

Dielectric Microstrip Line (DML)

- A New Transmission Line for Terahertz Applications

Quan Xue^{*1,2}, Haotian Zhu^{1,2}, Leung Chiu^{2,3}, Qingyuan Tang^{1,4}, Xinghai Zhao^{1,4}, and W. Stella Pang^{1,4}

¹Department of Electronic Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR,

² State Key Laboratory of Millimeter Waves, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, eeqxue@cityu.edu.hk,

³ Advanced Research and Development Centre, Telefield Limited 609-610, Bio-Informatics Centre, Hong Kong Science Park, eechiuleung@yahoo.com.hk

⁴ Centre for Biosystems, Neuroscience, and Nanotechnology, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, pang@cityu.edu.hk.

Abstract

This paper presents a multilayer dielectric transmission line – the dielectric microstrip line (DML), for the terahertz (THz) applications. This DML is a metal free transmission line eliminating metal loss, which can be a very serious problem at THz. The E_{11}^y mode is the main mode in the DML for the electromagnetic wave propagation. A DML with standard waveguide operating within 0.220THz-0.325THz is designed, fabricated and measured for demonstration. With TRL calibration method, phase constant and attenuation constant of the DML are obtained.

1. Introduction

Applications of microwaves have been expanded from wireless communications to radar, navigations, radio-astronomy, imaging, etc., with high data rate or high resolution. This trend has been boosting the working frequencies of systems from microwave range to millimeter-wave, and even to terahertz (THz). In the exploration of circuits in THz bands, the transmission line plays a key role because it is the basic medium for building passive/active components.

For conventional microstrip line, the current conducting volume in the metal is significantly reduced due to the skin effect at millimeter wave and THz [1], resulting in very high transmission loss. As a result, the metal loss dominates the total loss in this transmission line. In addition, physical dimensions of traditional microstrip THz components are very small, which are difficult to fabricate with good dimensional control to achieve satisfactory performance.

A new guided wave structure, the so-called dielectric microstrip line (DML), has been proposed. The proposed 3-layer structure keeps the merit of microstrip line for flexible implementation of various passive/active components, while induces the low loss characteristic of dielectric waveguide [2]-[7]. The

structure of the DML is very similar to that of microstrip line but with the top and bottom metal layers replaced by dielectric strip/sheet with higher permittivity than that of the middle substrate. DML was named since its' structure is similar to the conventional microstrip line, namely, planar structure. Detailed structure, simulation, and measured results of the DML will be presented in the following sections.

2. Dielectric Microstrip Line

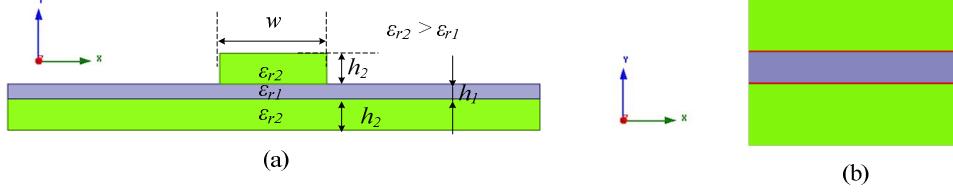


Fig.1. (a) Cross Section View of DML. (b) Cross section of narrowed-DML.

The DML consists of three layers of dielectric substrates, as shown in Fig.1 (a). For demonstration, a DML operating at $0.220\text{THz} \sim 0.325\text{THz}$ is designed. According to the theoretical analysis, the DML supports E_{11}^y propagation wave mode. To fulfill this EM mode request, the parameters of the DML are chosen as $\epsilon_{r1}=2.20$, $\epsilon_{r2}=2.94$, $\tan_1=0.0009$, $\tan_2=0.0012$, $h_1=127\mu\text{m}$, $h_2=254\mu\text{m}$ and $w=864\mu\text{m}$. The top strip and bottom sheet of DML are Duroid 6002. The material of the middle layer is Duroid 5880.

To simplify the fabrication process, the three layers can have the same width ($864\mu\text{m}$), which is equal to the width of the standard waveguide WR03, as shown in Fig.1 (b). The structure in Fig.1 (b) is called narrowed-DML (N-DML). This N-DML has similar EM field distribution and can reveal similar transmission characteristics of conventional DML in Fig. 1 (a).

3. Waveguide to DML Transition Design and Fabrication Process

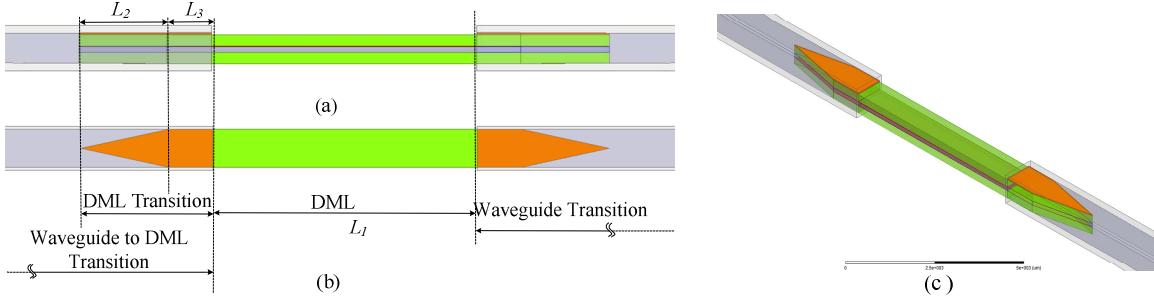


Fig. 2. (a) Side view of the N-DML and its waveguide transitions. (b) Top view of the N-DML and its waveguide transitions. (c) 3D view of the N-DML and its waveguide transitions. (Parameters: $L_1=6\text{mm}$ for shorter DML, $L_1=11\text{mm}$ for longer N-DML, $L_2=2\text{mm}$, $L_3=1\text{mm}$).

The height of the designed N-DML is $635\mu\text{m}$, which is larger than the height ($432\mu\text{m}$) of the standard waveguide WR03. Two tailor-made waveguide transitions are needed to transmit the EM waves from the standard waveguide WR03 ($864\mu\text{m} \times 432\mu\text{m}$) to an $864\mu\text{m} \times 700\mu\text{m}$ waveguide. With two waveguide-to- N-DML transitions, the N-DML is inserted into the two waveguides as shown in Fig. 2. The transition is basically a linearly tapered N-DML inserted into the rectangular waveguide such that the EM field can be coupled smoothly from the waveguide to the DML. The two copper sheets, as orange parts in Fig. 2, serve as markers of

N-DML length inserting into the waveguide transitions. Poly-methyl methacrylate (PMMA) with $2.5\mu\text{m}$ thickness is used to bond the three dielectric layers together.

4. Simulation and Measured Results

Two pieces of N-DMLs with different length were designed, as displayed in Figs.3 (a) and 3 (b), simulated and measured by the Agilent N5245A PNA-X network analyzer and the OML-WR03 extension heads. The simulation and measured results of the longer DML with its transitions are shown in Fig. 3(c). We observe that, within the range of 0.220THz - 0.270THz, the simulation and tested results have good agreement. Because of limited fabrication precision, the tested insertion loss is larger than the simulation results at high frequency. By comparing the two sets of measured parameters for the longer and shorter N-DMLs, the propagation parameter of the N-DML, namely the phase constant and the attenuation constant, can be calculated from the TRL calibration method [8]. Within the frequency of 0.220THz - 0.270THz, the normalized phase constant ranges from 1.27 to 1.37, while, the attenuation constant of the measured N-DML is less than 0.16dB/mm, which is pretty good for THz application.

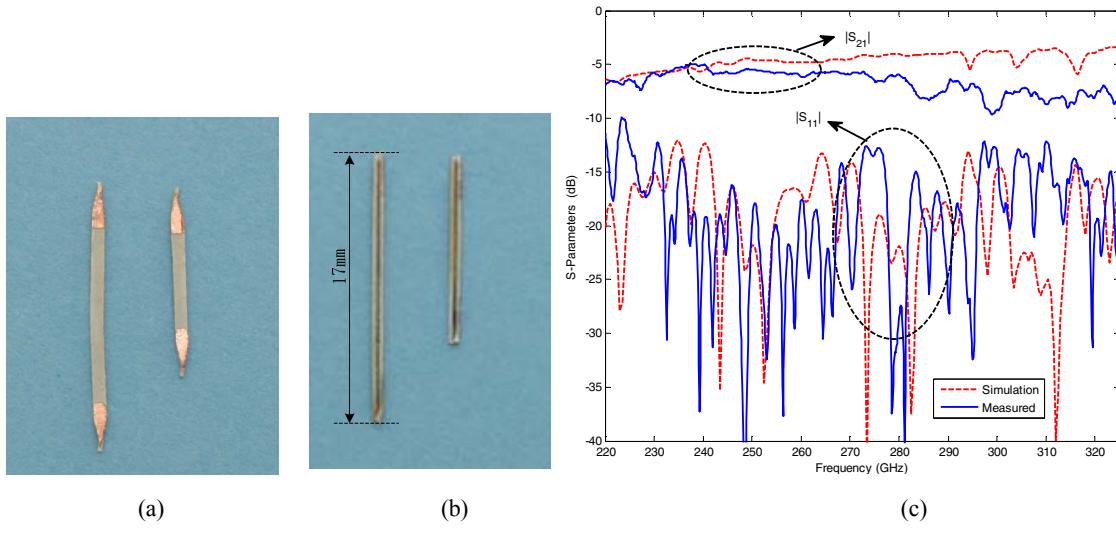


Fig.3. (a) Top view of the N-DMLs with their transitions. (b) Side view of the N-DMLs with their transitions. (c) Simulation and measured S-parameters of the longer N-DML with its waveguide transitions.

5. Conclusion

DML structure with transitions between the DML and the waveguide operating at THz band is introduced in this paper. A good guided wave characteristic at Terahertz frequency range has been experimentally confirmed by simulation and measurement at the band of 0.220THz-0.325THz. Within the designated band, the normalized phase constant ranges from 1.27 to 1.37, while, the attenuation constant of the measured N-DML is less than 0.16dB/mm, which is pretty good for THz application.

6. Acknowledgments

This work is supported by the National Natural Science Foundation of China (No.61372056) and the Center for Biosystems, Neuroscience, and Nanotechnology at City University of Hong Kong (9360148).

7. References

1. Q. Xue, L. Chiu, and H. Zhu, "A transition of microstrip line to dielectric microstrip line for millimeter wave circuits," *IEEE International Wireless Symposium, Beijing*, Apr. 2013.
2. Y. Cassivi, and k. Wu, "Substrate integrated nonradiative dielectric waveguide , " *IEEE Microw. Wireless Compon. Lett.*, vol. 14, no. 3, pp. 89-91, Mar. 2004.
3. W. V. McLevige, T. Itoh, and R. Mittra, "New waveguide structures for millimeter-wave and optical integrated circuits," *IEEE Trans. Microwave Theory Tech.*, vol. 23, no. 10, pp.788 - 794 , Oct. 1975.
4. K. Ogasu, "Numerical analysis of the rectangular-dielectric waveguide and its modifications," *IEEE Trans. Microwave Theory Tech.*, vol. 25, no. 11, pp. 847-885, Nov. 1977.
5. J. A. Paul and Y. W. Chang, "Millimeter-Wave Image-Guide Integrated Passive Devices," *IEEE Trans. Microwave Theory Tech*, vol. 26, no. 10, pp. 751 - 754, Oct. 1978.
6. A. G. Engel, Jr. and L. P. B. Katehi, "Low-loss monolithic transmission lines for submillimeter and Terahertz frequency applications," *IEEE Trans. Microwave Theory Tech.*, Vol. 39, no. 11, pp. 1847-1854, Nov. 1991.
7. G. E. Ponchak, N. I. Dib, and L. P. B. Katehi, " Design and Analysis of Transitions from Rectangular Waveguide to Layered Ridge Dielectric Waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. 44, no. 7, pp. 1032-1040, Jul. 1996.
8. David M. Pozar, "Transmission lines and waveguides," *Microwave Engineering, 3rd ed.* NewYork: JOHN WILEY & SONS, INC, 2005, pp. 91-160.