Transmission Loss in Coplanar Waveguide and Planar Goubau Line between 0.75 THz and 1.1 THz

Citation for the original published paper (version of record):
Cabello Sánchez, J., Rodilla, H., Drakinskiy, V. et al (2018). Transmission Loss in Coplanar Waveguide and Planar Goubau Line between 0.75 THz and 1.1 THz. International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz, 2018-September: 1-2.
http://dx.doi.org/10.1109/IRMMW-THz.2018.8510326

(article starts on next page)

Transmission Loss in Coplanar Waveguide and Planar Goubau Line between 0.75 THz and 1.1 THz

J. Cabello-Sánchez, H. Rodilla, V. Drakinskiy and J. Stake
Chalmers University of Technology, 412 96 Gothenburg, Sweden

***Abstract*—In many cases, metallic planar waveguides are required in the design of integrated circuits. However, at terahertz frequencies, metallic planar waveguides present high losses, which make necessary the use more efficient waveguides to avoid power limitations. In this work, the attenuation constant of two popular planar waveguides for terahertz frequencies, Coplanar Waveguide (CPW) and Planar Goubau Line (PGL), are compared between 0.75 THz and 1.1 THz. To measure the PGL, its transition is deembeded using a multiline Thru-Reflect-Line calibration standard. Measurement results show a lower attenuation constant across the band for a PGL (0.13 mm^{-1} < α < 0.39 mm^{-1}) than for a CPW (0.68 mm^{-1} < α < 0.99 mm^{-1}) when an ultra-thin substrate is used suspended in air, which greatly reduces the substrate mode coupling from the PGL. These results put the PGL as a less lossy metallic planar waveguide for terahertz applications.**

I. INTRODUCTION

WAVEGUIDES are a fundamental part of most high-frequency electronic circuits. A lack of low-loss waveguides would pose severe constraints on most circuit designs. At terahertz (THz) frequencies, high losses in metallic waveguides together with a low available power severely reduces the signal to noise ratio, thus making loss minimization crucial for waveguides at this frequency band [1], [2]. High losses are accentuated when metallic planar waveguides are needed for chip integration, due to their higher losses compared to their non-planar counterparts. This creates the need to study and optimize the performance of metallic planar waveguides used at THz frequencies to expand the possibilities of THz chip design. In this context, we present a comparison of the attenuation constant of two popular metallic planar waveguides suitable for THz applications, Coplanar Waveguide (CPW) (Fig. 1.a) [3] and Planar Goubau Line (PGL) (Fig. 1.b) [4], [5], in addition to general guidelines on how can losses be minimized in these waveguides at THz frequencies.

II. METHOD

In this work, the attenuation of a 1 mm long CPW (Fig. 2.a) and a 1 mm long PGL (Fig. 2.b) are compared using on-wafer S-parameter measurements from 0.75 THz to 1.1 THz. The CPW, designed to suit the ground-signal-ground probes' dimensions [6], has a 23.5 µm wide strip, a 1.5 µm ground separation and a characteristic impedance of 50 Ω; while the PGL has a 10 µm wide conducting strip and an approximate characteristic impedance of 230 Ω. The PGL was excited with the probes using a CPW to PGL transition [7].

To minimize substrate mode excitation [8], [9], and thus reduce losses, we chose a 23 µm thick polyethylene terephthalate (PET) film (with a relative permittivity of $\varepsilon_r = 3.15$ and a loss tangent of $\tan(\delta) = 0.017$ at 1 THz [10]) as the substrate. The PET substrate was placed on top of a polyethylene (PE) holder ($\varepsilon_r = 2.3$ and $\tan(\delta) = 0.004$ at 1 THz [10]) during measurements to avoid coupling of the structures with the metal chuck from the measurement's set-up. The conducting strips of both the PGL and the CPW were fabricated using e-beam lithography and e-gun evaporation of 10 nm Ti and 350 nm Au.

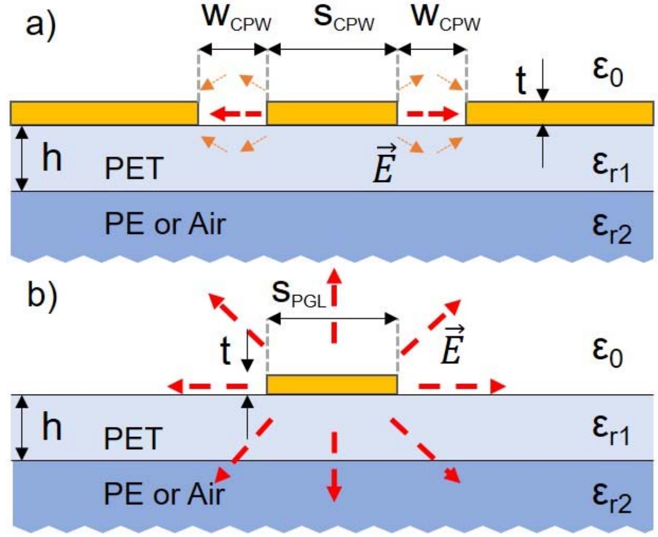

Fig. 1. Cross-section sketch of **a)** coplanar waveguide and **b)** planar Goubau line. Dashed lines indicate the electrical field of the main propagation mode in each waveguide. Both waveguides were measured in two environments: with PE ($\varepsilon_{r2} = 2.3$) or with air ($\varepsilon_{r2} = 1$) under the PET substrate.

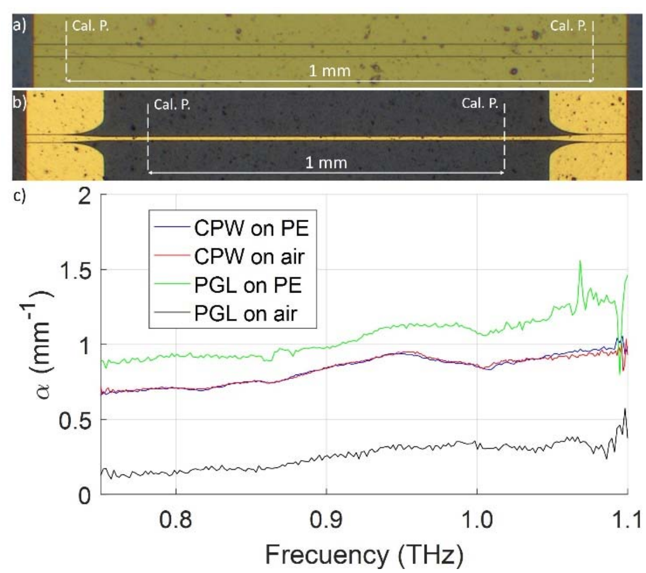

Fig. 2. a) Optical micrograph of the 1 mm long CPW with a 23.5 µm wide strip and ground separation of 1.5 µm. Vertical dashed lines indicate the location of the calibration planes. **b)** Optical micrograph of the 1 mm long and 10 µm wide PGL. Vertical dashed lines indicate the location of the calibration planes. Behind each calibration plane lies the CPW to PGL transition. **c)** Measured attenuation constant of the above structures having PE or air under the PET substrate.

The S-parameter measurements from 0.75 THz to 1.1 THz were performed using an Agilent N5242A PNA-X Network Analyzer attaching two VDI WR1.0SAX frequency extenders. To contact the planar structures, Cascade T-Wave ground-signal-ground probes [6] were used. The measurements were calibrated using multi-line TRL calibration standards [11], included in the PET substrate. To compare the PGL to the CPW without the effect of the PGL's transition, a dedicated calibration standard was used for each waveguide, CPW and PGL [12], which allowed setting the calibration plane along each line (see Fig 2.a and Fig 2.b). The waveguides were measured in two different environments: with PE under the PET substrate ($\varepsilon_{r1} = 3.15$; $\varepsilon_{r2} = 2.3$), or with air under the PET substrate ($\varepsilon_{r1} = 3.15$; $\varepsilon_{r2} = 1$), by micromachining a hole in the PE holder.

III. Results

When there is PE under the PET substrate ($\varepsilon_{r1} = 3.15$; $\varepsilon_{r2} = 2.3$), S-parameter measurement results of the 1 mm long CPW (Fig. 2.c) show an attenuation constant, α, between 0.68 mm^{-1} and 0.99 mm^{-1} and return loss above 15 dB across the band. On the other hand, measurements results of a 1 mm long PGL (Fig. 2 c) show $0.87\ mm^{-1} < \alpha < 1.38\ mm^{-1}$ and return loss above 15 dB across the band. Under these circumstances, there is an approximately 0.25 mm^{-1} lower attenuation constant across the band for the CPW than for the PGL.

When the PE under the PET substrate is removed ($\varepsilon_{r1} = 3.15$; $\varepsilon_{r2} = 1$), the CPW's S-parameter measurement results (Fig. 2.c) show negligible change. However, for the PGL there is an approximately 0.78 mm^{-1} decrease in the attenuation constant ($0.13\ mm^{-1} < \alpha < 0.39\ mm^{-1}$), compared to when there is PE under the PET substrate. In this case the PGL, with $0.39\ mm^{-1} < \alpha < 0.13\ mm^{-1}$ across the band, has an approximately 0.55 mm^{-1} lower attenuation constant than the CPW. These results suggest that the highly confined field in the CPW does not excite substrate modes in the PE under the PET substrate and that the attenuation is mainly caused by conductor and dielectric losses. In contrast, the PGL excites substrate modes in the presence of the PE holder, due to its lower field confinement, but has a fewer sum of conductor and dielectric losses compared to the CPW. Thus, to decrease losses in the PGL it's crucial to avoid substrate mode coupling.

For lowering the conductor losses in the CPW, it is necessary to increase the strip width and the strip-to-ground separation [13]. This comes at the cost of a higher tendency to excite substrate modes due to a lower confinement of the field. In the limit when conductor losses are minimized in the CPW, the ground planes would be too distant from the CPW's central strip to have an impact in the field, thus having a propagating mode similar to the PGL's.

Acknowledgment

This research was funded by the Swedish Research Council (*Vetenskapsrådet*).

References

[1] K. Wang and D. M. Mittleman, "Metal wires for terahertz wave guiding," *Nature*, vol. 432, no. November, pp. 376–379, Nov. 2004.

[2] F. Fesharaki, T. Djerafi, M. Chaker, and K. Wu, "Low-Loss and Low-Dispersion Transmission Line over DC-to-THz Spectrum," *IEEE Trans. Terahertz Sci. Technol.*, vol. 6, no. 4, pp. 611–618, 2016.

[3] C. P. Wen, "Coplanar Waveguide: A Surface Strip Transmission Line Suitable for Nonreciprocal Gyromagnetic Device Applications," *IEEE Trans. Microw. Theory Tech.*, vol. 17, no. 12, pp. 1087–1090, 1969.

[4] Y. Xu and R. G. R. G. Bosisio, "A study of planar Goubau lines (PGLs) for millimeter- and submillimeter-wave integrated circuits (ICs)," *Microw. Opt. Technol. Lett.*, vol. 43, no. 4, pp. 290–293, Nov. 2004.

[5] G. Goubau, "Surface waves and their application to transmission lines," *J. Appl. Phys.*, vol. 21, no. 11, pp. 1119–1128, 1950.

[6] M. F. Bauwens, N. Alijabbari, A. W. Lichtenberger, N. S. Barker, and R. M. Weikle, "A 1.1 THz micromachined on-wafer probe," *IEEE MTT-S Int. Microw. Symp. Dig.*, 2014.

[7] A. Treizebré, B. Bocquet, Y. Xu, and R. G. Bosisio, "New THz excitation of planar Goubau line," *Microw. Opt. Technol. Lett.*, vol. 50, no. 11, pp. 2998–3001, Nov. 2008.

[8] D. B. Rutledge, D. P. Neikirk, and D. P. Kasilingam, "Integrated-Circuit Antennas," in *Infrared and millimeter waves*, vol. 10, New York: Academic, 1983.

[9] M. Riaziat, R. Majidi-Ahy, and I. Feng, "Propagation Modes and Dispersion characteristics of CPW," vol. 38, no. 3, 1990.

[10] N. Fuse, T. Takahashi, Y. Ohki, R. Sato, M. Mizuno, and K. Fukunaga, "Terahertz Spectroscopy as a New Tool for Insulating Material Analysis and Condition Monitoring," *IEEE Insul. Mag.*, vol. 27, no. 3, pp. 26–35, 2011.

[11] R. B. Marks, "A Multiline Method of Network Analyzer Calibration," *IEEE Trans. Microw. Theory Tech.*, vol. 39, no. 7, pp. 1205–1215, 1991.

[12] J. Cabello-Sánchez, H. Rodilla, V. Drakinskiy, and J. Stake, "Multiline TRL Calibration Standards for S-parameter Measurement of Planar Goubau Lines from 0.75 THz to 1.1 THz," *IEEE MTT-S Int. Microw. Symp. Dig.*, 2018.

[13] Jingjing, S. Alexandrou, and T. Y. Hsiang, "Attenuation characteristics of coplanar waveguides at subterahertz frequencies," *IEEE Trans. Microw. Theory Tech.*, vol. 53, no. 11, pp. 3281–3287, Nov. 2005.