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(54) Title: SILICON BASED MILLIMETER WAVE WAVEGUIDE TRANSITION

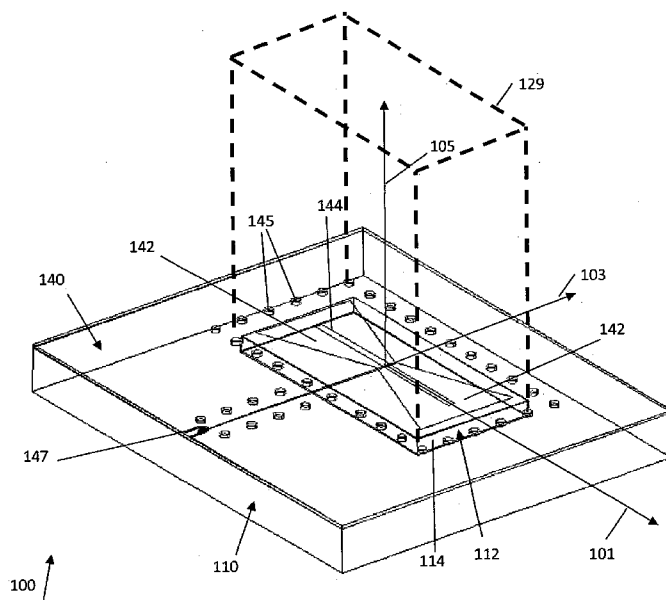


Figure 1

(57) Abstract: A waveguide to microstrip transition for converting electromagnetic wave signals to electrical signals comprises a silicon substrate having a trench in a top surface thereof; a polymer material disposed in said trench; a first thin film disposed on said top surface and covering said polymer; and a metallic signal line disposed on a top surface of said first thin film and extending at least partially over said trench; wherein said metallic signal line receives said electromagnetic wave signal and converts said electromagnetic wave signal to said electrical signal.

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SILICON BASED MILLIMETER WAVE WAVEGUIDE TRANSITION

FIELD OF INVENTION

- 5 Embodiments of the present invention provide a waveguide to planar transmission transition which uses a Silicon (Si) micro machined substrate.

BACKGROUND

- 10 In modern communications applications, a waveguide is used to direct electromagnetic wave signals to a waveguide input. In order to couple the electromagnetic signal to a signal processing component, it is often necessary that a waveguide and microstrip transmission line be coupled together. The various devices used to effect this coupling are known as waveguide to microstrip transition structures.

- 15 Due to the increasing demand of wireless communication traffic volume, the carrier frequency of these applications is expected to migrate towards the next available higher frequencies region, which is the 130GHz ISM band. It is also forecasted that the carrier frequency will move to the THz region, 300GHz. As the carrier frequency increases, the propagation losses increase. Therefore, the required RF front end circuit operating in
20 this frequency region will require a very high gain antenna, typically more than 18dBi for around a 1m communication distance.

- Various configurations of planar circuits and metallic waveguides have been used to provide waveguide to microstrip transitions. Although planar circuits provide the key
25 technology for integrated circuit design and low cost implementation, it is not viable to design very high gain antennas using planar waveguides due to the large circuit area required. In addition, the losses associated with planar circuits at millimeter wave (mmWave) and sub-mmWave frequencies are very high. Furthermore, the large circuit area increases the fabrication costs, thus eliminating the main low cost advantages of
30 planar circuits.

Rectangular metallic waveguides are known to have a relatively low insertion loss and high power handling capability. The performance of the metallic waveguide component

does not suffer significantly as compared to planar circuits when the frequency increases to the mmWave region. The design principal and theory for the metal hollow waveguide components are well understood and the fabrication process is matured. Its standard horn antenna can easily achieve more than 18dB gain using a single radiating element.

5 Moreover, scaling down of the components size at the high mmWave frequency region makes it suitable and attractive for various applications integration. However, when using metallic waveguides additional components are required to integrate a transition from the waveguide to other electrical systems.

10 Hence, in order to benefit from both planar and metallic waveguide technologies at mmWave and sub-mmWave wave bands, it is important to have an efficient planar to waveguide transition. There are several reported vertical planar to rectangular waveguide transitions which can be broadly classified into 2 major types, cavity backed and non-cavity backed. For cavity backed, the transition consists of a planar circuit
15 which is inserted at a distance, usually at $\frac{1}{4}$ wavelength from the short circuit section of the waveguide. For the non-cavity backed transition, the planar circuit is designed at the end of the open end of the waveguide. Although, the non-cavity backed transition has a smaller bandwidth, its structure is much simpler and can be manufactured at lower cost. This makes it suitable for commercial applications.

20

For all the planar circuit or transmission line designs, the most common substrate used at mmWave frequencies and above is quartz and Duriod. This is mainly due to its low material loss characteristics. However, these designs have limited functional integration capabilities.

25

Alternately, Thin Film Microstrips (TFMS) implemented on normal Silicon (Si) substrates have demonstrated that they can provide fairly low losses. Due to fabrication and process limitations, the TFMS has a limited maximum thickness of approximately $30\mu\text{m}$. This is not suitable for the design of circuits such as patch antennas and transitions in
30 which the performance, such as bandwidth, increases with the substrate thickness.

One prior art design provides a WR-6 rectangular waveguide to microstrip transition and patch antenna at 140GHz. (see eg. "A WR-6 Rectangular Waveguide to Microstrip Transition and Patch Antenna at 140GHz Using Low-cost Solutions", IEEE Radio and

Wireless Symposium, 22-24 Jan. 2008 Pages 355 – 358). This design suffers from some inadequacies. For example, it uses a microstrip as the planar transmission line. The back of the circuit is exposed and is subjected to interference. Additionally, this design has limited bandwidth, i.e. approximately 7GHz.

5

It would therefore be a great improvement in the art if a waveguide transition could be developed that addresses one or more of the problems discussed above.

10 SUMMARY

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One aspect of the present invention provides a waveguide to planar transmission transition for converting electromagnetic wave signals to electrical signals, the transition including a silicon substrate having a trench in a top surface thereof; a polymer material disposed in said trench; a first thin film disposed on said top surface and covering said polymer; and a metallic signal line disposed on a top surface of said first thin film and extending at least partially over said trench; wherein said metallic signal line receives said electromagnetic wave signal and converts said electromagnetic wave signal to said electrical signal.

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In alternate embodiments, the waveguide to planar transmission transition may also include a second thin film disposed on a top surface of said first thin film and said metallic signal line; a metal film disposed on a top surface of said second thin film, said metal film having a bowtie shaped cutout disposed above said trench; and a narrow rectangular metal strip disposed longitudinally within said bowtie cutout to enhance the coupling of said electromagnetic wave signal to said metallic signal line.

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In further embodiments, the waveguide to planar transmission transition may also include a second metallic film disposed within said trench such that said polymer and said first thin film are disposed on said second metallic film, and a plurality of vias extending through said first and second thin films to electrically connect said metal film to said second metal film, wherein said second metal film provides an electrical ground.

In some embodiments, the polymer may be approximately 100 micrometers thick, depending on the electrical performance, such as bandwidth and operating frequency requirement. Each of the thin films may be made from benzocyclobutene
5 having a thickness of approximately 10 micrometers. The waveguide may operate at a 135GHz ISM band, and may provide a signal band width of at least 10GHz. The transition may be a planar to rectangular waveguide transition.

An alternate aspect of the present invention provides a method for converting
10 electromagnetic wave signals to electrical signals using a waveguide to planar transmission transition, the method including the steps of: providing a silicon substrate having a trench in a top surface thereof; disposing a polymer material in said trench; disposing a first thin film on said top surface and covering said polymer material; and disposing a metallic signal line on a top surface of said first thin film
15 and extending at least partially over said trench; wherein said metallic signal line receives said electromagnetic wave signal and converts said electromagnetic wave signal to said electrical signal.

In alternate embodiments, the method may further include the steps of disposing a
20 second thin film on a top surface of said first thin film and said metallic signal line; depositing a metal film on a top surface of said second thin film, said metal film having a bowtie shaped cutout disposed above said trench; and disposing a narrow rectangular metal strip longitudinally within said bowtie cutout to enhance the coupling of said electromagnetic wave signal to said metallic signal line.

25 Additional embodiments may include a step for depositing a second metallic film within said trench such that said polymer and said first thin film are disposed on said second metallic film, and electrically connecting said metal film to said second metal film by extending a plurality of vias through said first and second thin films, wherein
30 said second metal film provides an electrical ground.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

5 Figure 1 illustrates a translucent perspective view of one embodiment of a waveguide to planar transmission transition according to the present invention;

Figure 1a illustrates an exploded translucent perspective view of the waveguide to planar transmission transition of Figure 1;

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Figure 2 illustrates a partial cutout perspective view of a portion of the waveguide to planar transmission transition of Figure 1 along the "y" axis;

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Figure 3 illustrates a partial cross-sectional side view of the waveguide to planar transmission transition of Figure 2;

Figure 4a illustrates a top view of a top layer of a waveguide to planar transmission transition according to the present invention;

20

Figure 4b illustrates a top view of one or more BCB layers of a waveguide to planar transmission transition according to the present invention;

Figure 4c illustrates a top view of additional layers of a waveguide to planar transmission transition according to the present invention.

25

DETAILED DESCRIPTION

Embodiments of the present invention provide a waveguide to planar transmission transition which uses a Silicon (Si) micro machined substrate combined with a stripline.

30

Figure 1 illustrates a translucent perspective view of one embodiment of a rectangular waveguide to planar transmission transition 100 according to the present invention. For purposes of illustration, arbitrary "x", "y" and "z" axes 101, 103, 105 respectively, are shown in Figure 1. Figure 1a illustrates an exploded

translucent perspective view of the waveguide transition 100 of Figure 1. Figure 2 illustrates a partial cutout perspective view of a portion of the waveguide transition 100 along the "y" axis 103 of Figure 1. Figure 3 illustrates a partial cross-sectional side view of the waveguide transition 100 of Figure 2. Figure 4a illustrates a top view of one embodiment of a top layer of the waveguide transition 100 of Figures 1-3. Figure 4b illustrates a top view of one embodiment of one or more BCB layers of the waveguide transition 100. Figure 4c illustrates a top view of one embodiment of additional layers of the waveguide transition 100.

- 10 With continuing reference to Figures 1-4c, the waveguide transition 100 includes a silicon substrate 110. The silicon substrate 110 may have a cavity or trench 112 machined therein. In some embodiments, the cavity 112 may be plated with a metal layer 120, which may cover the bottom and sides of the cavity 112, as well as a top surface 102 of the silicon substrate 110. The cavity 112 may be filled with a suitable
15 low-loss polymer 114.

A planar stripline transmission line structure (thin film) 130 coupling the signal through the board side of a rectangular waveguide 129, such as a WR6 horn antenna, etc., may then be applied to the top surface 102 of the silicon substrate 110. In embodiments
20 in which the metal layer 120 extends onto a portion of the top surface 102 of the silicon substrate 110, the planar stripline transmission line structure 130 may be applied onto the metal layer 120. In the embodiment illustrated in Figures 1 and 2, the planar stripline transmission line structure 130 may include, by way of example and not limitation, first and second benzocyclobutene (BCB) layers 132, 134
25 respectively having a metallic signal line 136 embedded therein. BCB is used as it is known to provide very low insertion losses for the structure. It is understood that one or more BCB layers may be used. In alternate embodiments, other types of dielectric materials may also be used.

- 30 In this design, the thickness of the substrate layers 132, 134 of the thin film planar stripline transmission line structure 130 may be increased using Si micro machining technology. In the Si substrate 110, the specific required area and depth may be etched to form the cavity 112. Depending on the design, the cavity 112 may be metal plated to form a ground plane to electrically isolate the Si substrate 110. The trench 112 may then

be completely filled with a suitable low loss polymer 114, which has a similar dielectric constant as the thin film structure 130. Subsequently, the thin film structure 130 may be processed on the whole Si wafer 110. In this way, a substrate section is created in which the thickness of the dielectric layer is the sum of the thicknesses of the polymer 114 in the trench 112 and the thin film structure 130 above it.

In this embodiment, the thickness of the polymer 114 in the trench 112 may be approximately 100 micrometers. The thickness of each of the BCB layers 132, 134 may be 10 micrometers. Thus, using this design, the effective thin film thickness of the planar stripline transmission line structure 130 is increased to 120 μ m, i.e. 20 μ m of thin film and 100 μ m of polymer. It is understood that the thickness of the polymer 114 and BCB layers 132, 134 may be adjusted as desired depending on the specific performance characteristics required for the transition 100. The signal line and other metal layers may be made from any material with a low electrical loss

In some embodiments, in order to increase the coupling efficiency between the electromagnetic signal and the metallic signal line 136, an additional metal layer 140 may be applied to a top surface 131 of the thin film structure 130. A portion of this metal layer 140 may be etched to form a bowtie aperture 142 therein. Additionally, a narrow strip 144 may be provided in the center of the bowtie aperture 142 to enhance the coupling efficiency of the electromagnetic signal to the rectangular waveguide in its fundamental mode of TE₀₁. The bowtie aperture 142 includes two narrowed sections or tips 142a, 142b. A plurality of interconnect vias 145 may be included to provide an electrical ground connection between the metal layers 120 and 140. In some embodiments, an input port 147 may be provided for testing of the structure. In other embodiments, a metal ground strip (not shown) may be provided in line with the vias 145.

The two tips 142a, 142b formed by the bow-tie aperture 142 help to guide the signal from the stripline 130 to couple mainly to the center of the metallic signal line 136 to strengthen the rectangular TE field. The metallic signal line 136 may be extended beyond the center of the cavity 112 for impedance matching. The resonance frequency and bandwidth of this transition 100 may be determined by the above interrelated parameters. Generally, the center frequency of the transition 100 is determined by the

lengths of the metallic signal line 136 and the rectangular cavity 112. The bandwidth may be determined using the interrelated parameters of the effective thin film thickness (i.e. the thickness of the cavity 112 when combined with the BCB layers 132, 134), the width of the metallic signal line 136, the width of the cavity 112, and the dimensions of the bow-tie aperture 142. Due to the interrelationship of the parameters, the design specific dimensions of the parts of this waveguide transition 100 may be done using, for example, a commercial 3D EM simulator. This provides flexibility in the design in order to tune the waveguide transition 100 to operate at specific target frequencies. By way of example and not limitation, such software may include 3D Electromagnetic Simulators such as the High Frequency Sensor Subsystem (HFSS)[®] and systems available from Computer Simulation Technology (CST)[®] may be used.

As is discussed in the background section of the present application, the bandwidth in these antennas increases when the substrate thickness is increased and the dielectric constant (ϵ_r) is reduced. In addition, the design of the aperture opening can also be optimized to increase the frequency. Based on these principles, the substrate thickness below the transition design for the present embodiments is increased using Si micromachining, and an optimized bow-tie pattern aperture is used to increase the bandwidth.

As discussed above, the bottom ground metal 120 shields the signal from the high loss normal Si substrate 110, while the top ground metal 140 allows the rectangular waveguide to be assembled directly. There is no modification required on the standard rectangular waveguide section to allow the planar transmission line to pass through.

In a preferred embodiment, the end of the metallic signal line 136 is open-circuit terminated over the polymer filled trench 112. The open-circuit terminated feature is important for circuits that may require a DC bias to be applied on the signal line. For short-circuit terminated signal lines, an additional DC block circuit (not shown) may be used. However the DC block, which has an operating bandwidth, will usually degrade the whole circuit performance.

In other preferred embodiments, the surface dimensions of the trench 112 micro-machined on the Si substrate 110 are designed to be equal to the internal dimensions of

the rectangular waveguide. The side walls and the bottom surface of the trench 112 are metal plated 120 and connected to the planar stripline transmission line structure 130 bottom ground (Metal 1). In this way, the normal silicon substrate is again isolated. The depth of the cavity 112 is 100 μ m and filled with polymer. A bigger trench 112 depth is preferred as it helps to increase the thickness of the substrate at the aperture, which help to increases the operating bandwidth. The top ground plane of the stripline is opened to form the aperture.

Embodiments of the present invention may be used in various applications. These may include, but are not limited to, mmWave and THz wireless communications, 77GHz automotive radar applications, imaging and sensing applications, measurement applications, and antennas designed on Si substrates. Additionally, the embodiments may be directly connected to, for example, the WR-6 20dB standard horn antenna.

The embodiments discussed above have several advantages over prior art designs. The Si micro-machined substrate is the preferred integration platform for mmWave and THz circuit. As compared to other substrates such as LTCC, Roger and Quartz substrates, the embodiments provide a higher feature resolution (metal size and gap) which are required at these frequency ranges. Furthermore, the embodiments provide a high level of circuit and functional integrations.

Instead of using the costly high resistivity Si substrate, the embodiments as described use thin film (BCB) technology on a normal Si substrate. The thin film BCB material has been shown to have low loss up to 600GHz. However, the thin film has limited thickness (typically <30 μ m), which is not suitable for circuits that required thicker substrates such as transitions and antennas. Hence, silicon thin film technology has not been previously used for designing these circuits. The embodiments provide a low cost solution to use Si thin film technology to design a planar to rectangular vertical transition. In this solution, the effective thickness of the thin film is increased using a polymer filled cavity, while at the same time a modified bowtie aperture pattern is used to realize a transition on a normal Si substrate.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific

embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A waveguide to planar transmission transition for converting electromagnetic wave signals to electrical signals, the transition comprising:
 - 5 a silicon substrate having a trench in a top surface thereof;
 - a polymer material disposed in said trench;
 - a first thin film disposed on said top surface and covering said polymer; and
 - a metallic signal line disposed on a top surface of said first thin film and extending at least partially over said trench;
 - 10 wherein said metallic signal line receives said electromagnetic wave signal and converts said electromagnetic wave signal to said electrical signal.
2. The waveguide to planar transmission transition of claim 1, further comprising:
 - 15 a second thin film disposed on a top surface of said first thin film and said metallic signal line;
 - a metal film disposed on a top surface of said second thin film, said metal film having a bowtie shaped cutout disposed above said trench; and
 - a narrow rectangular metal strip disposed longitudinally within said bowtie cutout to enhance the coupling of said electromagnetic wave signal to said metallic signal line.
 - 20
3. The waveguide to planar transmission transition of claims 1 or 2, further comprising a second metallic film disposed within said trench such that said polymer and said first thin film are disposed on said second metallic film.
 - 25
4. The waveguide to planar transmission transition of claim 3, further comprising a plurality of vias extending through said first and second thin films to electrically connect said metal film to said second metal film, wherein said second metal film provides an electrical ground.
 - 30
5. The waveguide to planar transmission transition of any one of the previous claims, wherein said polymer is approximately 100 micrometers thick.

6. The waveguide to planar transmission transition of any one of the previous claims, wherein each of said thin films comprises benzocyclobutene having a thickness of approximately 10 micrometers.

5 7. The waveguide to planar transmission transition of any one of claims 5 and 6, wherein said waveguide operates at a 135GHz ISM band.

8. The waveguide to planar transmission transition of any one of claims 5-7, wherein said waveguide provides a signal band width of at least 10GHz.

10

9. The waveguide to planar transmission transition of any one of the previous claims, wherein said transition is a planar to rectangular waveguide transition.

10. A method for converting electromagnetic wave signals to electrical signals
15 using a waveguide to planar transmission transition, the method comprising the steps of:

providing a silicon substrate having a trench in a top surface thereof;

disposing a polymer material in said trench;

20 disposing a first thin film on said top surface and covering said polymer material; and

disposing a metallic signal line on a top surface of said first thin film and extending at least partially over said trench;

wherein said metallic signal line receives said electromagnetic wave signal and converts said electromagnetic wave signal to said electrical signal.

25

11. The method of claim 10, further comprising:

disposing a second thin film on a top surface of said first thin film and said metallic signal line;

30 depositing a metal film on a top surface of said second thin film, said metal film having a bowtie shaped cutout disposed above said trench; and

disposing a narrow rectangular metal strip longitudinally within said bowtie cutout to enhance the coupling of said electromagnetic wave signal to said metallic signal line.

13

12. The method of claims 10 or 11, further comprising depositing a second metallic film within said trench such that said polymer and said first thin film are disposed on said second metallic film.

- 5 13. The method of claim 12, further comprising electrically connecting said metal film to said second metal film by extending a plurality of vias through said first and second thin films, wherein said second metal film provides an electrical ground.

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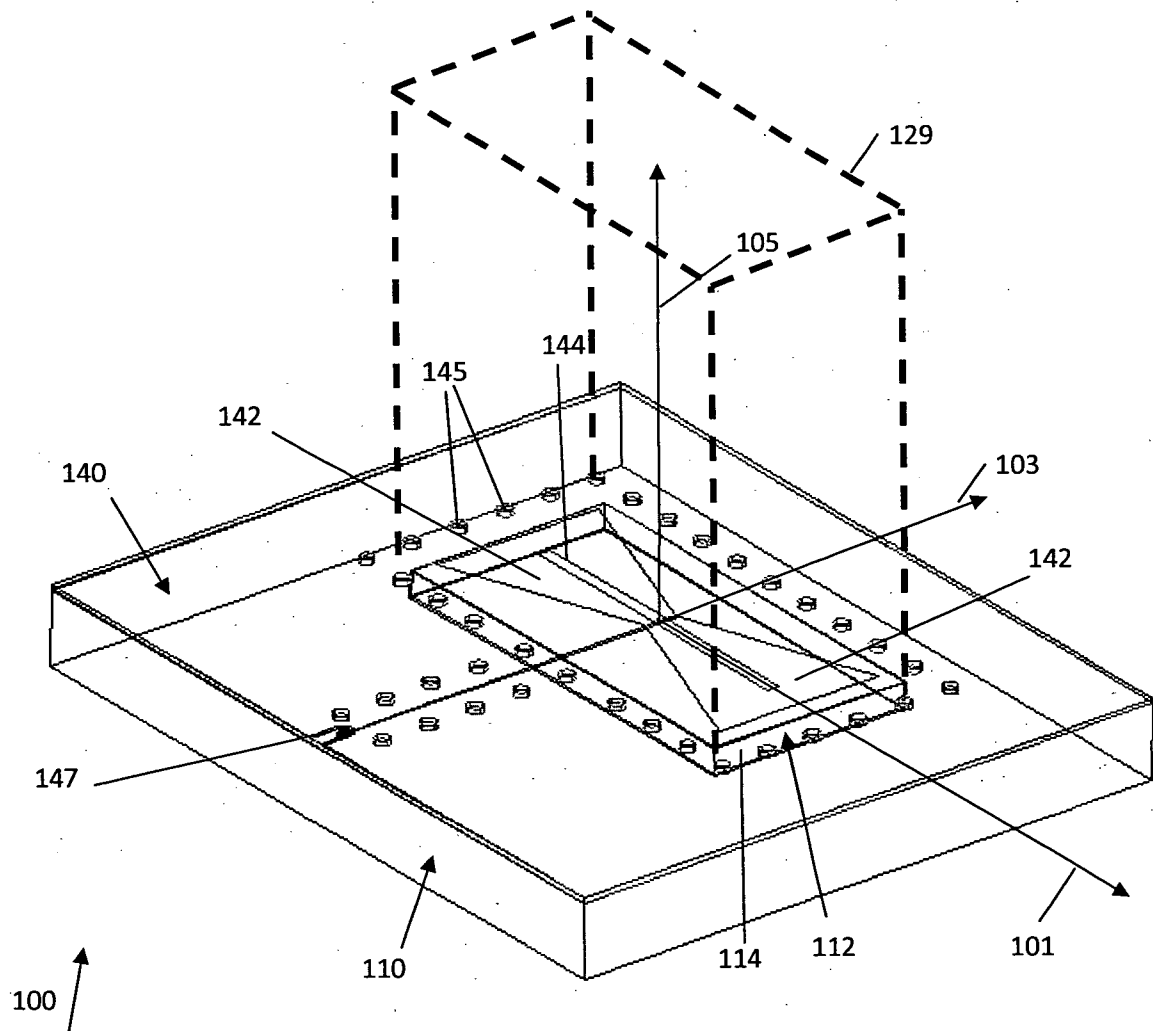


Figure 1

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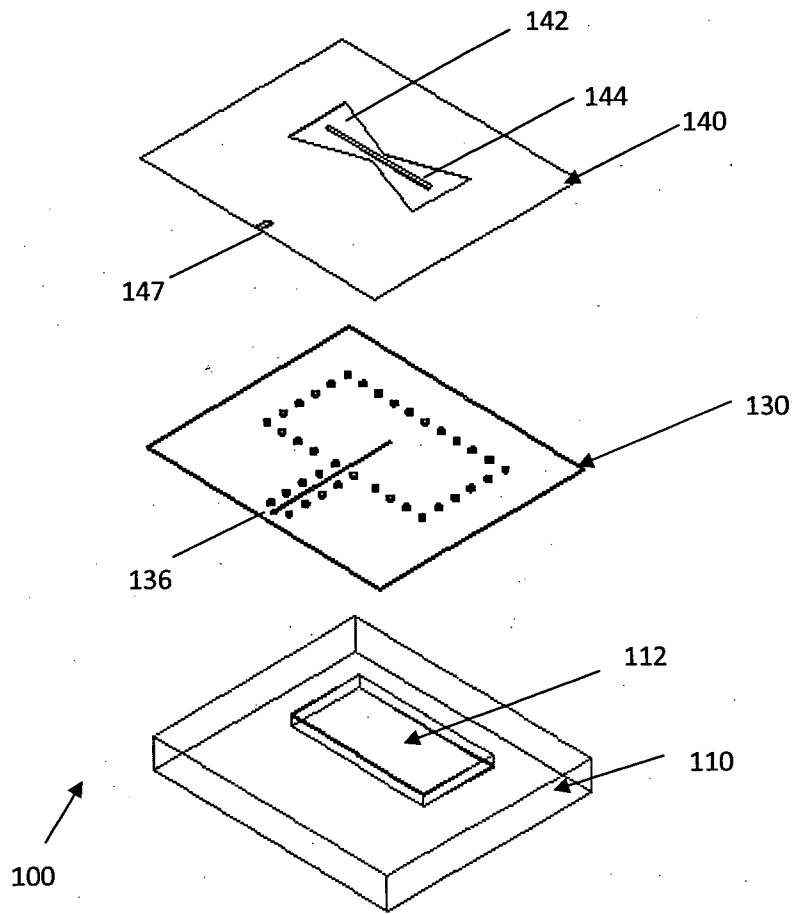


Figure 1a

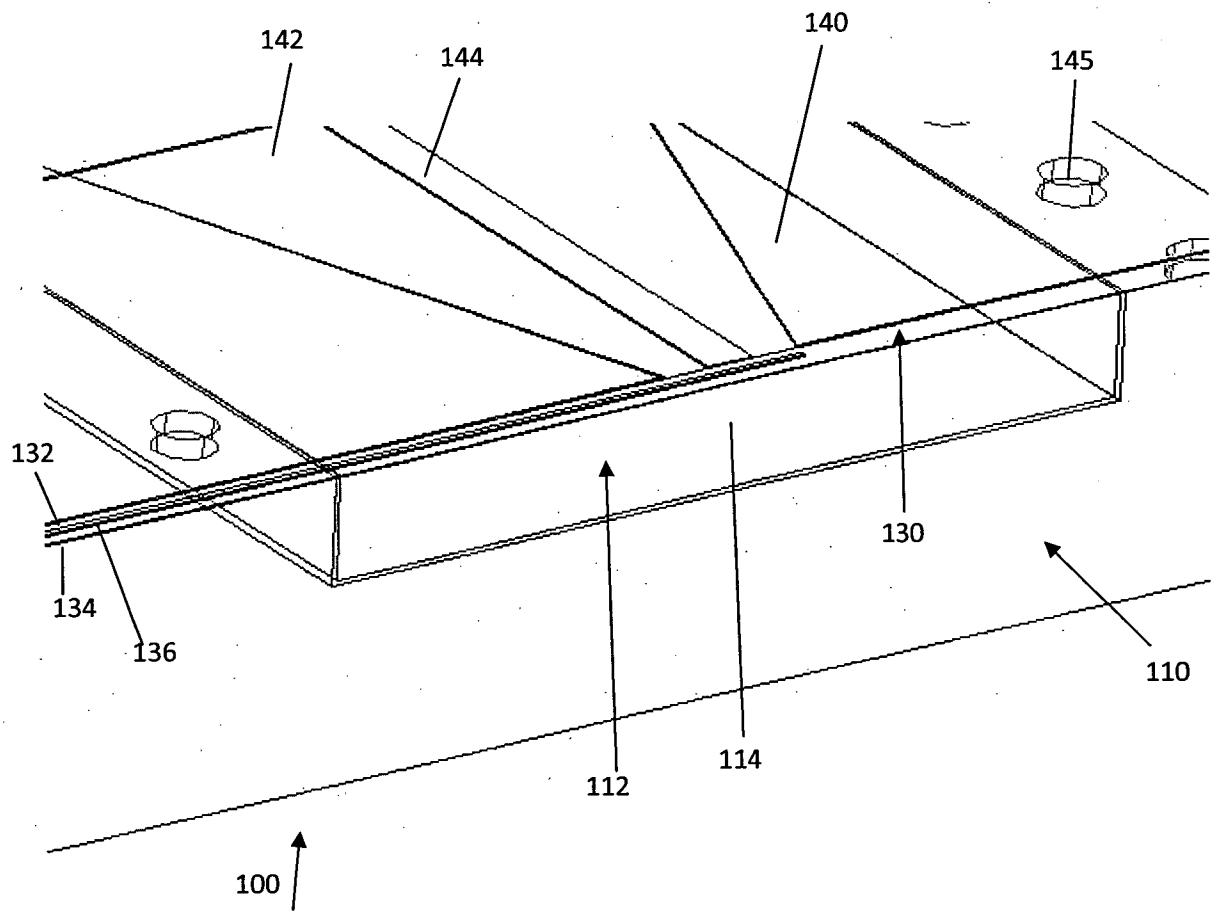


Figure 2

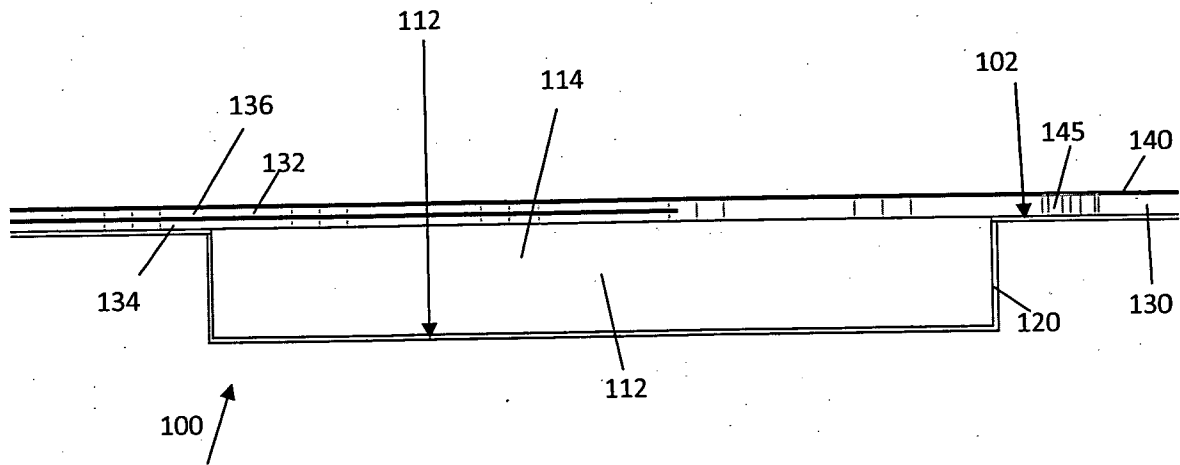


Figure 3

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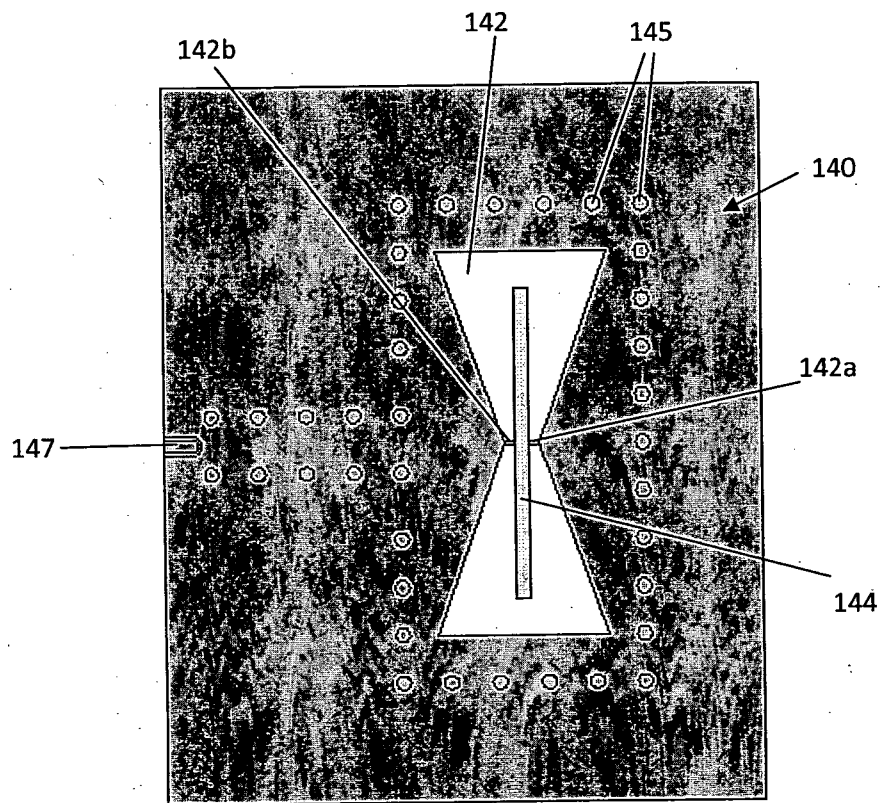


Figure 4a

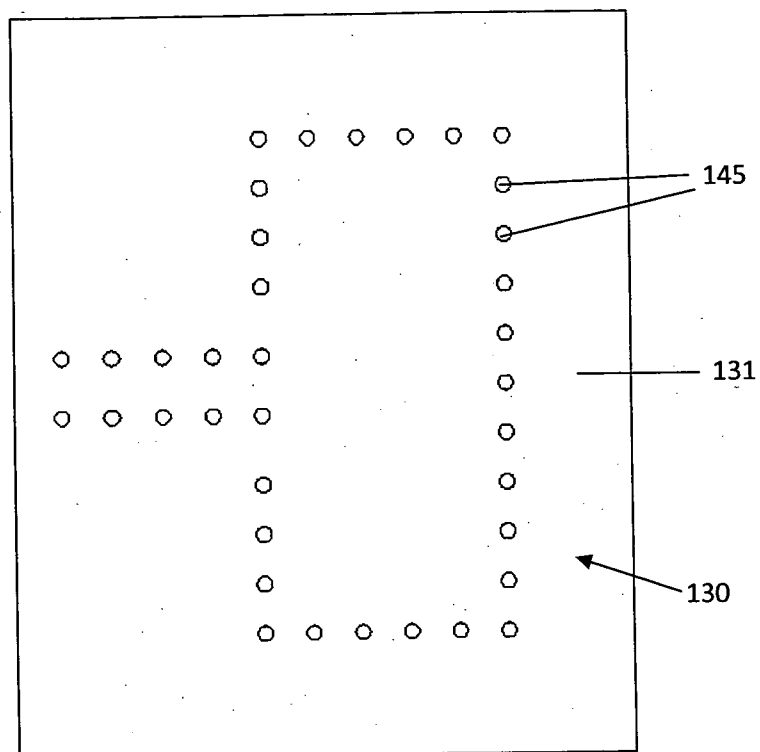


Figure 4b

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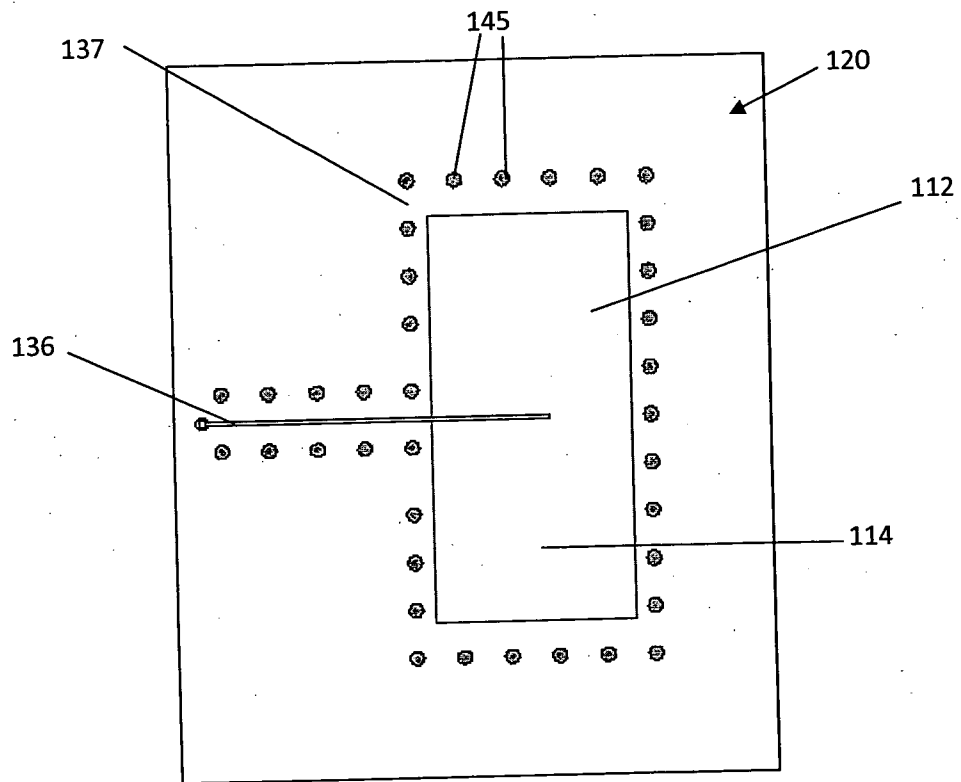


Figure 4c

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2010/000171

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

H01P 5/107 (2006.01)

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)

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)

Espacenet, EPODOC, WPI, Google Patents: waveguide, microstrip, stripline, transition, coupling, trench, hole, aperture, cavity, thin film and similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5311153 A (LAU et al.) 10 May 1994 Abstract, column 1 lines 28-29, column 2 lines 43-58, Figs 1-3	1-13
Y	US 6830806 B2 (HOLL et al.) 14 December 2004 Abstract, column 2 lines 11-23	1-13
Y	US 6023210 A (TULINTSEFF) 8 February 2000 Abstract, column 4, lines 29-33 and 51-56, Fig 1A	2, 11
A	US 6794950 B2 (du TOIT et al.) 21 September 2004 Whole document	



Further documents are listed in the continuation of Box C



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	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
12 August 2010

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2010/000171

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
US	5311153	NONE			
US	6830806	US	2002/0148640	WO	2002/087870
US	6023210	NONE			
US	6794950	EP	1346431	US	2002/0097109 WO 2002/052674
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.					
END OF ANNEX					