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(54) Title: A HEXAGONAL DUAL-POL NOTCH ARRAY ARCHITECTURE HAVING A TRIANGULAR GRID AND CON-
CENTRIC PHASE CENTERS

Cross section of new notch transition sections

(57) Abstract: A dual-pol notch step radiator that includes a plurality of notch step
elements formed from three fins (602), aligned to form a triangular grid having a
plurality of slots. The radiator also includes a plurality of current lines (1104, 1106)
connecting the elements.

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TITLE OF THE INVENTION:

A HEXAGONAL DUAL-POL NOTCH ARRAY ARCHITECTURE HAVING A

TRIANGULAR GRID AND CONCENTRIC PHASE CENTERS

BACKGROUND OF THE INVENTION

Field of the Invention

[0001]   The present invention relates to phased array antennas. More particularly,

the present invention relates to a novel dual-pol notched array architecture having a

triangular grid and concentric phase centers.

Description of the Related Art

[0002]   Notch radiating elements for phased array antennas can be designed to

support extremely large bandwidths. Notch radiating element designs have been

developed that exceed ratios of 9 to 1 bandwidths. One reason for these large

bandwidths is that the notch structure acts like a stepped transmission line

transformer that matches from free space on to the impedance at a stripline-slotline

interface. Typical arrays have a stepped notch transition with three or four stages in

the transformer.

[0003]   For dual polarization (dual-pol), the conventional design is the so-called

"egg-crate" architecture, in which the slots are placed on the sides of a square

periodic cell. Figure 1 shows the profile of a typical egg-crate notch section 100

looking into the array. The cross sections 100 in the periodic environment act like

transmission lines. Periodic modes (i.e., modes in the infinite array of the notch

cross sections 100) have scan and frequency dependent propagation constants and

impedances, which can be calculated using a two-dimensional periodic vector finite

element code.

[0004] One problem with the egg-crate architecture is that the elements are necessarily arranged in a rectangular grid. As a result, a significant greater density of radiators and T/R modules are needed per unit area for a given scan volume relative to the triangular grid of the present invention. In addition, the polarization of the element pattern used in the egg-crate design changes with scan angle. This results from the basic physics of two propagating periodic orthogonal modes that are supported in the notch sections shown in Figure 1, assuming that the array has been designed to avoid higher order propagating modes in the scan volume.

[0005] In an inter-cardinal plane, the notch structure of Figure 1 has a transverse magnetic (TM) mode, which has a relative propagation constant (k_z/k_0) equal to 1. However, another mode propagates at a slower rate, (k_z/k_0) <1. Horizontal or vertical polarization for the element pattern can become circular polarized in the inter-cardinal plane as shown in Figure 2, which shows the axial ratio from an egg-crate antenna in the inter-cardinal plane. In this example, Phi=45 and frequency was set to 13 GHz. A large value for dB axial ratio corresponds to a linear polarization, whereas a 0 dB value means that the polarization is circular. In this example the polarization is nearly at normal incidence (theta=0), becomes circular for a scan of theta=45 degrees, and tends to linear polarization again as one scans to the horizon (theta=90).

[0006] The difficulty with polarization is complicated by the fact that the phase centers for horizontal and vertical polarization are not concentric.

[0007] Alternative rectangular architectures have been attempted that consist of concentric notches in a rectangular pattern. One such example is illustrated in Figure 3. A cross section 300 of the notch transition is shown in Figure 3 in which the slots 302 are at the corners of a square rectangle.

[0008]   Such concentric rectangular notched arrays are used with the objective to produce concentric phase centers that coincide for both vertical and horizontal polarizations, to enable easier compensation for changes in polarization. Although the arrangement of rectangular notched arrays is that of a rectangular grid, this architecture has been shown to have significant scan problems for the TE scan in the inter-cardinal plane. Exemplary results from simulation of a full radiator element are shown in Figure 4. As shown in Figure 4, the TE scan completely fails at about 25°. This scan failure has been observed both in finite element analysis of periodic arrays as well as measurements of experimental arrays.

[0009]   The reason for the failure of the concentric fed rectangular array is related to the number and characteristics of the propagating modes in the notch transition. A two dimensional (2-D) periodic finite element analysis of the transmission properties of rectangular concentric notch fins as a periodic transmission line shows three propagating modes. Two modes have a relative propagation constant of k_z/k_0 equal to 1. One of these two modes always has its electric field in the TM plane. The third mode has k_z/k_0 less than 1.

[0010]   In the inter-cardinal plane, the waveguide mode and one of the TEM modes both carry a quadrature piece of the field, which does not radiate well because this field varies faster than the fundamental free space plane wave. This results in poor scan performance.

[0011]   As an illustration of this behavior, Figure 5 shows the three propagating modes supported by a periodic transmission line structure consistence of four metal fins per cell. The periodic boundary conditions support scanning off normal to a direction (theta,phi) = (60,30). The fields within a periodic cell are displayed. Each of the six cells in the figure corresponds to the cross section or the radiator periodic

3

cell just above the stripline-slotline transition. Because the array has been scanned

to show the undesired behavior, the modes supported by the periodic transmission

line structure are fields with real and imaginary components. These are graphically

displayed in Figure 5 by showing the portion in-phase with the field at the center and

the portion 90 degrees out of phase (quadrature) at the center. At the stripline-notch

transition, the quadrature components in the first and third modes cancel, which can

be seen from the direction of the quadrature fields in Figure 5 (b1) and (b3). The

significant result, however, is that as modes 1 and 3 propagate with different

propagation constants, the cancellation of the quadrature part between these two

modes diminishes because they are no longer synchronized. This quadrature part

will not radiate well because it varies more quickly than the fundamental radiated

plane wave pair. A similar behavior exists for steps with a wider slot dimension.

[0012]   Thus, there is a continued need for new and improved radiating

architectures that address the above-described problems with prior solutions.

SUMMARY OF THE INVENTION

[0013]   According to an embodiment of the present invention, a Dual-Pol notched

array includes a triangular grid comprising metal fins of the notches form an array of

hexagons. At the "throat" (base) of each radiating element near a stripline-slotline

transition, three metal sheets form a slot structure. Three elements contact each

hexagon with two fins from each radiator forming the hexagon.

[0014]   The present invention has several non-limiting advantages and features:

[0015]   First, unlike the egg-crate architecture of notch arrays, the present

invention has an equilateral triangular grid, meaning that the number of radiating

elements and associative circuitry is reduced by a significant factor.

[0016]   Second, unlike a concentric rectangular dual-pole notch structure, which will not scan the TE polarization well in the inter-cardinal planes, the present invention can support only two orthogonal modes and scans well.

[0017]   Third, unlike an egg-crate architecture, the hexagonal notch structure of the present invention has concentric phase centers, and is therefore much easier to adjust polarization purity in the inter-cardinal plane.

[0018]   Fourth, the present invention includes a feed that has been devised for supporting vertical and horizontal polarizations using a single dielectric sheet parallel to the aperture.

[0019]   According to an embodiment of the present invention, a dual-pol notch step radiator is provided that includes notch step elements formed from three fins aligned to form a triangular grid having a plurality of slots. The radiator also includes a plurality of current lines connecting the elements.

[0020]   According to another embodiment of the present invention, a dual-pol notch step radiator is provide which includes triangular grid means for forming a plurality of triangular slots. The radiator also includes a plurality of exciting means for effecting vertical and horizontal polarization.

[0021]   Further applications and advantages of various embodiments of the invention are discussed below with reference to the drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]   Figure 1 shows a cross-section of a prior art egg-crate notch structure;

[0023]   Figure 2 shows an axial ratio from the egg-crate antenna in the inter-cardinal plane;

[0024]   Figure 3 shows a cross-section of prior art concentric-fed rectangular notches;

[0025]   Figure 4 shows a graph of an inter-cardinal scan of one concentric fed dual-pole rectangular notch array;

[0026]   Figure 5 shows three propagating modes for notch near stripline-slotline transition showing in-phase and quadrature-phase components of a prior art arrangement;

[0027]   Figure 6 shows a cross-section of notch transition sections of a triangular grid;

[0028]   Figure 7 illustrates modes calculated in periodic cell of hexagonal notch array's propagating notch scanned in the inter-cardinal plane;

[0029]   Figures 8-8b show a rectangular dual-pol notch array with feed in single dielectric sheet;

[0030]   Figure 9 shows a Stripline-to-Slot transition at the base of a novel egg-crate radiator design;

[0031]   Figure 10 shows feeding horizontal and vertical modes in a hexagonal notch array;

[0032]   Figure 11 is a perspective view of the triangular gird of an embodiment of the present invention;

[0033]   Figure 12 is a perspective view of a hexagonal trough radiator according to an embodiment of the present invention;

[0034]   Figure 13a shows as top view or the trough balun feed;

[0035]   Figure 13b shows the relation of the hex fins to feed;

[0036]   Figure 14 shows a stripline formed from three dielectric layers;

[0037]   Figure 15 shows fins form stepped periodic slotline transformer to free space; and

[0038]   Figure 16 shows the fins being electrically grounded to the base.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0039]	While the present invention may be embodied in many different forms, a number of illustrative embodiments are described herein with the understanding that the present disclosure is to be considered as providing examples of the principles of the invention and such examples are not intended to limit the invention to preferred embodiments described herein and/or illustrated herein.

[0040]	It can be observed from the impedances for the modes in Figure 5 (the concentric phase rectangular notch architecture) that the impedances obey a quasi-static model. From this perspective, three modes can be considered to exist because the unit cell for the concentrically fed notch antenna has four pieces of metal at different potentials. In the egg-crate architecture, this same potential model shows two sets of two pieces of metal at different potentials resulting in a total of two modes.

[0041]	In the present invention, a dual-pol notch propagating structure with three metal fins forms a triangular grid. This novel architecture yields a propagating structure with only two propagating modes and consequently avoids the problems of having an unwanted mode propagating. According to an embodiment of the present invention, notch transition sections 600 each have the cross section like the one shown in Figure 6.

[0042]	In Figure 6, fins 602 on a dielectric sheet 606 connect a strip line (not shown) at a center point 604. The notch sections 600 are laid out in an array such that a hexagonal structure is created, which creates concentric phase centers. A periodic finite element analysis of the propagating modes shows that indeed, only two modes will propagate in the structure of Figure 6.

[0043]   Figure 7 shows modes calculation in periodic cell of hexagonal notch array's propagating notch scanned in the inter-cardinal plane at theta (degrees from normal) =60 and Phi=30. The mode in the TM plane of incidence always has $k_z/k_0=1$, while the other mode has k_z/k_0 less than 1. This notch propagating structure is expected to exhibit changes in polarization in its element pattern as the array is scanned. However, the phase centers for radiating vertical and horizontal polarizations are concentrically located, which facilitates the compensation of non-linear polarization. Also, there are different principal planes from the rectangular array with symmetries located at 120 degree planes, which can be exploited.

[0044]   The present invention supports dual-polarized modes with a concentric feed. Further, because the grid architecture for the propagating structure is triangular, the number of elements needed per unit area is reduced relative to the rectangular notch arrays.

[0045]   Vertical and horizontal polarizations are excited in the hex-notch array at the base of the notch transition. Because there are three arms to the notch radiator instead of two or four, it is essential to construct the feed so that coupling will not occur between the input ports. As a model for the feed, a recently developed dual-pol egg-crate feed in which the stripline feed is restricted to a single dielectric substrate parallel to the plane of the array is shown in Figures 8-9.

[0046]   Figures 8a-b show a rectangular dual-pol notch array with feed in single dielectric sheet. The stripline-to-slot transition for this rectangular array is shown in Figure 9. This device has many similarities to the feed transition used in the "Frisbee" radiator except that the bandwidth is considerably greater because true notch transition is constructed. GPPO connectors (manufactured by W. L. GORE &

ASSOCIATES, INC.) are used to connect to striplines in the dielectric sheet. Current is injected across the base of the slots that form the notches.

[0047] The power delivered to the slots is proportional to the current injected and the electric field in the slot mode that one wishes to excite. Using a pin to short the stipline across the slotline on the dielectric card, one maximizes the current. Placing a grooved periodic cavity region backed by a ground plane below the point where current is injected across the slot maximizes the modal field the stripline. Basically, a short at the base of the grooved region is pulled to a high impedance by placing the transition a quarter of a wavelength above the base of the groove.

[0048] An extension to the hexagonal notch array is shown in Figure 10. The key concept in this feed for the hexagonal array is that the horizontal polarization is excited by injecting current across one of the slots formed at the junction at the mouth of the hexagonal notch transition via horizontal feed 1002. For vertical polarization, one must inject the current from the second stripline 1004 across both of the other slots to excite the vertical polarization. Had the second stripline connector been connected to only across one of the other slots between the notch fins, there would be coupling between the two input striplines. In other words it is essential to excite orthogonal polarizations at the base of the hexagonal structure.

[0049] One should note that the vertical feed should not end in two shorted pins because such an arrangement would short out the horizontal feed. In other words, the ends of the vertical feed should be regarded as low impedance flags that pull a stripline open back to a short.

[0050] A triangular grid is shown in Figures 11-16 according to a second embodiment of the invention. In Figure 11, a perspective view of the triangular grid is shown. As shown, triangular elements 604 are constructed of fins 602 on hexagonal

elements 1102. As shown in Figure 12, the hexagonal elements 1102 are connected

by striplines 1104 (vertical feeds) and 1106 (horizontal feeds). Trough modes are

excited by the horizontal current line 1106 and vertical current line. These can be

fed by GPPO coaxial adapters. Note that current lines 1104 and 1106 are in

different planes and do not intersect.

[0051]   There are three planar dielectric layers with striplines on the interface of

two layers. The rest of the hexagonal elements are metal.

[0052]   Figure 13a shows a diagram of the trough balun feeds of the device of this

embodiment. Current stripline paths (1104, 1106) end in opens, which are pulled

back to a low impedance over the gap, which is the trough grooved channel. The

point of low impedance is where the striplines are over the channel.

[0053]   Figure 13b is a perspective view showing only one triangular grid to show

the relation between the hexagonal elements 1102 and the triangular fins 602, 604.

As shown in Figure 14 in more detail, three dielectric layers 1402-1406 are used to

isolate the current lines 1106 and 1104. As shown in Fig. 15, the fins form a stepped

periodic slotline impedance transformer 1500 to free space.

[0054]   Figures 16A and 16B show a side views respectively of the fin and of the

fin and base of the device. The fins 602, 604 can be electrically grounded to the

base 1102 by, for example, a metallic pin 1600 that connects the fin to the base.

The pin 1600 slides into groves in the balun 1102.

[0055]   Thus, a number of preferred embodiments have been fully described

above with reference to the drawing figures. Although the invention has been

described based upon these preferred embodiments, it would be apparent to those

of skilled in the art that certain modifications, variations, and alternative constructions

would be apparent, while remaining within the spirit and scope of the invention.

IN THE CLAIMS:

We claim:

1.   A dual-pol notch step radiator, comprising:

notch step elements formed from three fins aligned to form a triangular grid

having a plurality of slots; and

a plurality of current lines connecting the elements.

2.   The radiator of claim 1, wherein the elements have concentric phase centers

for vertical and horizontal polarization.

3.   The radiator of claim 1, wherein said current lines include at least one

horizontal current line and one vertical current line between each element for

actuating horizontal and vertical polarization respectively.

4.   The radiator of claim 1, further comprising a plurality of hexagonal bases on

which each element is positioned and a plurality of dielectric layers separating each

said element from each said base, said dielectric layers insulating each said current

line.

5.   The radiator of claim 4, where each said element is electrically grounded to

the base upon which it is positioned.

6.   The radiator of claim 5, wherein each said element is electrically grounded to

the base upon which it is positioned by a metallic pin formed in the element.

7.   A dual-pol notch step radiator, comprising:

triangular grid means for forming a plurality of triangular slots; and

a plurality of exciting means for effecting vertical and horizontal polarization.

8.   The radiator of claim 7, wherein said triangular grid means includes a plurality

of three-pronged elements having a center, formed on hexagonal bases.

9.   The radiator of claim 8, wherein elements are notched from the outside to the

inside, such that the center of where the three prongs connect has a height greater

than the edges of the prongs.

10.   The radiator of claim 9, wherein the elements have concentric phase centers

for vertical and horizontal polarization.

11.   The radiator of claim 7, wherein said exciting means includes horizontal

current lines and vertical current lines between elements of said triangular grid

means for actuating horizontal and vertical polarization respectively.

12.   The radiator of claim 7, further comprising hexagonal base means on which

said triangular grid means is formed, said base means including insulation means for

insulated said exciting means from said hexagonal base means.

13.   The radiator of claim 9, wherein each element is electrically grounded to the

base upon which it is positioned.

14.   The radiator of claim 13, wherein each said element is electrically grounded to the base upon which it is positioned by a metallic pin formed in the element.
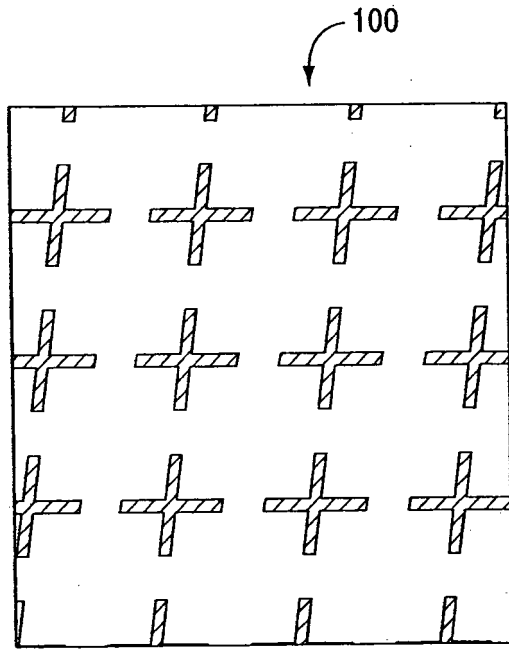
Egg-crate notch cross-section

Fig.1

Prior Art

Ku band radiator 15 July 2002

Vertical Element Pattern Axial Ratio
Inter-Cardinal Plane
Phi=45 F=13 GHz
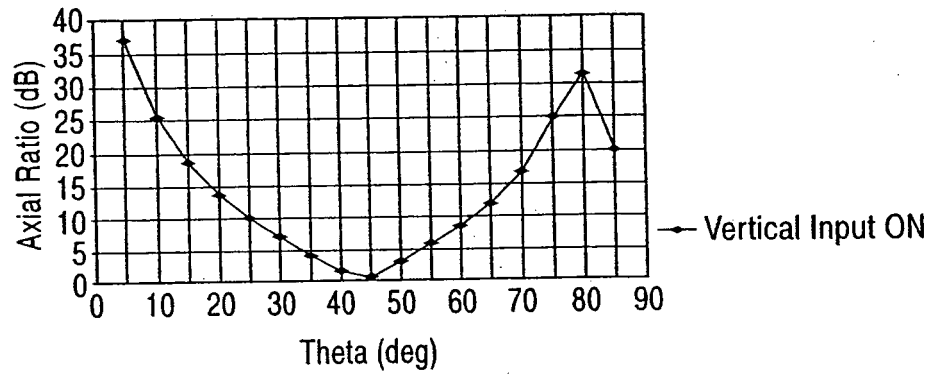
Axial ratio from an egg-crate antenna in the inter-cardinal scan

Fig.2

Prior Art
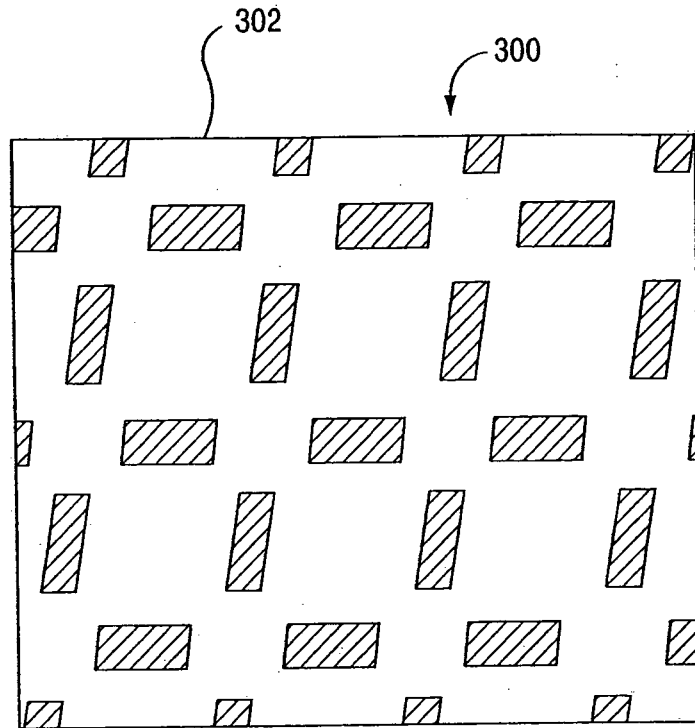
Cross section of concentric-fed rectangular notches.

Fig.3
Prior Art
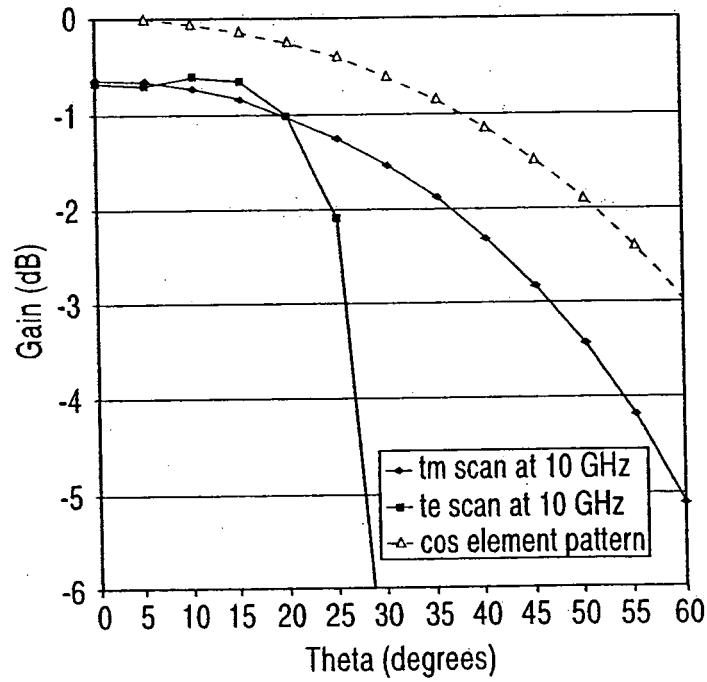
Inter-cardinal scan of one concentric fed dual-pol rectangular notch array

Fig.4

Prior Art

Freq= 10.0000 GHz
Mode 3
kz=(1.945, 0.6168E-11)
kz/kO=(0.9280, 0.2943E-11)

(a3)

(b3)

Freq= 10.0000 GHz
Mode 2
kz=(2.106, -0.7799E-12)
kz/kO=(1.005, -0.3721E-12)

(a2)

(b2)

Fig.5

Freq= 10.0000 GHz
Mode 1
kz=(2.106, -0.1820E-12)
kz/kO=(1.005, -0.8683E-13)

(a1)

(b1)
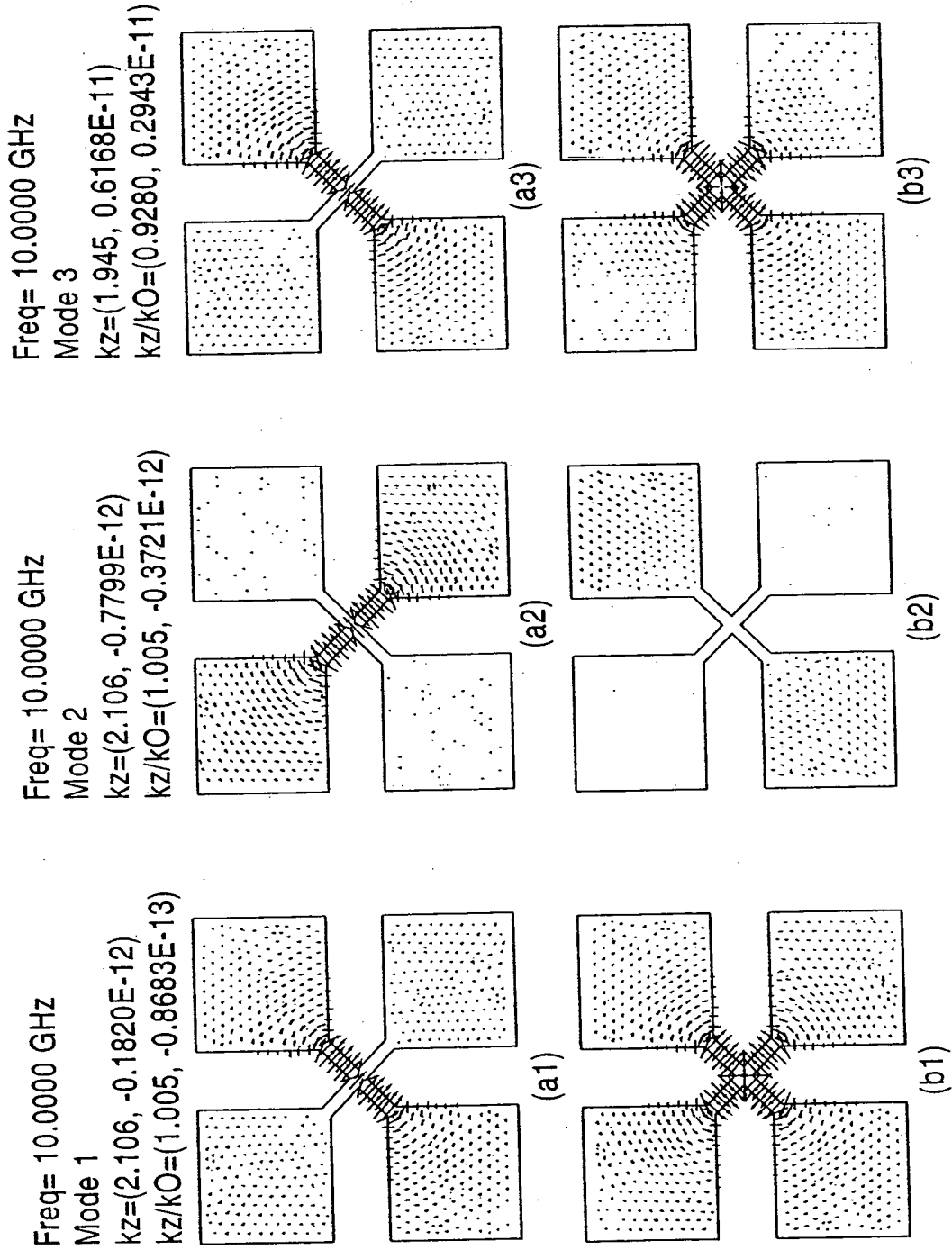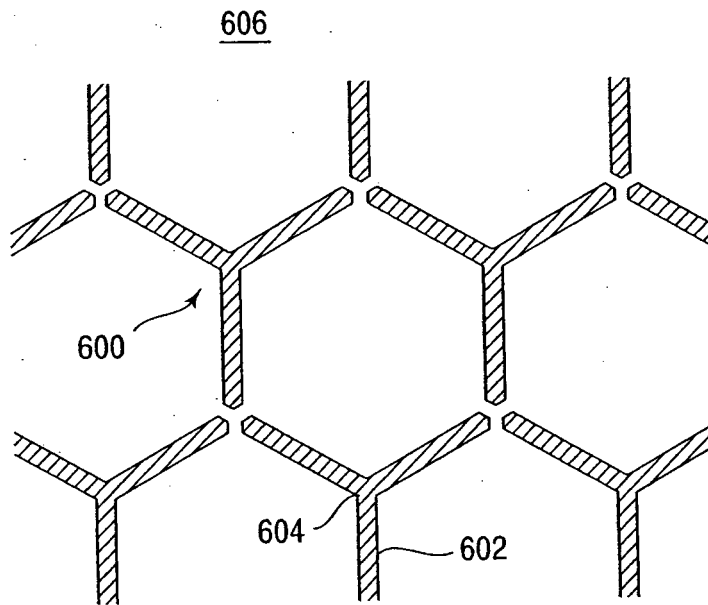
Cross section of new notch transition sections

Fig.6

Fig.7

Ku Band Radiator at Normal
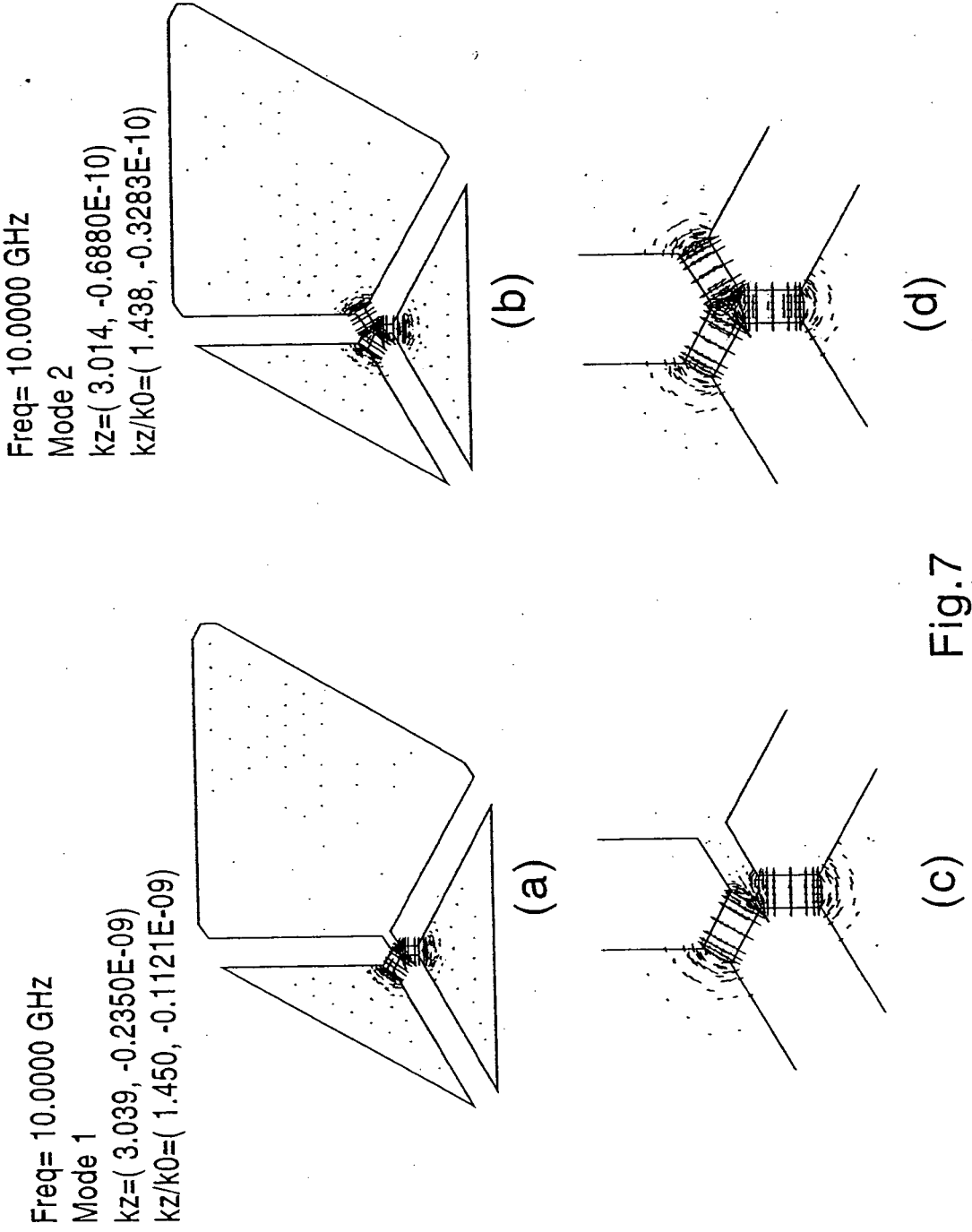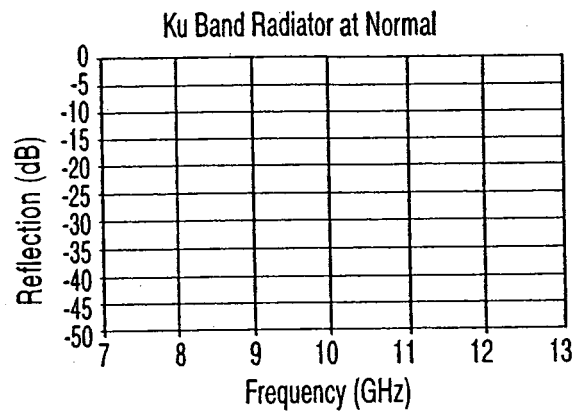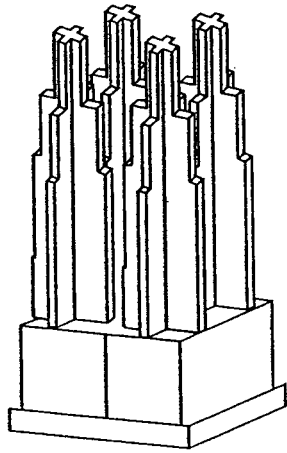
Fig.8a
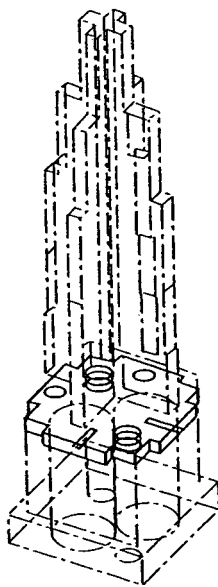
Rectangular dual pol notch array with feed in single dielectric sheet.

Fig.8b
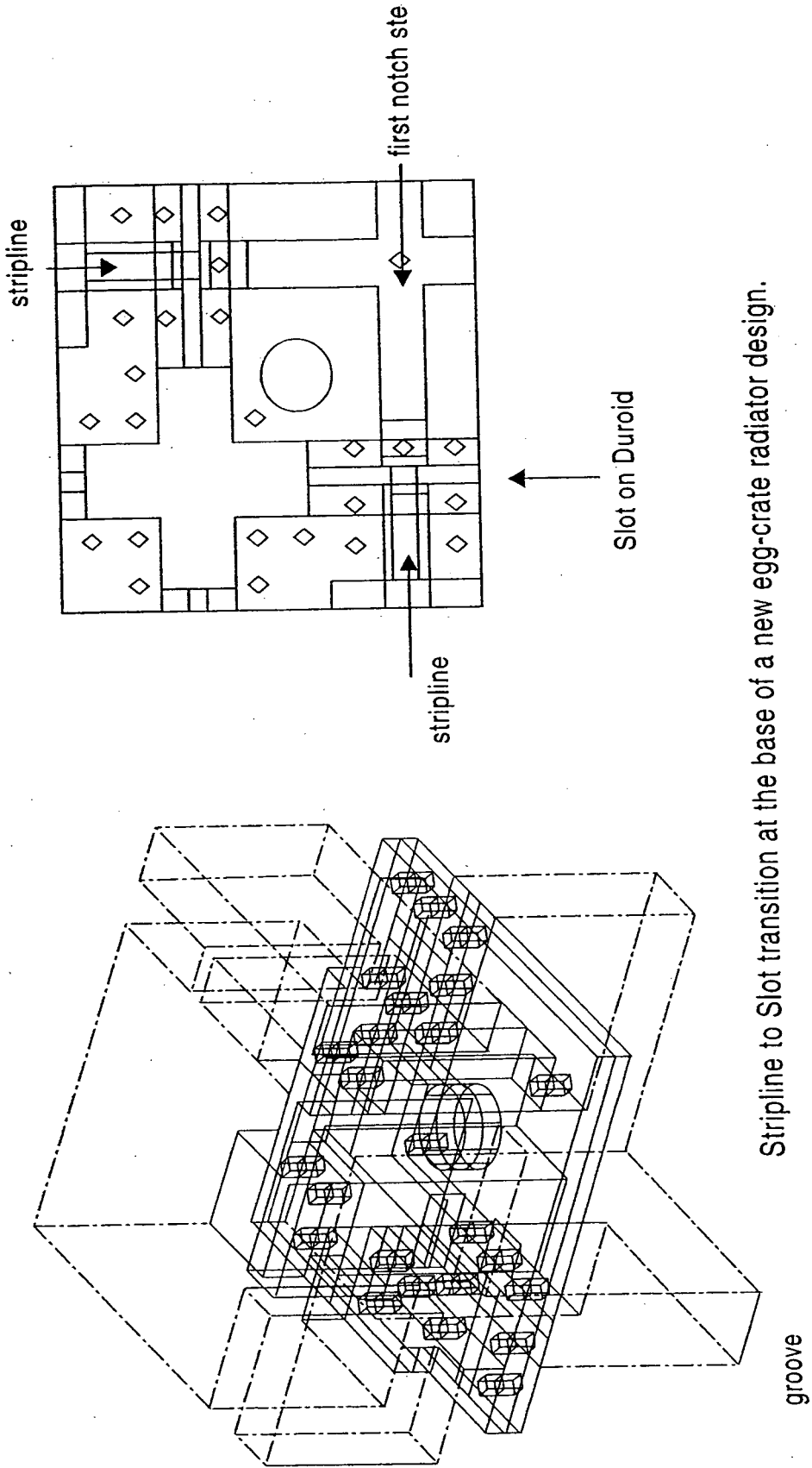
Stripline to Slot transition at the base of a new egg-crate radiator design.

Fig.9

Fig.10

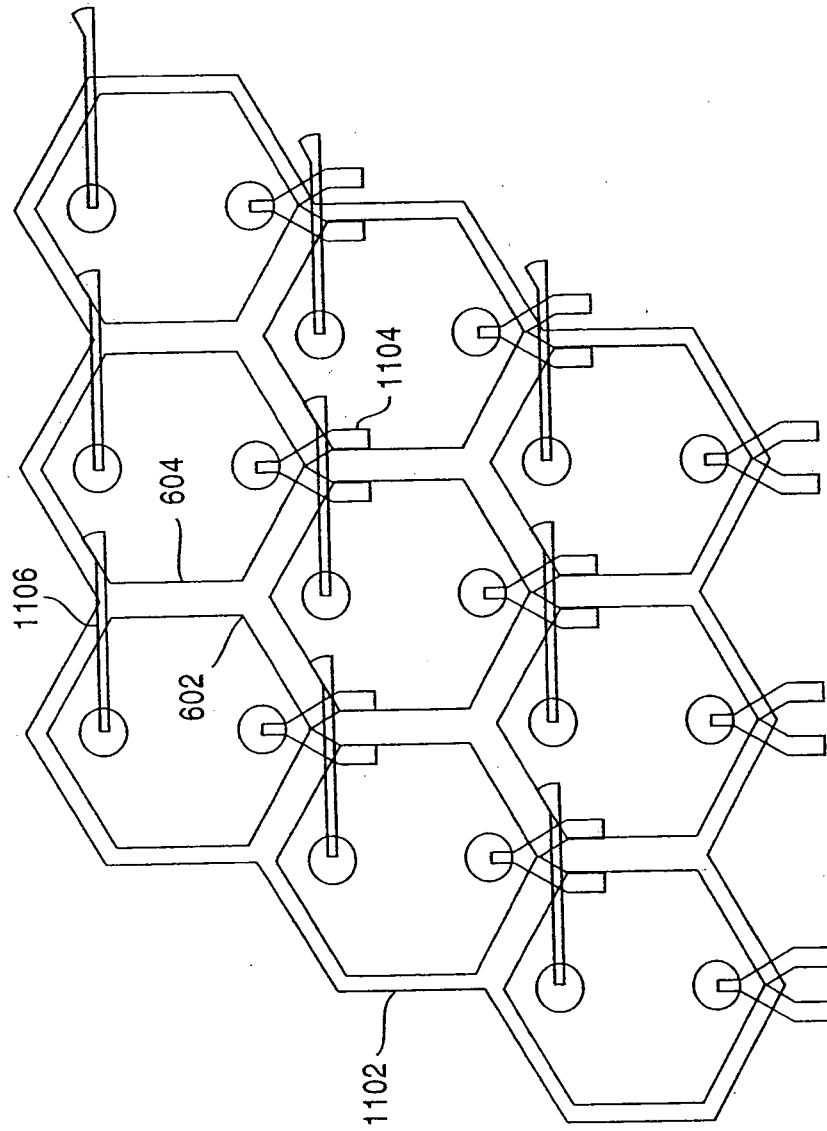The extension to the hexagonal notch array is shown
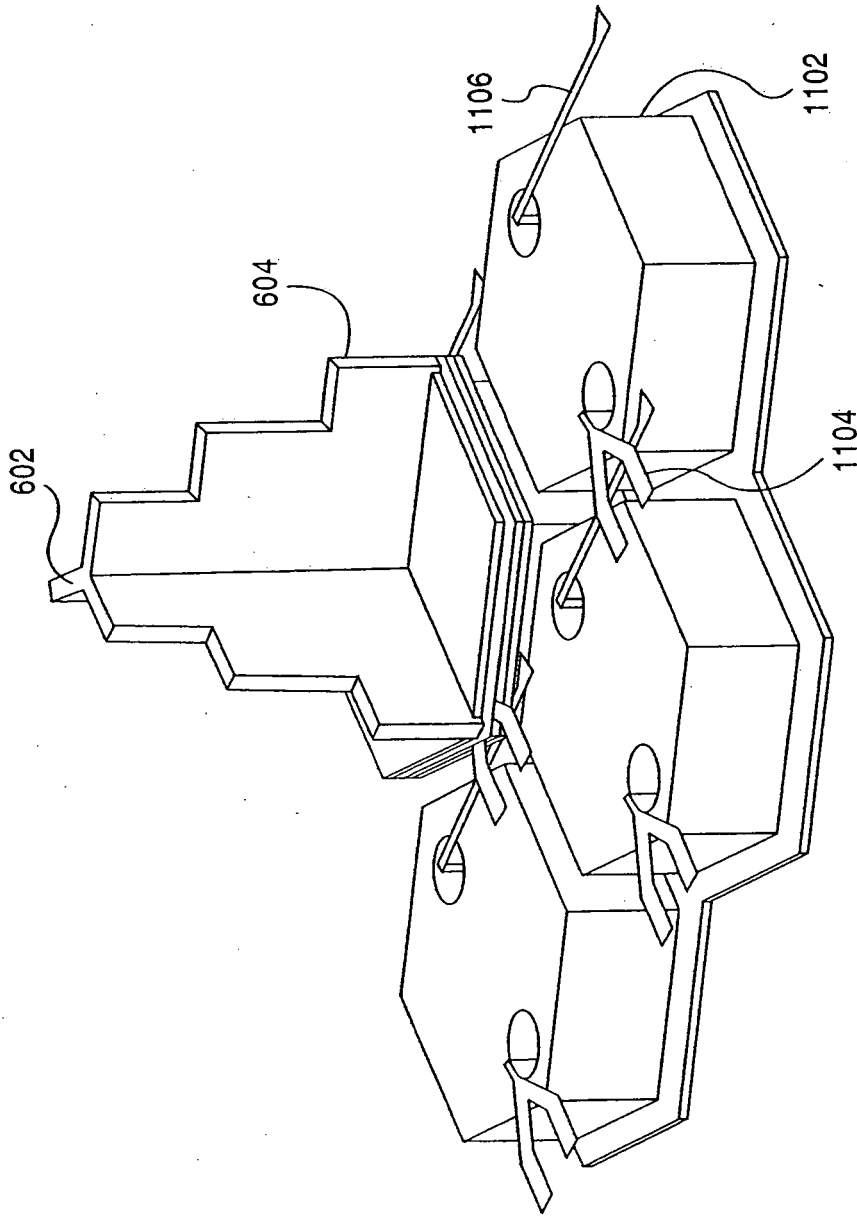
Fig.11

WO 2008/008050   PCT/US2006/024016

12/17
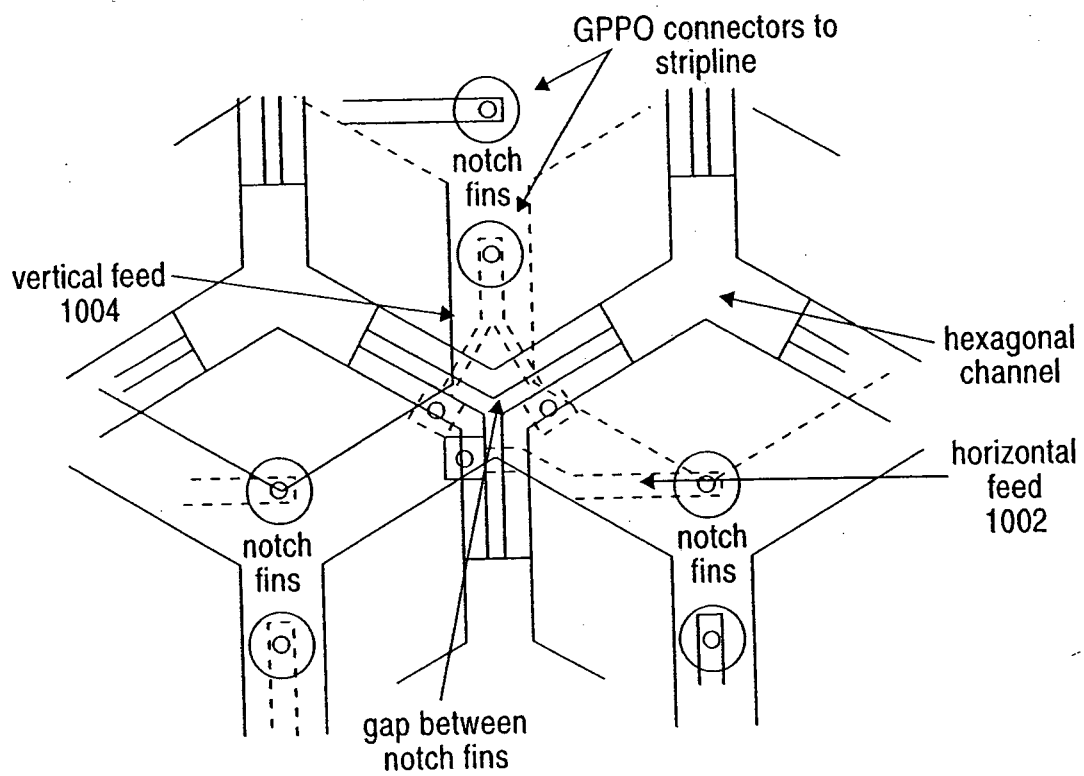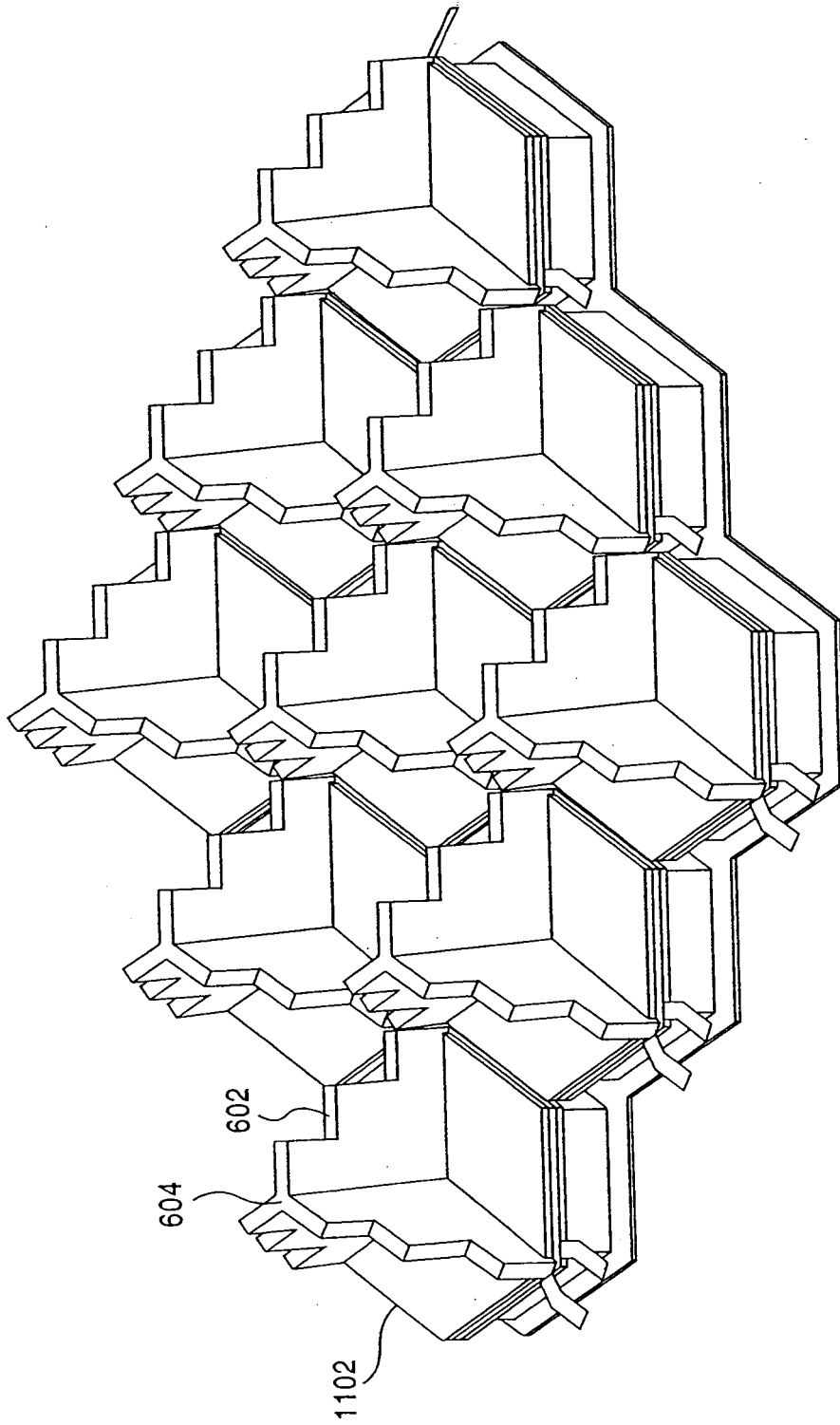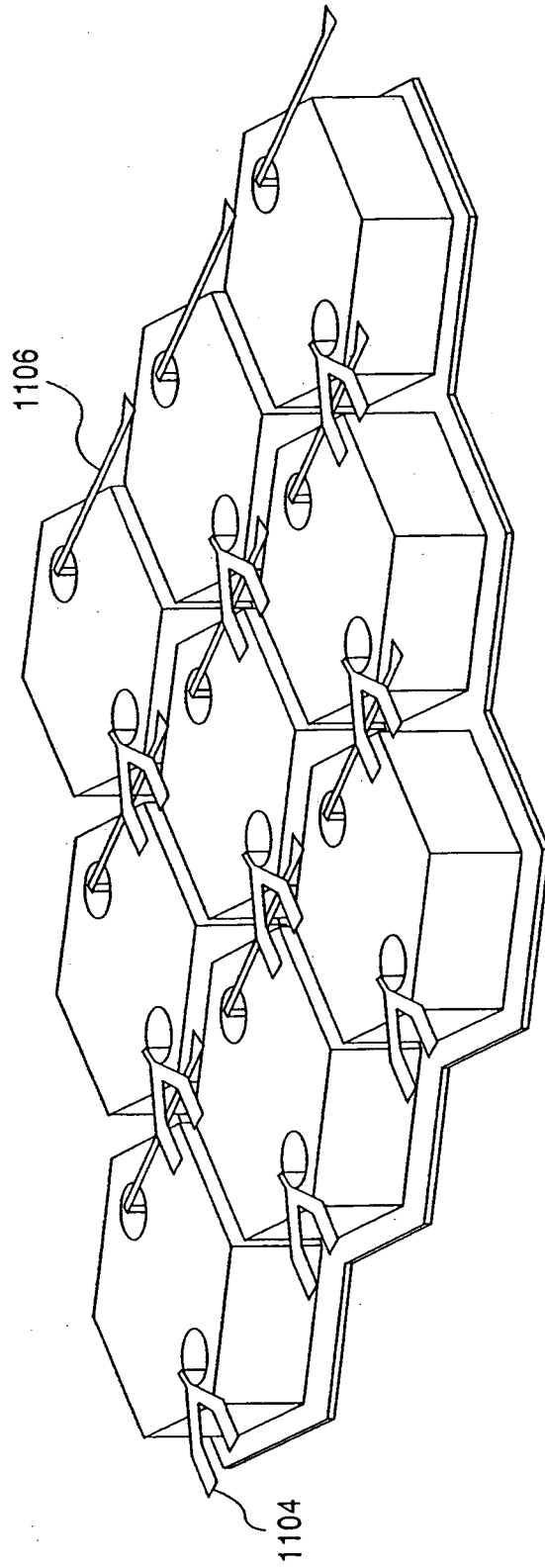
Fig.12

Fig.13A

Fig.13B
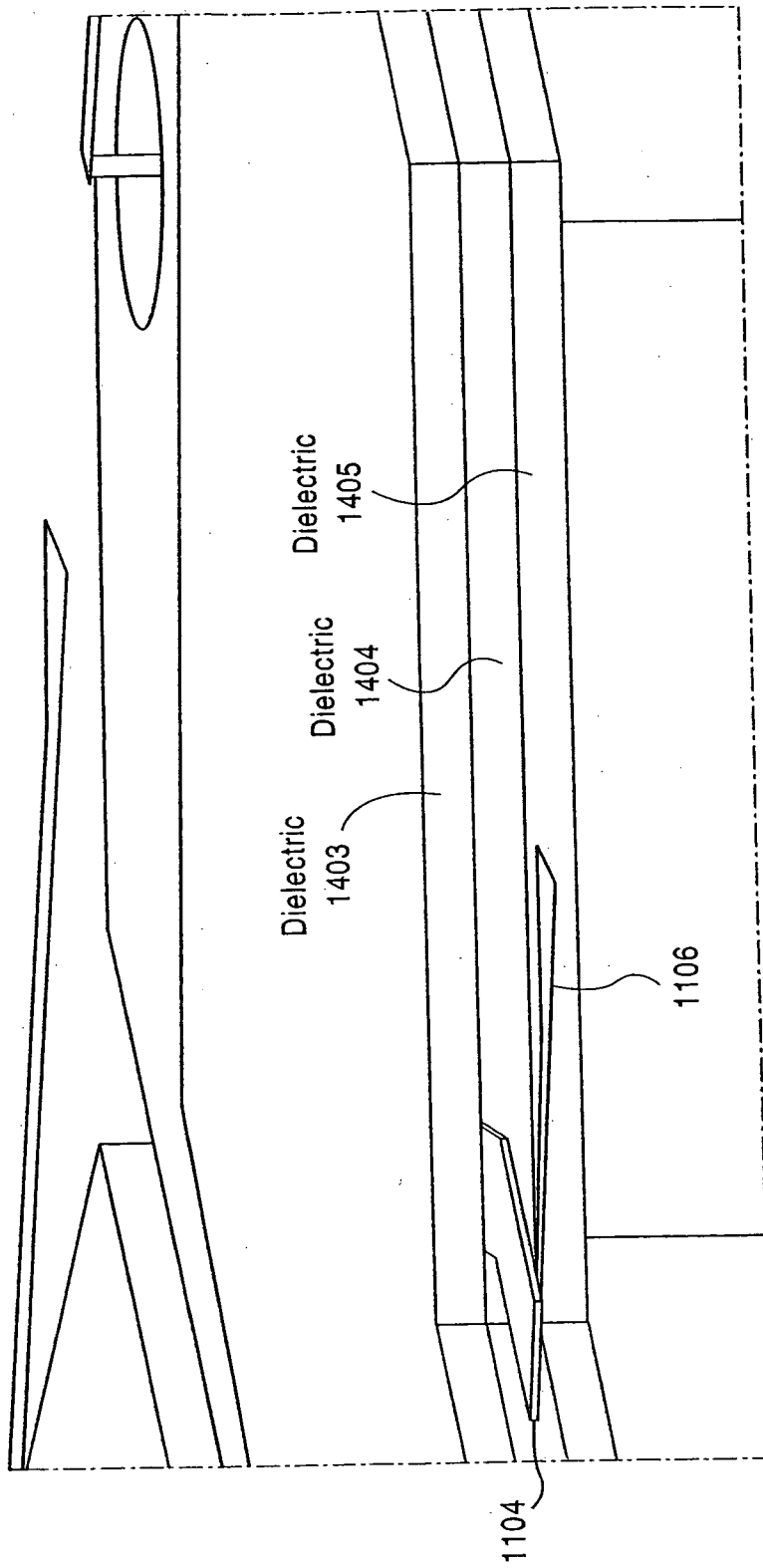
Fig.14

Fig. 15

Fig.16B

Fins

1500

1102

Base of trough
balun

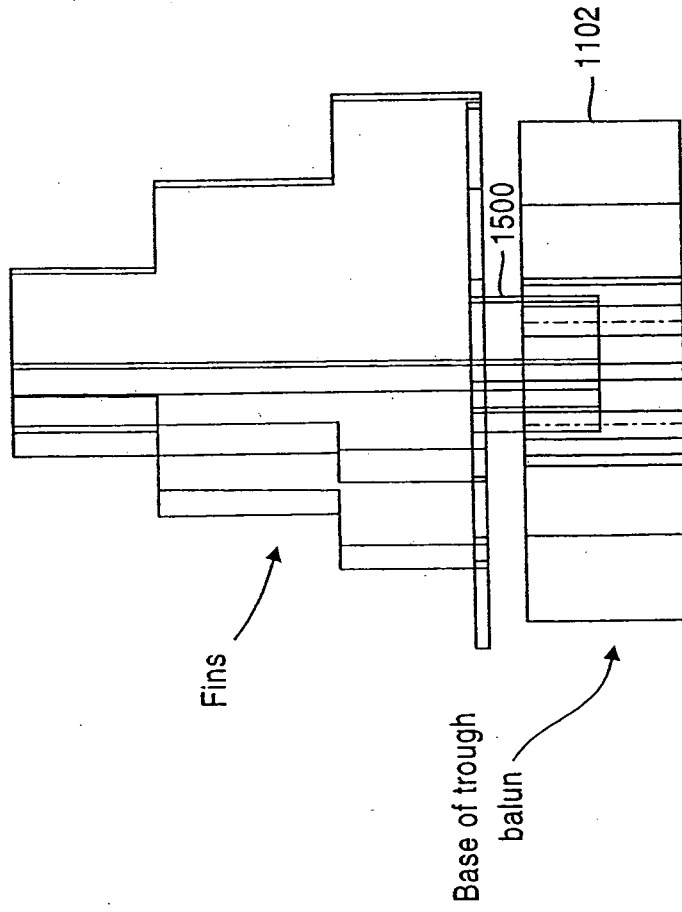## Fig.16A

Fins

602

604

1600
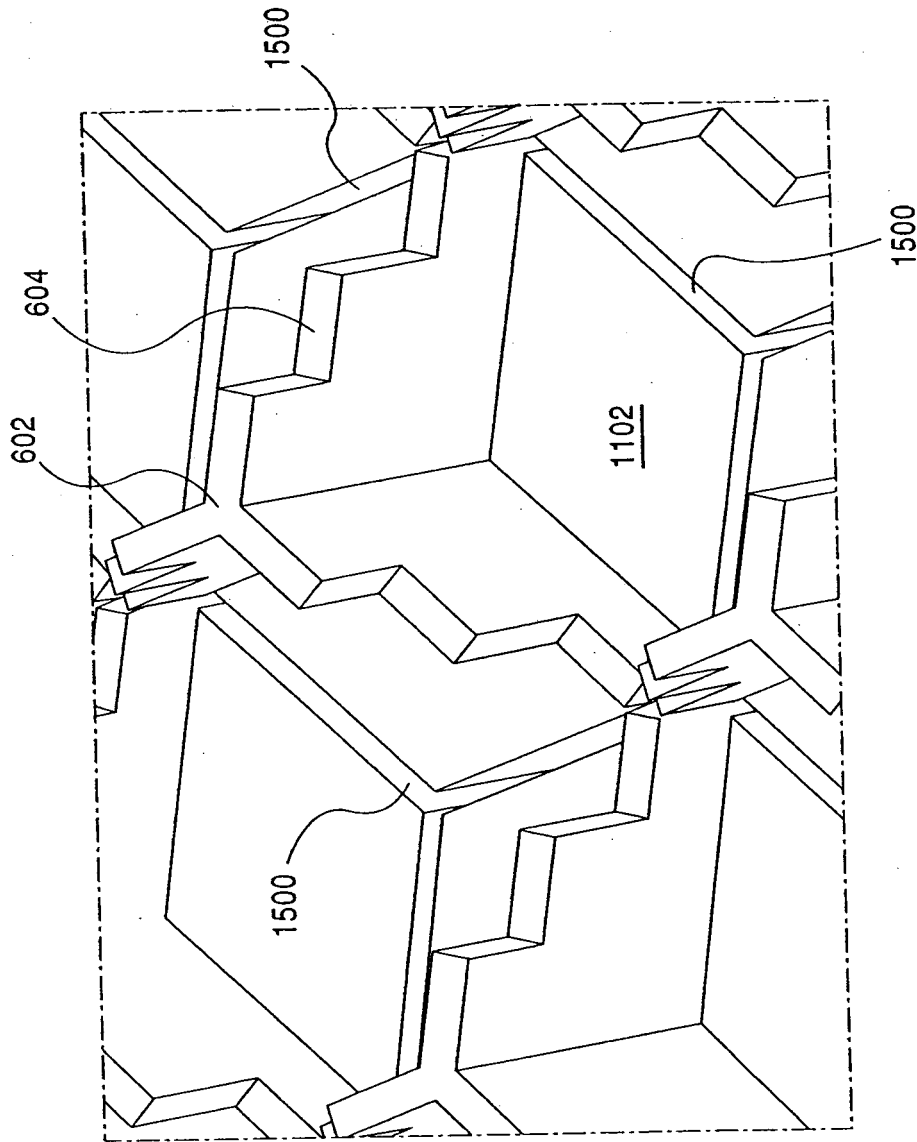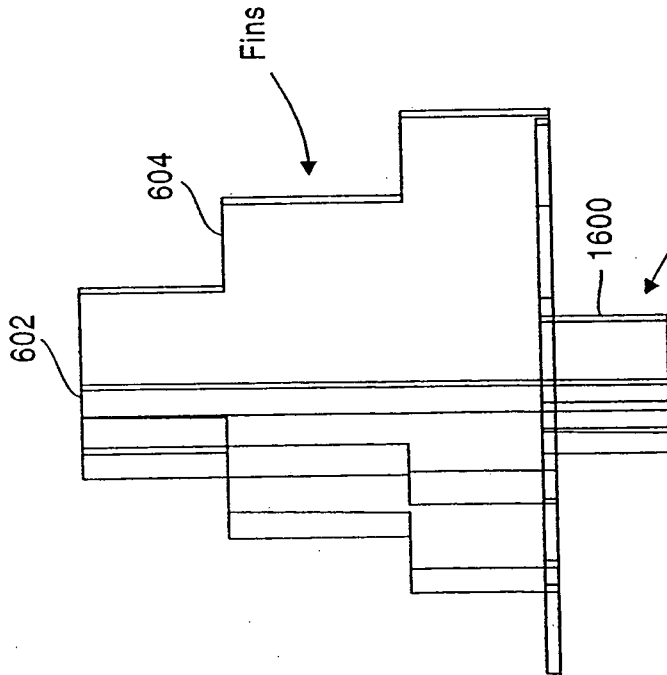
Example of metallic pin that
connects fin to base pedestal

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q21/00   H01Q21/06

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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2 507 528 A (KANDOIAN ARMIG G) 16 May 1950 (1950-05-16)	7
A	column 3, line 60 – line 72; figure 6	1
A	US 2004/004580 A1 (TOLAND BRENT T [US] ET AL) 8 January 2004 (2004-01-08) paragraph [0022] – paragraph [0030]; figures 4,5	1,7

-/--

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 2007	14/12/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	LA CASTA MUNOA, S

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	LEE J J ET AL: "Performance of a wideband (3-14 GHz) dual-poll array" ANTENNAS AND PROPAGATION SOCIETY SYMPOSIUM, 2004. IEEE MONTEREY, CA, USA JUNE 20-25, 2004, PISCATAWAY, NJ, USA,IEEE, vol. 1, 20 June 2004 (2004-06-20), pages 551-554, XP010721104 ISBN: 0-7803-8302-8 abstract; figures 1-3	1,7
A	US 3 975 738 A (PELTON EDWARD L ET AL) 17 August 1976 (1976-08-17) column 2, line 50 - line 61; figures 2,3	1,7
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