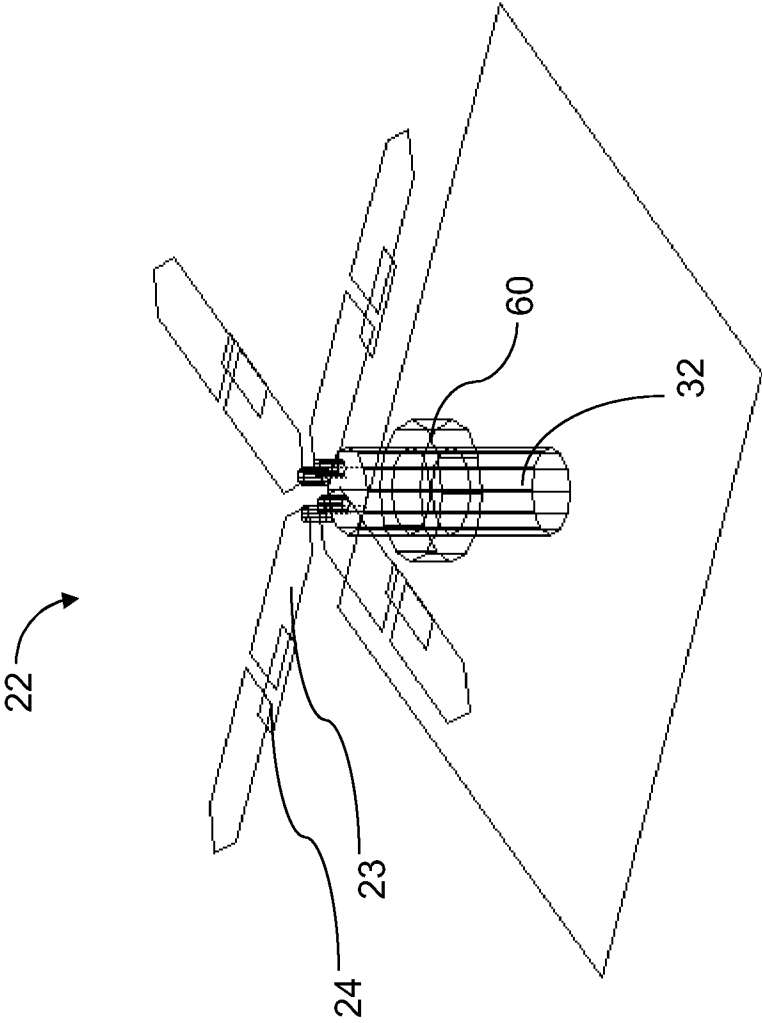


Fig. 6

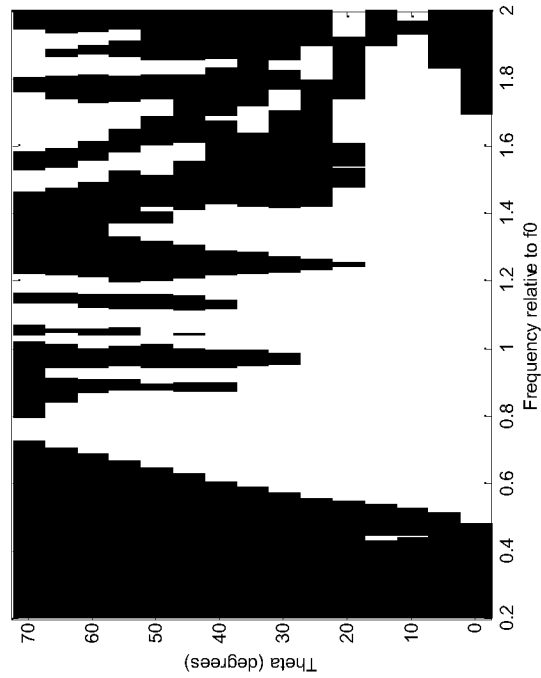


Fig. 7b E plane VSWR threshold 2

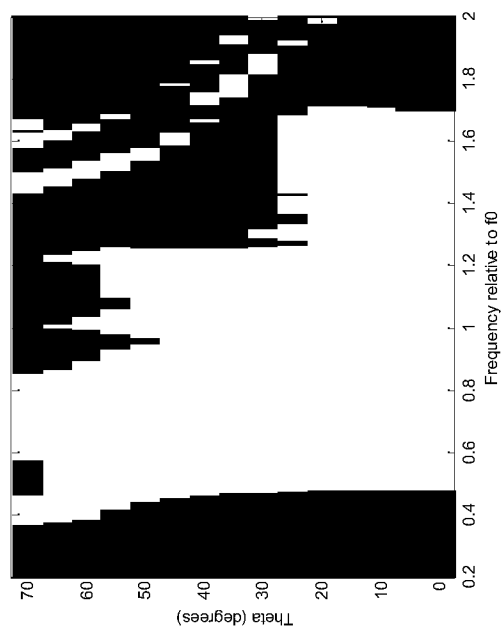


Fig. 7d H plane VSWR threshold 2

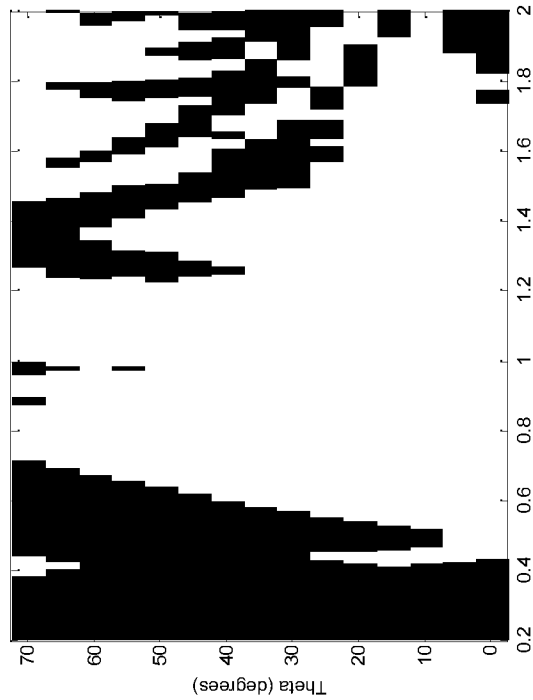


Fig. 7a E plane VSWR threshold 2.5

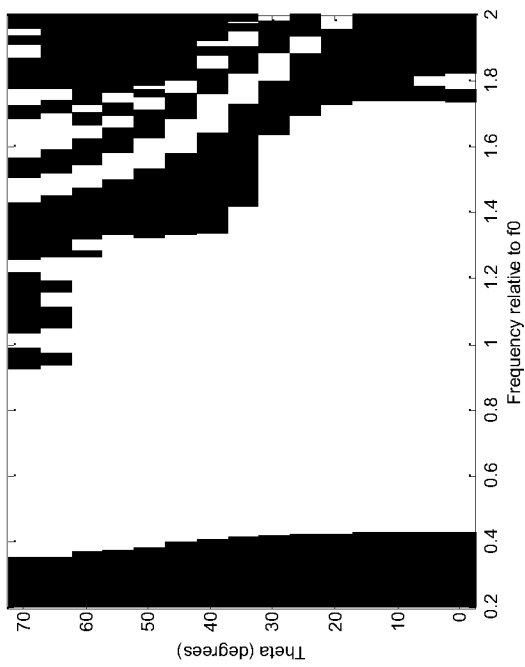


Fig. 7c H plane VSWR threshold 2.5

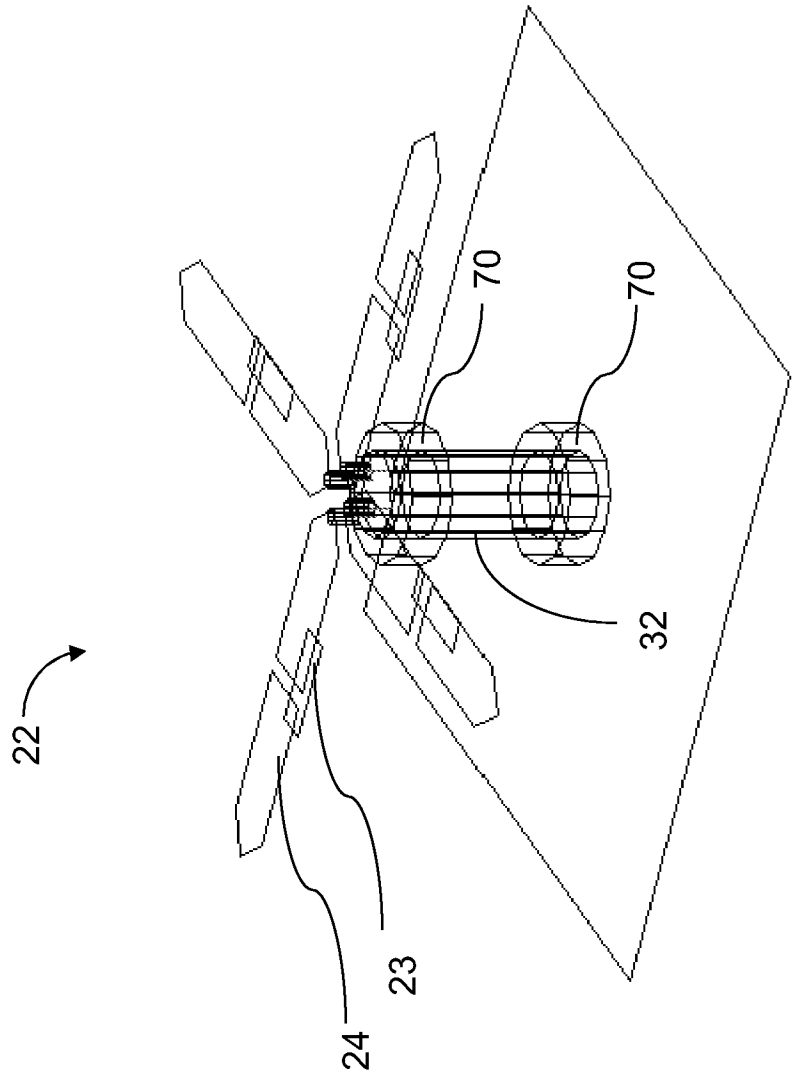


Fig. 8

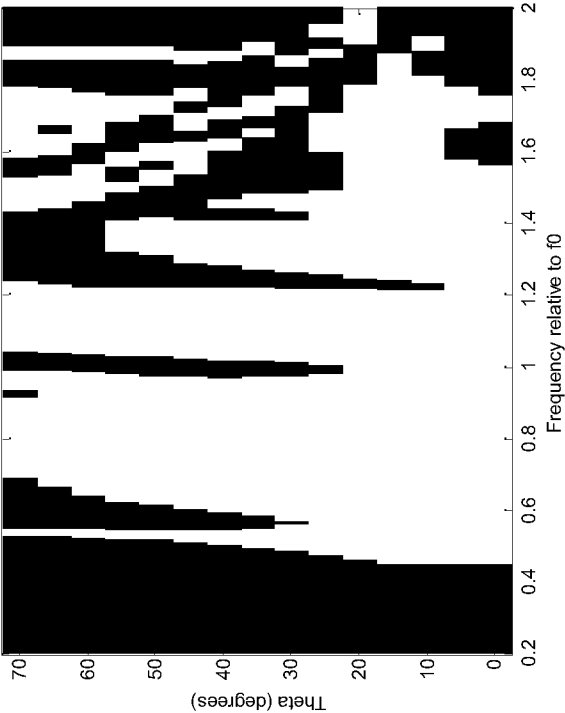


Fig. 9a E plane VSWR threshold 2.5

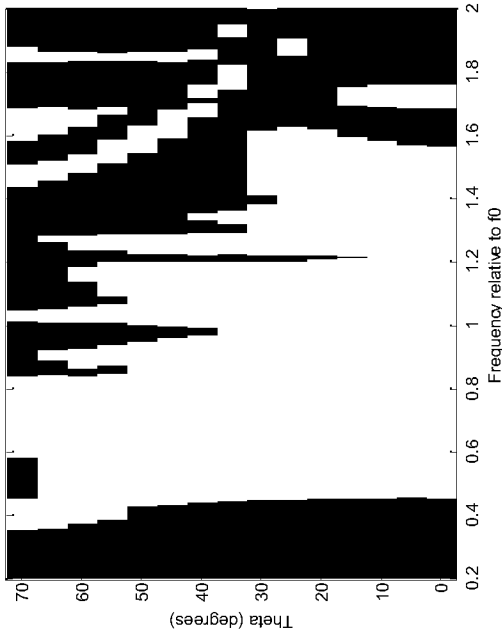


Fig. 9b E plane VSWR threshold 2

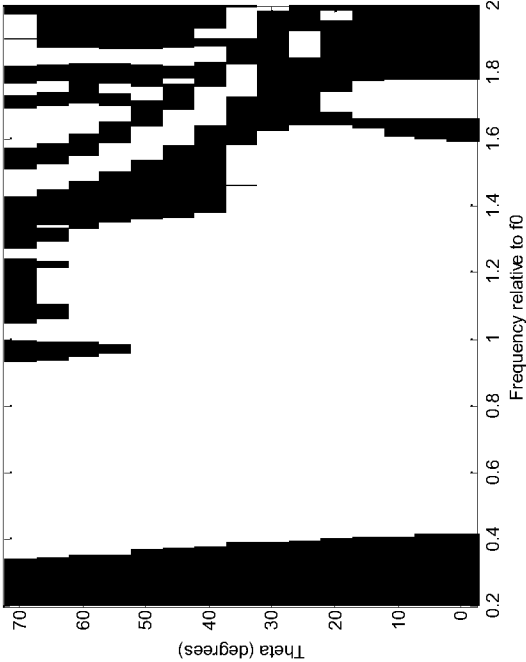


Fig. 9c H plane VSWR threshold 2.5

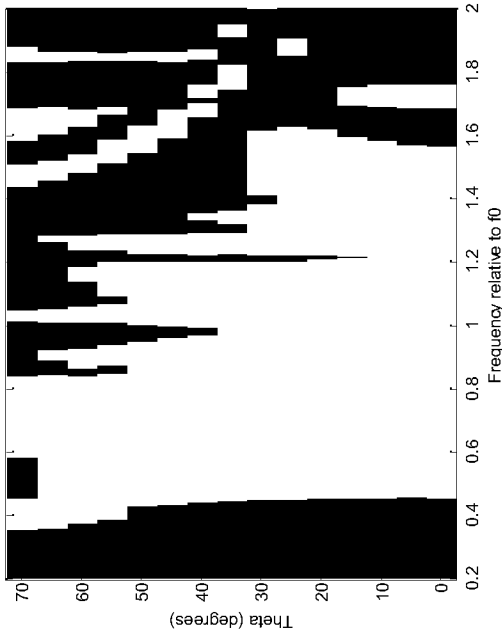


Fig. 9d H plane VSWR threshold 2

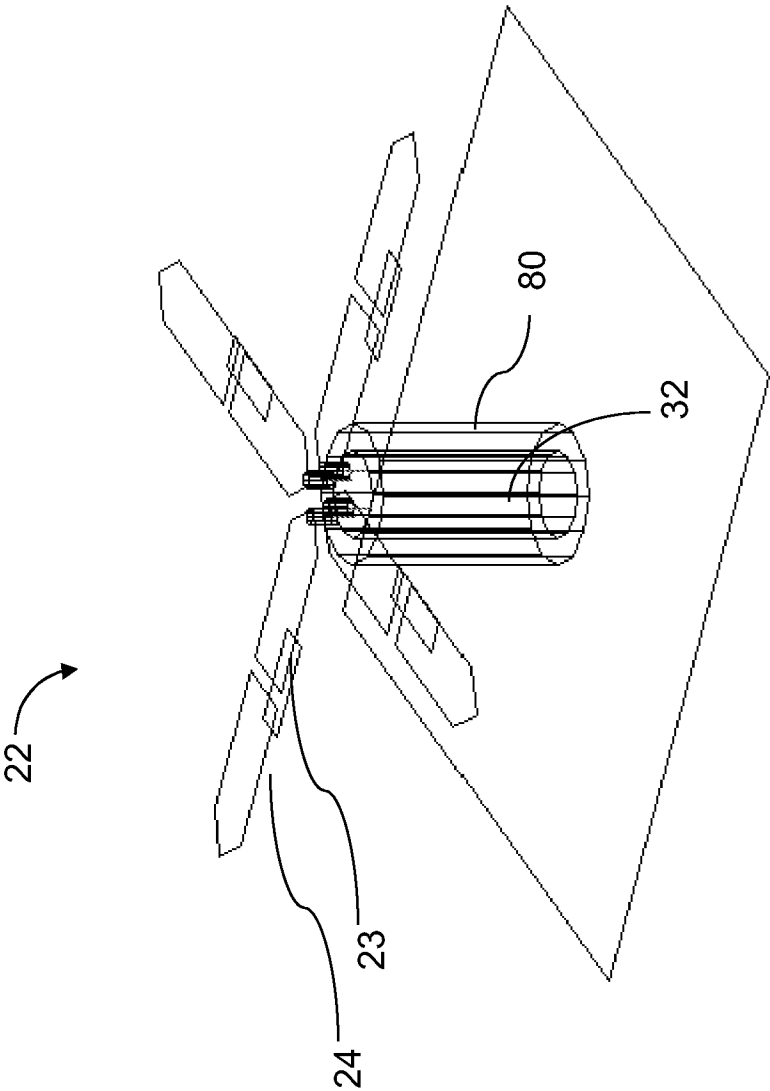


Fig. 10

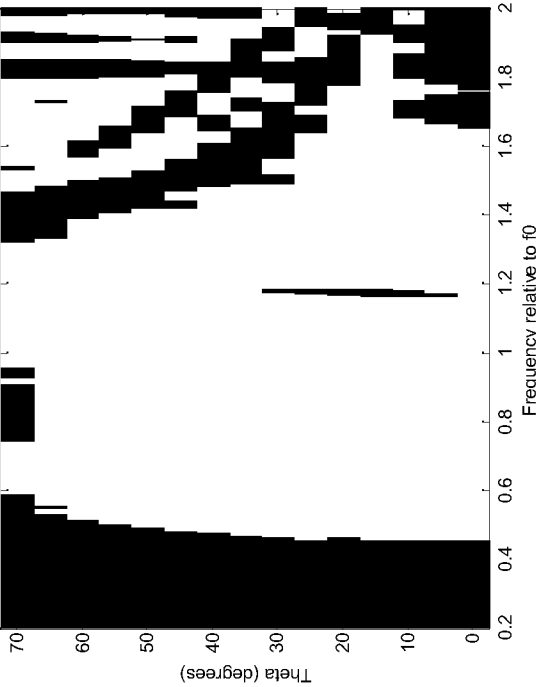


Fig. 11b E plane threshold 2

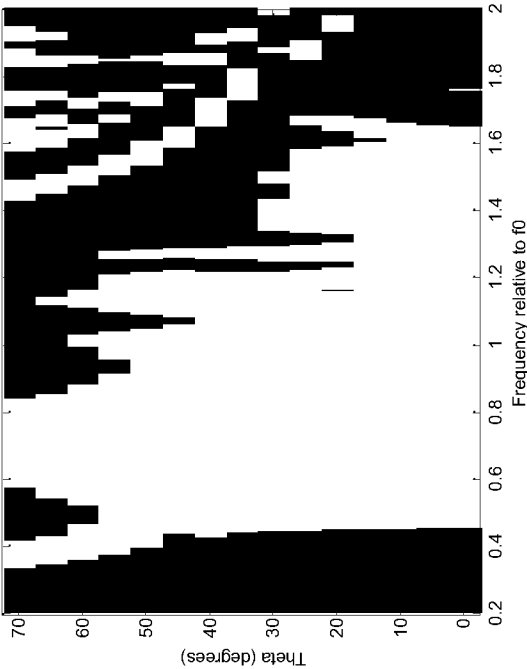


Fig. 11d H plane threshold 2

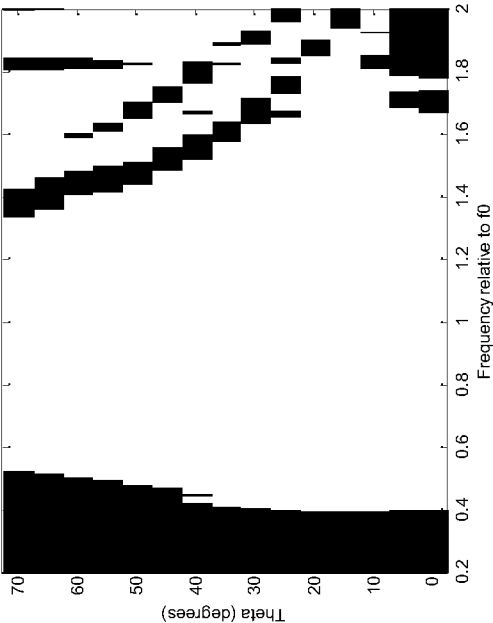


Fig. 11a E plane threshold 2.5

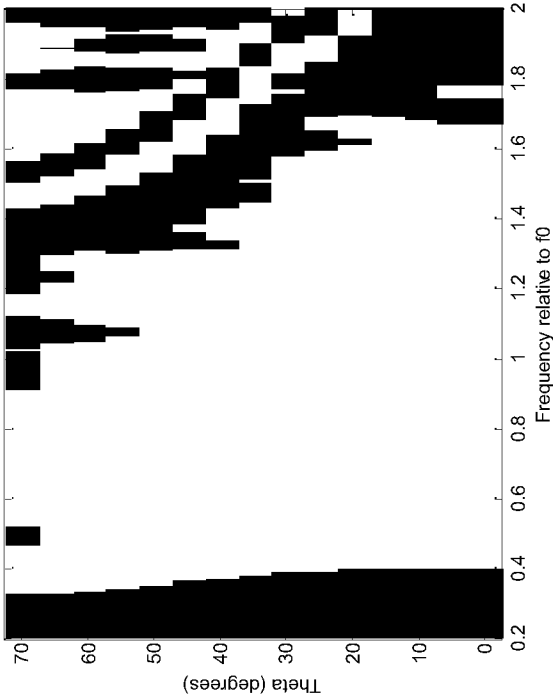


Fig. 11c H plane threshold 2.5

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2008/050901

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01Q1/52 H01Q21/06 H01Q21/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/030246 A1 (DURHAM TIMOTHY E [US] ET AL) 10 February 2005 (2005-02-10)	1,2,5-10
Y	paragraph [0062]; figures 2,4,10	3,4
Y	WO 99/21247 A (RANGESTAR INTERNATIONAL CORP [US]; JOHNSON GREG [US]) 29 April 1999 (1999-04-29)	3,4
Y	page 10; figure 1	
Y	US 2007/188398 A1 (MOHUCHY WOLODYMYR [US] ET AL) 16 August 2007 (2007-08-16)	1-10
Y	paragraph [0027] - paragraph [0041]; figures 1-4	
Y	DE 10 2006 004806 A1 (ARC SEIBERSDORF RES GMBH [AT]) 10 August 2006 (2006-08-10)	1-10
	paragraph [0027]; figures 4,5	
	-/--	

☒ Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2008/050901

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 229 744 A (LUEDTKE ARTHUR ET AL) 21 October 1980 (1980-10-21) column 3, line 20 - line 26; figure 4 -----	4
A	US 5 872 543 A (SMITH RALPH L [US]) 16 February 1999 (1999-02-16) column 17, line 19 - line 40; figure 16 -----	1-4
A	US 2007/075908 A1 (GANESHAN PREM K [US] ET AL) 5 April 2007 (2007-04-05) paragraph [0038] - paragraph [0039]; figure 7 -----	1-5

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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