(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 September 2013 (26.09.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/140036 A1

(51) International Patent Classification:
H01Q 21/00 (2006.01) *H01Q 1/38* (2006.01)
H01Q 21/06 (2006.01)

(21) International Application Number:
PCT/FI2013/050303

(22) International Filing Date:
15 March 2013 (15.03.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
20125308 20 March 2012 (20.03.2012) FI

(71) Applicant: **TEKNOLOGIAN TUTKIMUSKESKUS VTT** [FI/FI]; Vuorimiehentie 3, FI-02044 Vtt (FI).

(72) Inventor: **LAMMINEN, Antti**; c/o VTT, P.O. Box 1000, FI-VTT 02044 (FI).

(74) Agent: **SEPPO LAINE OY**; Itämerenkatu 3 B, FI-00180 Helsinki (FI).

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

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

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: ANTENNA ARRAY WITH WAVEGUIDE FEED NETWORK

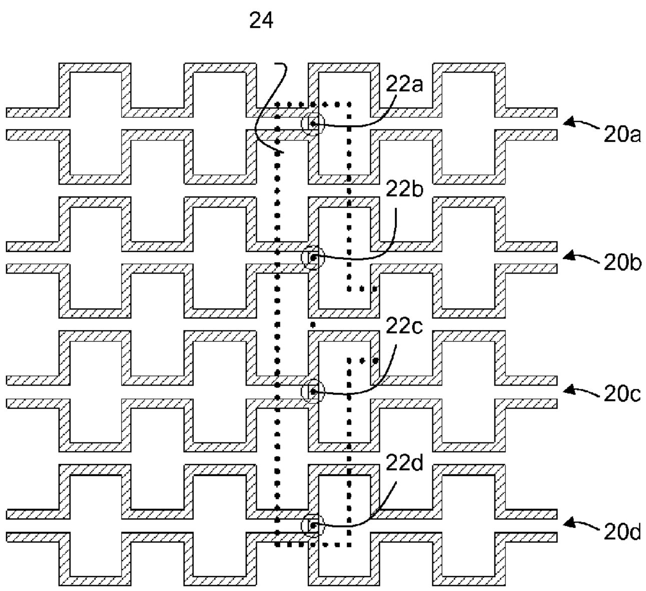

Fig. 2

(57) Abstract: The invention relates to a traveling-wave antenna array comprising a feed network,a radiating structurecomprising at least four elongated grid antenna sub-arrays arranged side-by-side and parallel to each other so as to form a two-dimensional antenna array,and a plurality of interface elements coupled to the grid antenna sub-arrays and to the waveguide feed network for exciting each of the grid antenna sub-arrays. According to the invention the feed network comprises a waveguide network which is at least partly arranged below the radiating structure, and there are at least two of said interface elements for each of the elongated grid antenna sub-arrays for exciting the sub-arrays simultaneously at least two points. The invention allows for high directivity and high gain to be achieved in a millimetre-wave antenna array.

WO 2013/140036 A1

ANTENNA ARRAY WITH WAVEGUIDE FEED NETWORK

Field of the Invention

The invention relates to antenna arrays. In particular, the invention relates to millimetre-wave chain antenna arrays and power distribution networks for the arrays.

Prior Art

Chain antennas, related to grid antennas, are known to exhibit a moderate gain even with a single chain. Gain can be further increased by forming chains into an array. In a fixed-beam array, the power is distributed equally from one point into all chain elements with a feed network. Conventionally, this has been done using microstrip lines and T-junctions or Wilkinson power dividers.

Säily et al, “Low cost high gain antenna arrays for 60 GHz millimetre wave identification (MMID),” in Sixth ESA Workshop on Millimetre Wave Technology and Applications, Espoo, Finland, May 2011, pp. 1–6*,* discloses a chain antenna array manufactured using printed circuit board (PCB) technology. The antenna comprises a branched open microstrip feed network and a radiating structure comprising several elongated chain antenna sub-arrays arranged side-by-side and parallel to each other, thereby forming a two-dimensional antenna array. Each of the sub-arrays is coupled at its one end to one branch of the feed network for excitation of the sub-array. Problems with this kind of arrangement include beam tilting from the desired broadside direction and beam scanning with frequency. Also high gain is difficult to achieve due to losses in the microstrip line feed network

In a more general level too, one of the main challenges at millimetre-wave frequencies is to achieve high antenna gain (and efficiency) for large antenna arrays due to losses in the feed network that usually consists of microstrip lines, coplanar waveguides, striplines or other open transmission lines, like in the abovementioned publication. It is known that the feed network losses can be reduced using e.g. substrate-integrated waveguides (SIW).

Bauer F. et al, “A 79 GHz Microstrip Grid Array Antenna Using a Laminated Waveguide Feed in LTCC”, *“A 79 GHz microstrip grid array antenna using a laminated waveguide feed in LTCC,” in 2011 IEEE International Symposium on Antennas and Propagation*

(APSURSI), Washington, USA, July 2011, pp. 2067–2070, discloses a technique for feeding microstrip grid array antennas using a SIW. The publication discloses a two-branch array which is suitable for automotive radar applications. In the design disclosed, the branches are oriented linearly and parallel with an elongated waveguide cavity in the SIW. A problem with this kind of arrangement is that high gain cannot be achieved with only two chain/grid antennas. In addition the disclosed structure allows for exciting only two antennas from one SIW. Thus, the design is not scalable up in size.

Another kind of medium-gain grid antenna is disclosed in US 2011/0241969, without describing the feed network structure or up-scaling of the system detail.

To summarize, a problem with prior art technologies is that high directivity and high gain have not been simultaneously achieved.

Summary of the Invention

It is an aim of the invention to achieve an antenna design which is solves at least some of the abovementioned problems.

The aim is achieved by the antenna array having the features of claim 1.

According to one aspect of the invention, a traveling-wave antenna array is provided, the array comprising a feed network, a radiating structure comprising at least four elongated grid antenna sub-arrays arranged side-by-side and parallel to each other so as to form a two-dimensional antenna array, and a plurality of interface elements coupled to the grid antenna sub-arrays and to the waveguide feed network for exciting each of the grid antenna sub-arrays. According to the invention the feed network comprises a waveguide network which is at least partly arranged below the radiating structure, and there are at least two of said interface elements for each of the elongated grid antenna sub-arrays for exciting the sub-arrays simultaneously at at least two points.

The advantages of the present antenna array design include that total losses remain relatively low even when the antenna array is scaled up in size to a 2x4 or even larger antenna array, and high antenna gain is achieved. At the same time the whole a sub-antenna array can be efficiently excited due to the plurality of excitation points for each sub-antenna.

The invention can be used to replace lens, reflector, horn-or other heavy and bulky directive antennas at millimetre-wave applications with low-cost directive planar array antennas. For example, the invention can be used as an alternative to conventional lens or reflector antennas in millimetre-wave point-to-point radio links.

Since the antennas are not parallel, but preferably at a right angle to the feeding waveguide, the present design allows for exciting a large amount of antennas and is therefore scalable up in size.

The present invention is most suitable for centimetre and millimetre wave applications at the frequency range of 3-300 GHz, in particular 30-300 GHz, but can be used also at higher frequencies.

The proposed antenna could be used in emerging wireless millimetre-wave applications such as millimetre wave identification (MMID), Wireless high definition (HD), Wireless Personal/Local Area Networks (WPAN/WLAN) and point-to-point radio links.

Further advantageous embodiments are characterized in the dependent claims.

Next, embodiments of the invention are described with reference to the attached drawings.

Brief Description of the Drawings

Fig. 1a shows a single chain antenna.

Fig. 1b shows a "vertically" up-scaled 4-chain antenna array.

Fig. 1c shows a "vertically" and "horizontally" up-scaled 4-chain antenna array.

Fig. 2 shows a "vertically" up-scaled 4-chain antenna array with feed network according to one embodiment of the invention.

Fig. 3 shows a "vertically" up-scaled 8-chain antenna array with feed network according to one embodiment of the invention.

Fig. 4 shows a "horizontally" and "vertically" up-scaled 8-chain antenna array with feed network according to one embodiment of the invention.

Fig. 5 shows a "vertically" up-scaled 4-chain antenna array with antenna sub-arrays extending into different directions from their feed points.

Fig. 6 shows a cross-sectional view of a SIW feed network structure integrated with a chain antenna array according to one embodiment of the invention.

Detailed Description of Embodiments

As briefly discussed above, the idea of the invention is to utilize a highly-efficient antenna radiator(s) with a low-loss feeding network to obtain high efficiency for the whole antenna array. A chain antenna array with a SIW feed network arranged with respect to each other according to the invention is described below in detail by way of example.

Antenna Array

Thus, referring to Fig. 1a, the elongated antenna sub-arrays 10 may comprise chain antennas, which typically have two symmetrically meandering conductors 11a, 11b, thus forming chain-like formation. In one embodiment, the length L of each chain element is $\lambda/2$ and the maximum distance D between the meanders is λ, i.e. the wavelength used. Between the chain elements, there are linking parts, where the meanders are parallel and close to each other. At one linking part, there is provided a feed point 12 which is electrically connected to both meandering conductors 11a, 11b for exciting the antenna.

As shown in Figs. 1b and 1c, and discussed blow in more detail, the structure is scalable in size and high antenna gain and directivity can be achieved with a large antenna array. Fig. 1b shows a vertically expanded grid antenna having four chain antennas sub-arrays 10a-10d according to Fig. 1 arranged in parallel side-by-side configuration. In the shown configuration, there is one feed point at each of the sub-arrays at corresponding positions of the chain.

With reference to Fig. 1c, showing a vertically and horizontally expanded grid antenna according to one embodiment of the invention, each of the sub-arrays 100a-100d is a single continuous grid antenna section having more than one (four shown) feed points at each sub-array. In the configuration shown, the spacing of the feed points equals to two chain elements, but the spacing could be a multiple of two as well.

More generally speaking, the spacing of the feed points can be chosen freely to obtain a desired illumination profile for the antenna array. For example, more narrow spacing at the center area than at the edge could be used for targeting as lower side lobes in the radiation pattern.

According to an alternative embodiment (not shown), each of the sub-arrays comprises a plurality of separated chain antennas and there is at least one interface element coupled to each grid antenna section. This configuration is therefore similar to that shown in Fig. 1c, but the chains 100a-100d are not continuous but disconnected at least at some point between any two feed points.

The number of side-by-side sub-arrays may be for example 4 - 100, in particular 4 - 24. The number of feed points in each sub-arrays may be for example 2 - 50, in particular 2 - 12. In one embodiment, the number of side-by-side sub-arrays is 8 or more and the number of feed points 4 or more.

Instead of a chain antennas, the antenna sub-arrays may be other types of meander lines or closed-loop grid antennas.

The dielectric material of the antenna substrate can be partly removed in order to decrease the effective permittivity of the substrate to obtain wider bandwidth and higher gain for the antenna array.

<u>Geometry of the Feed Network</u>

With reference to Figs. 2 and 3, according to one embodiment, the waveguide feed network comprises an elongated interface cavity 24; 34, which is oriented at an angle, preferably perpendicularly, to the elongated grid antenna sub-arrays 20a-20d; 30a-30h. In Fig. 2, there are four interface elements in the interface cavity 24 coupled to four separate chain antennas 20a-20d. In Fig. 3, the number of interface elements and chain antennas is 8.

With the aid of the present invention, the principle shown in Figs 2 and 3 can be easily scaled up so as to form a larger high-gain antenna array. This can be achieved by branching the feed network so that at least two elongated interface cavities are formed. Fig. 4 shows an example of such array. The array comprises a multiply branched feed network comprising four H-shaped portions in which the vertical branches of “H” form interface cavities each having four interface elements of the antenna chains coupled to. The four H-shaped portions are arranged in a 2-by-2 matrix so that an even grid of feed points to the antenna chains above the feed network is formed. The matrix can be also larger n-by-m matrix, where n and m are integers selected from a group of e.g., 2...100.

Characteristic to the configurations shown in Figs. 1-4 is that the grid antenna sub-arrays are similar to each other and are located symmetrically adjacent to each other. They extend from the interface cavities (feed points) to into the same direction.

According to one embodiment, the sub-arrays extend from the interface elements alternatingly into opposite directions. This kind of arrangement may be produced with a similar feed network as discussed above by only modification of the conductor pattern of the antenna. If the chains are extended into opposite directions, the spacing of the chains can be reduced from one wavelength into a half wavelength. A larger antenna array can be excited from a single SIW.

In all of the above embodiments, if it is desired that the distance between neighboring interface elements corresponds to another value than the operating wavelength of the antenna array, the feed network and antenna pattern may be modified correspondingly. For example, it may be preferably to make an antenna where the distance between neighboring interface elements corresponds to half of the operating wavelength of the antenna array.

<u>SIW Feed Network</u>

As discussed above, the waveguide feed network is a substrate-integrated waveguide (SIW) feed network, although it can be realized by any know waveguide technology. An advantage of using a waveguide, in particular SIW, network is that the feed network losses are significantly reduced compared with a microstrip line or other open transmission line.

According to one embodiment the SIW-to-chain-antenna-array transition is implemented by providing a plurality of interface elements formed by electrically conducting probes from the antenna sub-arrays to a single SIW cavity. The This kind of transition between the waveguide and the radiating portion of the antenna enables scaling of the structure into a large antenna array as discussed above without sacrificing too much in efficiency.

It should be noted that the excitation from SIW to antenna can be done using conducting probes, as described above, or alternatively by coupling apertures in the upper conductor layer of the SIW. More generally speaking, the interface elements may comprise voids or other channels allowing radiation power to pass from the feed network to the radiating structure.

The SIW feed network and the antenna pattern may be integrated in to a single multilayered substrate. The substrate may be for example a low temperature co-fired ceramic (LTCC) substrate, liquid crystal polymer (LCP), or a standard printed circuit board (PCB) substrate.

The dielectric material inside the SIW can be partly removed in order to decrease the dielectric losses of the SIW and to improve the antenna efficiency and gain.

According to one embodiment, the interface elements comprise probes in electrical connection with the grid antenna sub-arrays and extending into a wave-guiding cavity of the waveguide feed network for coupling to the waves in the wave-guiding cavity.

In a multilayer SIW structure, the probes can be implemented with the same technology as used for forming the conductive boundary vias of the SIW waveguides. The vias can be connected to the antenna pattern by T-junctions.

With reference to Fig. 6, according to one embodiment, the multilayer structure comprises

- a bottom conductor layer 62 forming a waveguide bottom boundary,
- a multilayered dielectric waveguide portion 60 on the bottom conductor layer 62 and having a plurality of boundary vias 64 (only some of which are shown in the marked area 65) for defining side boundaries for the waveguide network,
- a top conductor layer 63 on the waveguide portion 60 and forming a waveguide top boundary, the top and bottom conductor layers 62, 63 being connected to

the boundary vias 64,

- apertures 66 in said top conductor layer 63 and probe vias 67 extending through the apertures 66 into the waveguide portion 60,
- a separating layer 69 on top of the top conductor layer 63, the probe vias 67 extending also through the separating layer 69,
- a conductive antenna layer 68 connected with the probe vias and patterned so as to form the radiating portion of the antenna.

According to one embodiment, the probes are equal in lengths. According to an alternative embodiment, at least two of the probes extend to different depths into the wave-guiding cavity. This embodiment allows for modifying the amplitude distribution in the antenna array and hence the radiation pattern of the antenna. By modifying the amplitude distribution in the antenna array, the radiation pattern can be modified. Coupling strength from the SIW to the antenna is in relation to the probe depth.

For example, in the millimetre-wave point-to-point radio links, a low side-lobe level is very important. The low side-lobe level can be achieved by tapering the amplitude distribution in the antenna array. In practise, less power is delivered to the edges of the array while more power is fed to the center of the array. Therefore, in one advantageous embodiment, at least one, preferably a plurality of probes at the center of the array are longer than those more distant from the center.

A transition from the SIW structure to a microstrip line or other transmission line known *per se* can be used in the array input in order to integrate the antenna with millimetre-wave circuits into a single radio module.

Claims

1. A traveling-wave antenna array comprising

   – a feed network,

   – a radiating structure comprising at least four elongated grid antenna sub-arrays arranged side-by-side and parallel to each other so as to form a two-dimensional antenna array,

   – a plurality of interface elements coupled to the grid antenna sub-arrays and to the waveguide feed network for exciting each of the grid antenna sub-arrays,

   characterized in that

   – the feed network comprises a waveguide network which is at least partly arranged below the radiating structure, and

   – there are at least two of said interface elements for each of the elongated grid antenna sub-arrays for exciting the sub-arrays simultaneously at at least two points.

2. The antenna array according to any of the preceding claims, **characterized** in that each of the elongated grid antenna sub-arrays comprises a plurality of separated elongated grid antenna sections, whereby there are at least one interface element coupled to each grid antenna section.

3. The antenna array according to any of the preceding claims, **characterized** in that each of the elongated grid antenna sub-arrays is a single continuous grid antenna section, whereby there are at least two interface elements coupled to each grid antenna section.

4. The antenna array according to any of the preceding claims, **characterized** in that

– the waveguide feed network comprises a branched waveguide having at least two elongated interface cavities, which are oriented perpendicularly to said elongated grid antenna sub-arrays,

– at least four interface elements coupled to different grid antenna sub-arrays are provided for each of said elongated interface cavities.

5. The antenna array according to claim 4, **characterized** in that the waveguide feed network comprises at least one, preferably at least four, "H"-shaped portions in which the vertical branches of "H" form said interface cavities.

6. The antenna array according to any of the preceding claims, **characterized** in that said four elongated grid antenna sub-arrays extend from the interface elements into the same direction.

7. The antenna array according to any of the preceding claims, **characterized** in that said four elongated grid antenna sub-arrays extend from the interface elements alternatingly into opposite directions.

8. The antenna array according to any of the preceding claims, **characterized** in that the distance between neighboring interface elements corresponds to the operating wavelength of the antenna array.

9. The antenna array according to any of the preceding claims, **characterized** in that the distance between neighboring interface elements corresponds to half of the operating wavelength of the antenna array.

10. The antenna array according to any of the preceding claims **characterized** in that the waveguide feed network is a substrate-integrated waveguide (SIW) feed network.

11. The antenna array according to claim 10, **characterized** by comprising

- a bottom conductor layer forming a waveguide bottom boundary,
- a multilayered dielectric waveguide portion having a plurality of boundary vias for defining side boundaries for the waveguide network,
- a top conductor layer forming a waveguide top boundary,
- apertures in said top conductor layer for said interface elements,

– a separating layer on top of the top conductor layer, the separating layer comprising a plurality of probe vias forming said interface elements and extending through the apertures to the waveguide portion,

– a conductive antenna layer patterned on the separating layer so as to form said radiating structure.

12. The antenna array according to any of the preceding claims, **characterized** in that the elongated grid antenna sub-arrays are chain antennas, meander lines or closed-loop antennas.

13. The antenna array according to any of the preceding claims, **characterized** in that the interface elements comprise probes in electrical connection with the grid antenna sub-arrays and extending into a wave-guiding cavity of the waveguide feed network for coupling to the waves in the wave-guiding cavity.

14. The antenna array according to claim 13, **characterized** in that at least two of the probes extend to different depths into the wave-guiding cavity.

15. The antenna array according to claim 13 or 14, **characterized** in that at least one, preferably a plurality of probes at the center of the array is/are longer than at least one probe more distant from the center of the array.

16. The antenna array according to any of claims 13 - 15, **characterized** in that the probes are non-equally spaced in the array, the spacing at the center of the array preferably being smaller than more distant from the center of the array.

17. Use of the antenna array according to any of the preceding claims for millimetre wave radio communication.

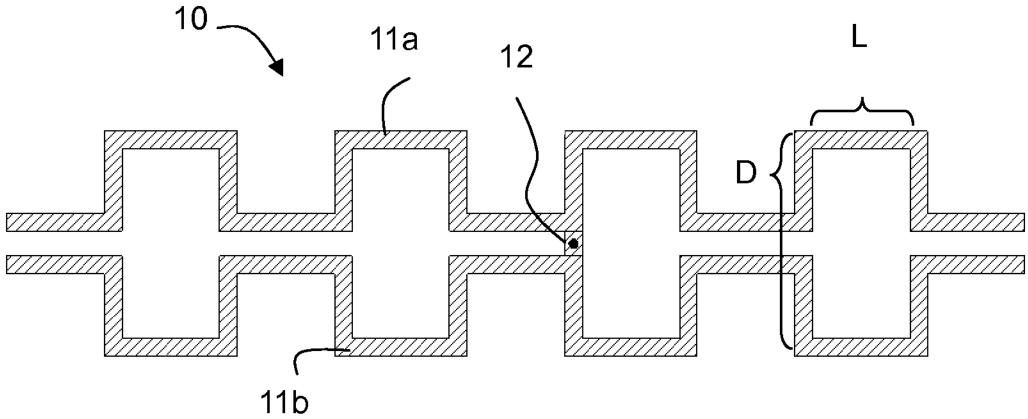

Fig. 1a

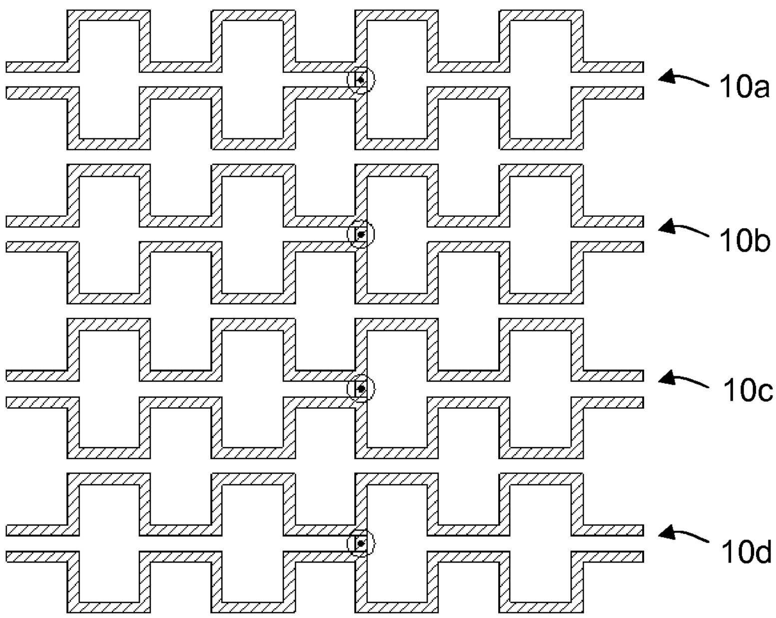

Fig. 1b

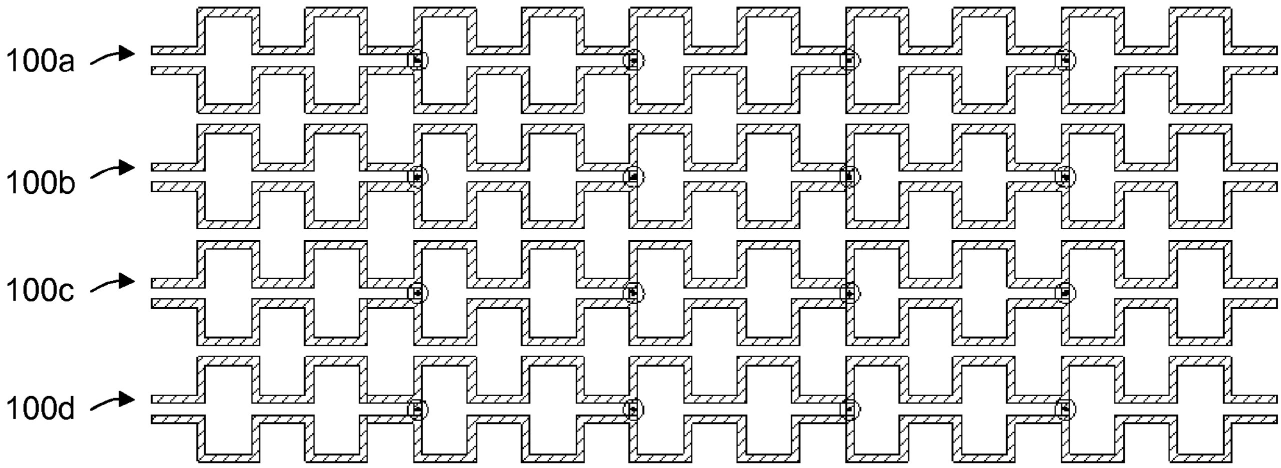

Fig. 1c

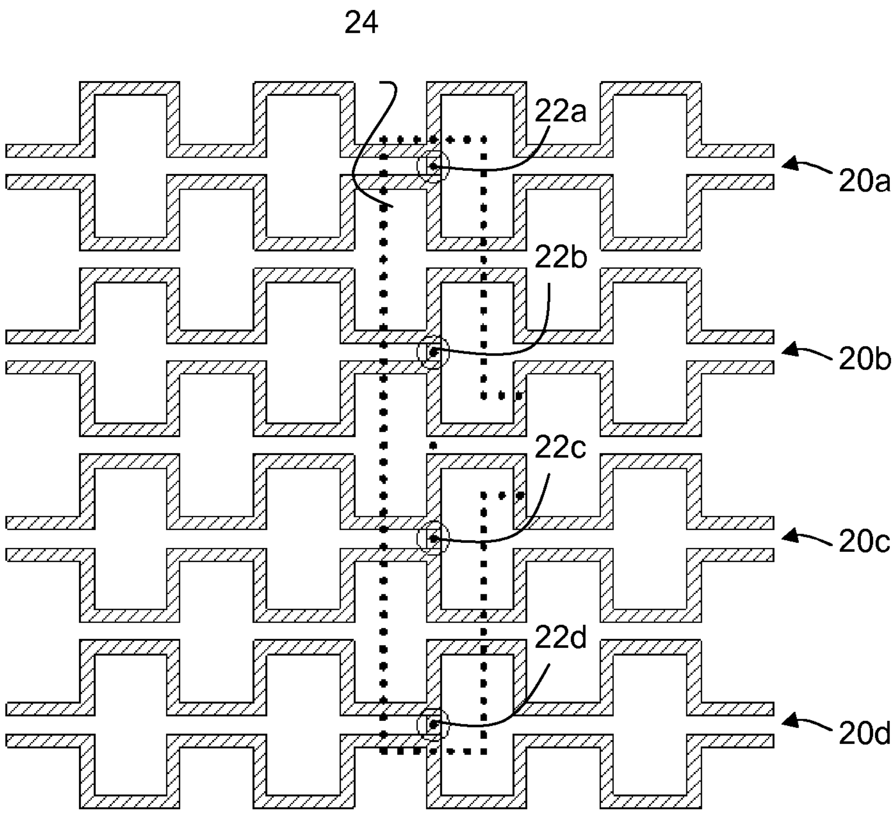

Fig. 2

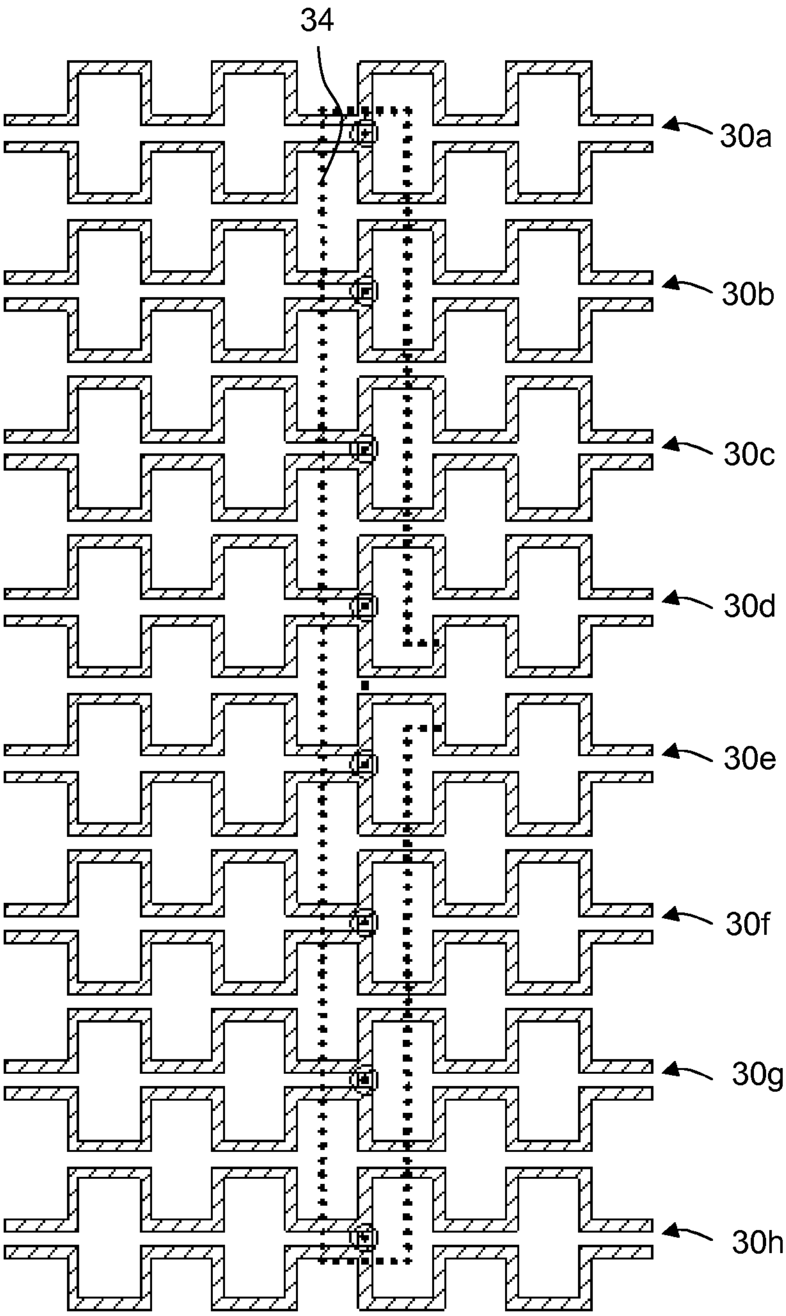

Fig. 3

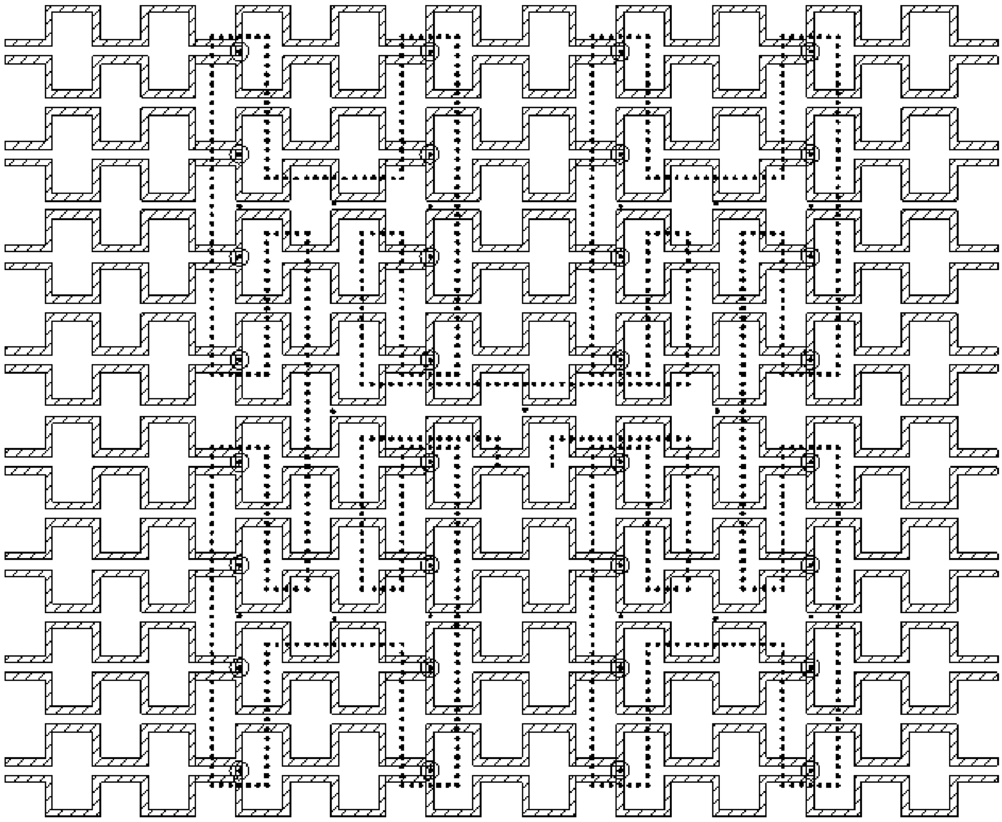

Fig. 4

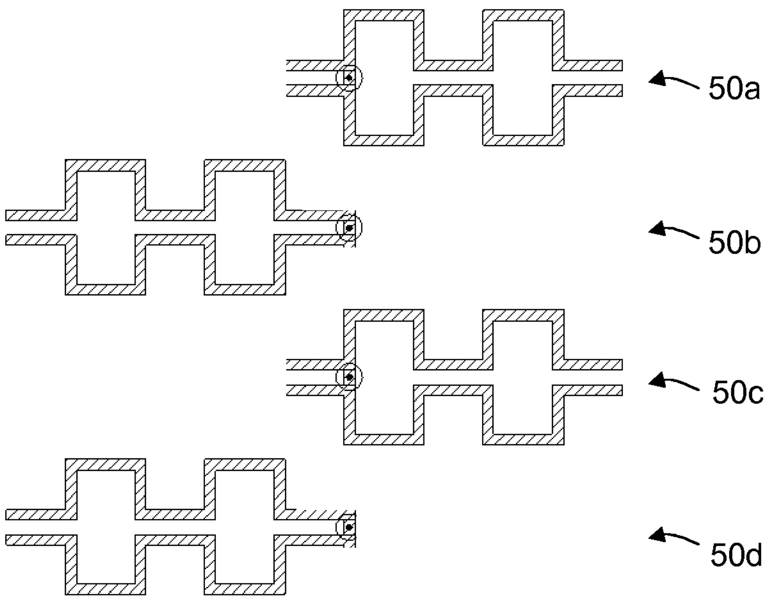

Fig. 5

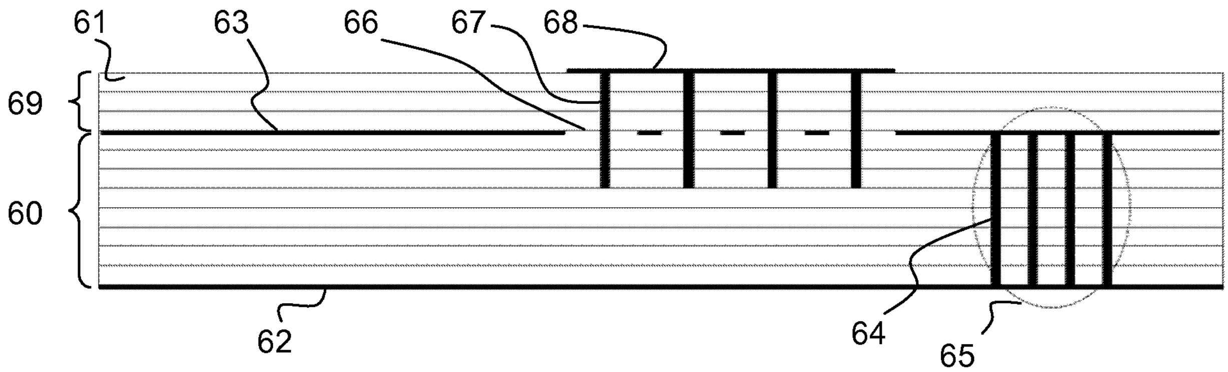

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2013/050303

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q21/00 H01Q21/06 H01Q1/38
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01Q

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 923 295 A (NAKANO HISAMATSU [JP] ET AL) 13 July 1999 (1999-07-13) abstract; figures 1,2,5 column 5, line 31 - column 7, line 22 column 1, lines 9-15 -----	1-9,12, 13,17
X	BAUER F ET AL: "A 79 GHz microstrip grid array antenna using a laminated waveguide feed in LTCC", ANTENNAS AND PROPAGATION (APSURSI), 2011 IEEE INTERNATIONAL SYMPOSIUM ON, IEEE, 3 July 2011 (2011-07-03), pages 2067-2070, XP032191623, DOI: 10.1109/APS.2011.5996915 ISBN: 978-1-4244-9562-7 page 2067 - page 2068 ----- -/--	1,10,11

[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 application or patent but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 June 2013	11/06/2013

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, Fax: (+31-70) 340-3016	Unterberger, Michael

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2013/050303

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/140556 A1 (OHNO TAKESHI [JP] ET AL) 30 June 2005 (2005-06-30) abstract; figure 5 paragraphs [0102] - [0110] -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/FI2013/050303

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5923295	A	13-07-1999	NONE		
US 2005140556	A1	30-06-2005	CN 1636300	A	06-07-2005
			EP 1479130	A1	24-11-2004
			US 2005140556	A1	30-06-2005
			WO 03071632	A1	28-08-2003