Novel compact substrate integrated waveguide resonators at 60 GHz for LCP

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NOVEL COMPACT SUBSTRATE INTEGRATED WAVEGUIDE RESONATORS AT 60 GHz FOR LCP

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Abstract – In this paper a new approach to design of compact substrate integrated resonators is presented. LCP substrate integrated waveguide is loaded by array of multilayer metallic plates situated inside the substrate. Resonators are designed and simulated with a resonant frequency of 60 GHz. Proposed structures are twice more compact than their conventional substrate integrated counterparts.

I. Introduction

World wireless communications show tremendous growth during the last 10-15 years led by customers demand for mobile, convenient and reliable information services. As a result, at microwaves utilized for either civil or military purposes, cheap, low-loss passive devices are strongly required in order to design the basic components satisfying rapidly increasing needs of communication systems.

Organic substrates have been of great interest for research of the integration of RF and millimetre-wave modules. Liquid Crystal Polymer (LCP) is a material which offers a unique combination of electrical (ε_r = 2.9–3.16, tanδ = 0.002–0.004), absorption, thermal properties and multilayer design capability, making it very suitable for various applications [1, 2].

Compact, high quality resonators are very important for microwave and millimetre-wave circuits and systems. The difficulty of integration and high fabrication cost of conventional rectangular waveguides makes it unsuitable to utilize them for modern applications. One of relatively new approaches viable to meet the actual requirements of cheapness and compactness of microwave components is utilization of substrate integrated waveguides (SIWG), based upon classical rectangular waveguide theory, which are very convenient for field transmission at micro and millimetre waves [3].

Moreover, SIWG's are highly applicable for mass production using well developed modern IC-technologies [4]. Recently SIWG approach has been combined with LCP substrate for millimetre-wave applications using System-on-Package (SoP) technology [5].

The rectangular waveguide, which is filled by a dielectric material of higher permittivity constant, is known to operate at lower frequency. It has been recently reported that new artificial materials composed of lattices of split ring resonators (SRR's) [6] and complementary split ring resonators (CSRR's) may exhibit permeability and permittivity different from those of conventional media and even negative. Therefore, a rectangular waveguide resonator filled by adjusted lattice of CSRR's acts as a resonator filled by a dielectric with high ε_r, i.e. operates at lower frequencies. Similar approach has already been studied in [7] using the concept of electromagnetic bandgap (EBG). In this paper we propose a substrate integrated waveguide resonator loaded by lattice of multilayer metallic plates, which allow the structure to reduce physical dimensions significantly showing good electrical performance.

II. Design and Analysis of Substrate Integrated Waveguide Resonators

A waveguide resonator is usually organized as a $\lambda/2$-length section of a transmission line limited by the conductive walls with slots for wave launching purposes. If employing a SIWG as a basic transmission line, the conductive walls of the resonator are formed by via-holes connecting top and bottom ground planes. A role of the launching slot is acted by the gap in a wall between via-holes. The side walls of the rectangular waveguide can be realized within the substrate, either as an array of metallized posts, metallized grooves or paste side walls. The losses in integrated structures, such as conductor losses, dielectric losses and radiation losses, can be overcome using the planar-to-waveguide transitions. Tapers provide the modal energy conversion from waveguide, supporting mode TE_{10}, to the microstrip, and vice versa.

Fig. 1 shows a general configuration of $\lambda/2$ substrate integrated rectangular waveguide resonator. The waveguide structure is designed as an LCP dielectric substrate, which integrates the guiding part, microstrip and taper in one complete module. The permittivity of the dielectric LCP material ε_r = 3.16, tanδ = 0.004 and thickness h = 0.254 mm. Copper with the conductivity of $\sigma = 5.8 \cdot 10^9$ Sm/m is chosen for metallization. The commercial Ansoft HFSS™ software with finite element method (FEM) is employed for analysis of the proposed structures.

Analysis of a resonator shown in Fig. 1 is based on the common rectangular waveguide theory. The structure integrates a resonator, a microstrip and a taper, keeping the guided wave properties of a conventional rectangular waveguide. The integrated waveguide resonator consists of the resonant part, which is formed by two walls with the launching slots realized as metallic via-holes inserted into the substrate transversely to the direction of propagation. Both side walls of the waveguide connect the top surface to the ground plane and are constructed by via-grooves filled with copper.

Simulated S_{21} and S_{11} parameters of the discussed resonator are plotted in Fig. 2. The structure exhibits a first-order resonant at 60 GHz.

Layout of the metallic plates loaded resonator is depicted in Fig. 3. Its construction is based on the rectangular SIWG resonator structure shown in Fig. 1. An array of metallic plates is realized using stacked topology at which square plates are situated on five layers of the substrate. Plates are connected with vias forming a 2-D distributed LC-structure interacting through capacitance with top and bottom surfaces of the waveguide. This new structure changes electromagnetic properties of the waveguide and alert a permittivity of the media inside the waveguide for the either TE or TM mode waves.

Incorporating a lattice of multilayer metallic plates in the way shown in Fig. 3 for substrate integrated rectangular waveguide one can achieve the new type of resona-

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tors. These circuits, exhibiting metamaterial effect, can operate at lower frequencies. This results in significant reduction of physical dimensions of such resonators.

Proposed structure is realized as a multilayer LCP circuit. The structure is designed on a dielectric substrate, as described above, but five layers inside the substrate contain a lattice of square plates and vias between them.

The side length of each square plate is R = 340 μm and the distance between the centers of the plates (period of the lattice) is equal to O = 425 μm. Copper-filled vias are D_{via} = 100 μm in diameter. Distance between adjacent vias is 150 μm. The thickness of the LCP substrate is h = 0.254 mm, relative permittivity is ε_r = 3.16, dielectric tangent loss is tanδ = 0.004.

The resonator has been designed and adjusted in order to achieve the same resonant frequency as the resonator free of the metallic plates, described above. The width of the waveguide is W_{wg} = 1.4 mm, length of the resonator part totals L_{res} = 1.4 mm.

A graph containing simulated S_{21} and S_{11} parameters of the metallic plates-loaded resonator is plotted in Fig. 4. The structure shows a first-order resonant at 60 GHz. Consequently, it is shown that utilization of metallic plates inside the rectangular SIWG resonators leads to at least twice square reduce.

Details on comparison of dimensions of conventional and metallic plates-loaded SIWG resonators are shown in Table I.

Table I. Comparison of Resonators by Dimensions

Parameter	Conventional resonator	Proposed resonator
Area occupied, mm^2	2×2	1.4×1.4
Waveguide width, mm	2	1.4

Proposed resonators can be applied for waveguide filters with improved dimensions, particularly direct and cross-coupled.

III. Conclusion

Novel low cost, compact resonator structures have been designed and simulated. A conventional substrate integrated rectangular waveguide resonator has been reconfigured, incorporating the multilayer metallic plates in the design. Altered electromagnetic properties of such structures have been shown to give an advantage for further improvement of resonator structures. A novel approach allows reducing the size of the conventional waveguide resonators and can result in design of novel compact microwave filters.

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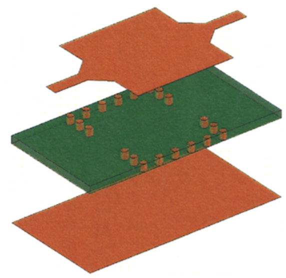

Fig. 1. View of the conventional SIWG resonator

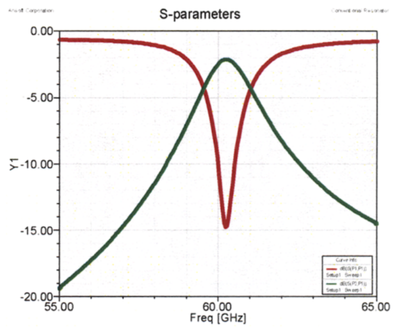

Fig. 2. S-parameters of the conventional resonator

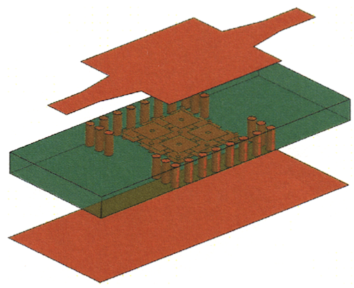

Fig. 3. View of the proposed SIWG resonator

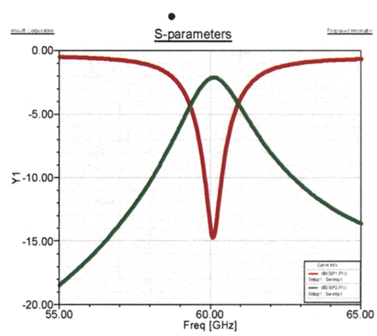

Fig. 4. S-parameters of the proposed resonator

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