A Broadband Integrated LTCC Laminated Waveguide to Metallic Waveguide Transition

Yong Huang and Ke-Li Wu

Department of Electronics Engineering, The Chinese University of Hong Kong
e-mail: klwu@ee.cuhk.edu.hk

Abstract — **In this paper, a compact and broadband integrated transition between laminated waveguide in a multi-layers Low Temperature Co-fired Ceramic (LTCC) substrate and metallic rectangular waveguide (RWG) is presented. A Ka-band prototype of the proposed broadband transition is designed and fabricated in an LTCC substrate. The simulated and measured results of the prototyped transition show excellent agreement. It has been demonstrated, through the experimental results of the Ka-band prototype, that the proposed transition configuration gives an effective bandwidth of over 8% with –15dB return loss and average -0.4dB insertion loss over the bandwidth at Ka frequency band.**

I. INTRODUCTION

Low Temperature Co-fired Ceramic (LTCC) technology offers many advantages to microwave and millimeter wave applications, such as low losses, high-density integration and low cost for high volume production. The recently development of the laminated waveguide concept [1] by making use of LTCC in millimeter wave frequency ranges has called tremendous attentions to the engineers in the field.

An effective 3D laminated waveguide is constructed by depositing metal planes on the top and bottom surfaces of a multi-layered substrate and using grid-like conductive walls as sidewalls. The grid-like conductive sidewalls in laminated waveguide comprise a plurality of filled through via-holes disposed at predetermined intervals and a plurality of sub-conductor layers deposited between layers of the dielectric substrate so as to electrically connect the filled via-holes together inside the dielectric substrate. Due to its negligible radiation and low transmission losses, laminated waveguide is considered as a high performance transmission line for integrated millimeter wave applications such as integrated antenna array for collision avoidance radar [2, 3]. Laminated waveguide can also be used to design some integrated passive components such as a miniaturized ridge waveguide filter [4, 5]. Nevertheless, in many practical applications, an integrated laminated waveguide module is only a part of a system; it needs to be interfaced with other types of transmission line. Among them, a conventional metallic waveguide would likely be a popular one.

Metallic rectangular waveguides, due to their excellent electric performance, are still essential components in many practical millimeter wave systems such as Local Multipoint Distributed System (LMDS). An effective transition that connects a laminated waveguide module with a standard metallic waveguide system would be a compulsory and critical part for overall system design.

Since the cross-section of a laminated waveguide is much smaller than that of a metallic waveguide due to the high dielectric constant (about 7 to 10) of the filled substrate and the thickness limitation of the laminated waveguide, there is a large dimension mismatch between the two types of waveguide. The mismatch causes tremendous difficulties in impedance matching and energy losses. Therefore, designing a broadband and compact transition between the two types of waveguides is a fundamental and challenging problem. To the best knowledge of the authors, till now there are no any configurations ever proposed for a laminated waveguide to standard metallic waveguide transition.

In this paper, a broadband integrated laminated waveguide to standard metallic waveguide transition is proposed. A prototype of an integrated Ka-band transition between an LTCC laminated waveguide (using Dupont® 943 Green Tape™ with 140X35.2mils^2 in cross-section) and WR28 standard waveguide, which cross-section is 280X140 mils^2, was designed and fabricated for proving the concept. A 2.5 GHz bandwidth defined at -15 dB return loss is obtained for the transition at center frequency of 29 GHz. The experimental result correlates very well with the EM designed performance. An average insertion loss of -0.4 dB is observed from the experimental results for the prototyped transition including a 120mils thick WR28 waveguide flange and 200mils long laminated waveguide, demonstrating a promising low loss and broadband features. Such a transition provides a broadband, compact, and low cost interface for LTCC integrated laminated waveguide modules. It is believed that the transition would be widely used in future integrated millimeter wave systems.

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II. THE CONFIGURATION OF THE TRANSITION

Fig. 1 shows the 3D structure of the proposed multi-layered transition. The top and bottom layers of the LTCC module are fully covered by metal except a rectangular aperture on the bottom layer. The aperture that is called input coupling aperture thereafter has the same size as the inner cross-section of the standard metallic waveguide connected to the LTCC laminated waveguide module. The microwave energy is transferred between a standard metallic waveguide and laminated waveguide regions through the input-coupling aperture. As shown in Fig.1, inside the LTCC module, separated by a partition conductive wall, two parallel laminated waveguides are formed and excited by the input-coupling aperture. The two laminated waveguides are shorted at one end by a grid-like conductive shorting wall and connected to a single laminated waveguide port on the other end through a Y branch structure.

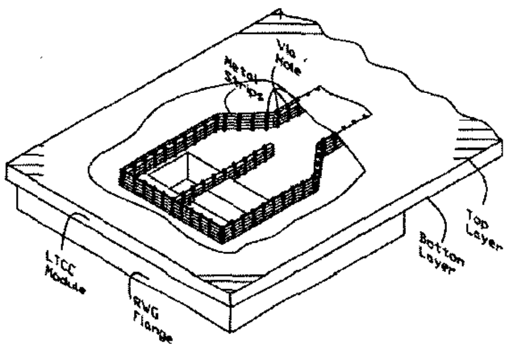


Fig.1. Prospective view of the LTCC integrated laminated waveguide to standard waveguide transition.

Part of metallic strips and correlative via-holes in the partition wall are removed to improve the matching performance at interface between air and LTCC substrate; hence an aperture called matching aperture is formed on the partition wall. Fig.2 is a side view of the transition along the partition wall.

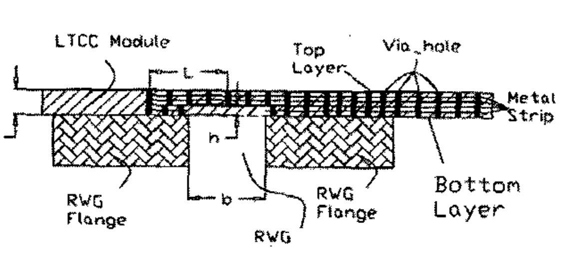


Fig.2. The side view of the transition along the partition wall.

In Fig.2, *lb* and *b* denote the dimension of the narrow sidewall of laminated waveguide and standard metallic waveguide, respectively. The height of the matching aperture on partition wall is denoted as *h*. The width of the matching aperture is as long as narrow side dimension of metallic waveguide and is measured from metal strips edge to edge. The distance from the center of the input-coupling aperture to the grid-like conductive shorting wall is denoted as *L* in Fig.2.

The whole circuit is built inside a multi-layer LTCC substrate. A standard metallic waveguide flange is soldered on the bottom of the LTCC module with the inner aperture of the standard metallic waveguide lined with the coupling aperture on LTCC bottom layer, as shown in Fig.1. With the transition configuration, the LTCC laminated waveguide module can be very easily connected with any RWG sub-system and components.

It is obviously that the two parallel laminated waveguides and the metallic waveguide form an E-plan T-junction structure. By altering *L* and *h*, a good transmission performance between laminated waveguide and metallic waveguide can be achieved.

A numerical parametric study is performed with Ansoft® HFSS™, a full wave finite element method 3D EM simulator. A WR28 waveguide is used in the study as metallic waveguide, whose cross-section dimension is 280×140 mils^2. The laminated waveguide with cross section dimension of 140×35.2 mils^2 is chosen. The property of substrate used in simulation is ε_r=7.5 and δ = 0.002. A piece of 120 mils long air-filled waveguide and a piece of 200 mils long laminated waveguide are incorporated in the transition model of the EM simulation. A full conductor wall transition modal is used in parametric study.

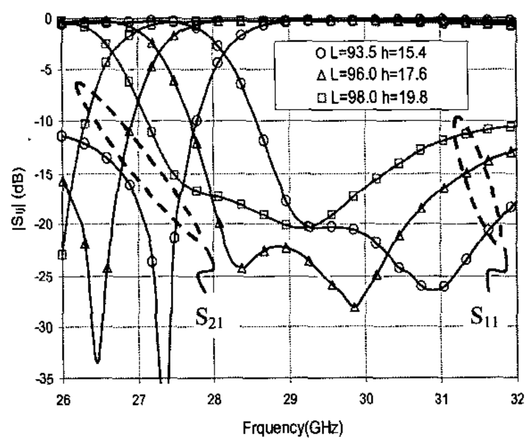


Fig.3. Simulated result of transition working in different center frequency

Fig.3 shows a group of transmission performance of proposed transition working in different center frequency. The values of two important parameters L and h are shown in Fig.3 too. Simulated results show that a more than 11% bandwidth defined less than −15dB return loss can be achieved. The in-band insertion loss is about −0.30dB according to simulated results.

III. Experimental Results

A prototype of the proposed transition working in the LMDS frequency band was designed at center frequency of 29GHz. In order to facilitate the measurement, two testing modules were fabricated and measured to verify the overall performance of the transition. One module is a back-to-back configuration with two laminated waveguide ports of two identical transitions connected with a piece of 560 mils long laminated waveguide. Another module is a single transition being connected with long laminated waveguide and being terminated by absorbing material at the end of laminated waveguide. All transition ports of the two modules are interfaced with WR28 standard metallic waveguides.

The transversal dimension of laminated waveguide and WR28 are 140mils by 35.2mils and 280mils by 140 mils, respectively. The transition modules were built on an 8-layer LTCC tile. Dupont® Green tape943™ with ε_r=7.5 and δ = 0.002 is used as substrate, which each layer thickness is 4.4mils. Metallic strips with width of 5.5 mils are employed to connect the via-holes of 3.5 mils in diameter to form effective grid-like laminated waveguide sidewalls. The center to center via pitch of the grid-like walls is 20 mils. The other main dimensions are h=13.2mils, L=92mils. Fig. 3 is a photo of the back-to-back transition module and the single transition module. WR28 waveguide flanges have been mounted on the panel to interface the modules.

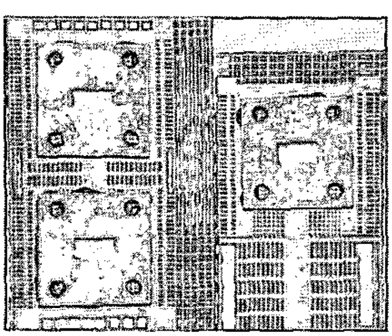


Fig.3. Photo of the back-to-back configuration module (left) and the single transition module (right) in an LTCC tile with 35.2 mils in thickness.

The S parameters of the transition modules are directly measured using HP8510C vector network analyzer. TRL calibration was used to move the reference planes to the interface surface of the metallic waveguide flanges. The measured reflection coefficient of the single transition module is superposed with that of the EM simulated in Fig.4. Very good correlation between the two results can be observed. The measured bandwidth is about 2.5GHz with return loss below −15dB. A slight frequency shift and a bandwidth reduction might be caused by a slight offset of dimension L in the prototype hardware.

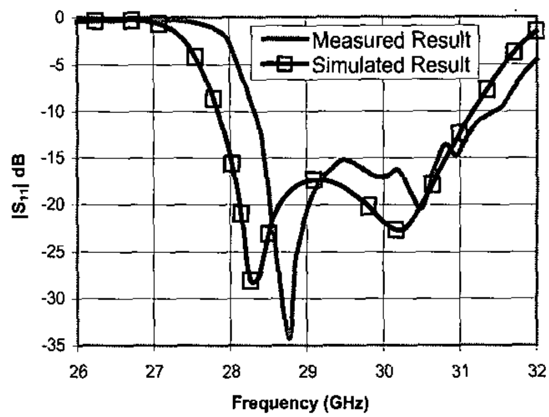
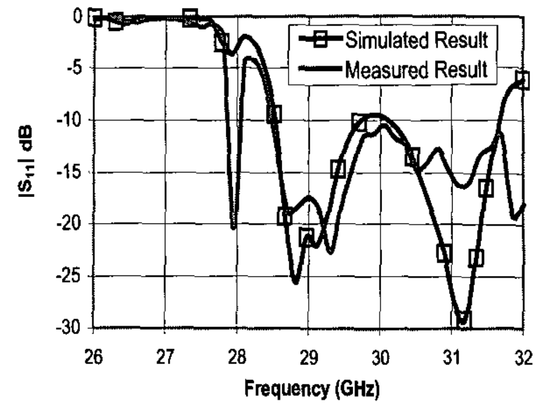


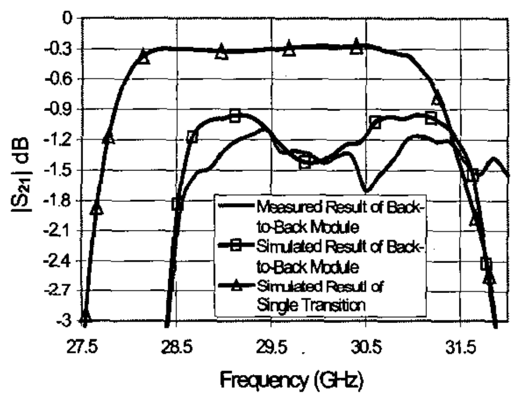
Fig. 4. The measured and the EM simulated |S11| of a single transition.

Fig.5 (a) shows the comparison of the simulated and the measured return loss of the back-to-back module. Excellent correlation between the measured and the EM simulation results are obtained.

The simulated and measured insertion losses of the back-to-back module are shown in Fig.5 (b), also showing good correlation. As a matter of fact, because of unequal waveguide interfaces of the transition, it is difficult to experimentally characterize the insertion loss of a single transition. Therefore, EM simulated insertion loss, which has been validated indirectly by the back-to-back module, is used to characterize the transition, which is also superposed in Fig.5 (b). It can be observed that the insertion loss of a single transition can be as low as −0.3dB from 28.2 GHz to 31.0 GHz. It can be observed that the insertion loss of a single transition can be as low as −0.3dB from 28.2 GHz to 31.0 GHz. Accounting for a slight under-estimation of insertion loss learnt from the difference between simulated and measured result of back-to-back module, it can be concluded that an average insertion loss of a single transition should be better than -0.4dB in whole pass band. It should be mentioned that the insertion loss also includes insertion losses dissipated in a piece of 120 mils long WR28 waveguide and a piece of 200 mils laminated waveguide.



(a) $|S_{11}|$ of the back-to-back configuration



(b) $|S_{21}|$ in the pass band of the single transition and the back-to-back configuration

Fig. 5. The measured and the simulated S21 of the back-to-back module and EM simulated S21 of the single transition module.

IV. CONCLUSION

A broadband and compact laminated waveguide to air-filled waveguide transition has been proposed. The transition configuration is tailored to multi-layers structures and can be easily integrated with any laminated waveguide integrated module for high volume productions.

With its attractive features the transition will be widely used in various wireless and radar systems where an integrated module with laminated waveguide interface needs to be inter-connected with an air-filled waveguide interfaced module.

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REFFERENCES

[1] H.Uchimura, T. Takenoshita, and M. Fujii, "Development of a Laminated waveguide," *IEEE Trans. Microwave Theory Tech.*, vol.46, No.12, pp2438-2443, Dec. 1998.

[2] J. Hirokawa and M. Ando, "Efficiency of 76-GHz post-wall waveguide-fed parallel-plate slot arrays," *IEEE Trans., Antennas Propagat.*, vol.48, No.11, pp1742 –1745, Nov. 2000.

[3] H. Uchimura and T. Takenoshita, "A Ceramic Planar 77GHz Antenna Array," *IEEE MTT-S Int. Microwave Symp. Dig.*, 1999, pp453-456.

[4] A. Piloto, K. Leahy, B. Flanick and K. A. Zaki, "Waveguide Filters Having a layered Dielectric Structures", U.S. Patent 5,382,931, January 17, 1995.

[5] Y. Rong, K. A. Zaki, M. Hageman, D. Stevens and J. Gipprich, "Low Temperature Cofired Ceramic (LTCC) Ridge Waveguide Bandpass Chip Filters," *IEEE Trans. Microwave Theory Tech.*, vol.47, No.12, pp2317-2324, Dec. 1999.