Low loss Goubau Line on high-resitivity silicon in the 57–64 GHz band

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Abstract—**Planar Goubau Line (PGL) structures on high resistivity silicon are simulated and measured in the 57-64GHz frequency band. It is shown that the increase of the substrate thickness permits to adapt this line, used at THz frequencies, to this frequency band. Very low losses are attained with a measured average attenuation of 0.064dB/mm on the whole band. Another advantage of the PGL consists in its very simple technological process, as just one level of metallization is necessary. A transition between the PGL and a coplanar waveguide is designed in order to perform on-wafer measurements, and very good agreement is obtained with simulation results for the attenuation of PGL.**

I. INTRODUCTION

We have optimized a Planar Goubau Line (PGL), initially developed for THz applications, for an use around 60 GHz. The 57 to 64 GHz frequencies band, which satisfies the European as well as US standard bandwidth for 60 GHz Wireless Local Area Networks (WLANs), has attracted much attention in recent years [1] not only for licence-free accessible for UWB signals, which leads to a high-speed transmission rate, but also for the miniaturization of the systems and the security aspect of short range indoor data communications thanks to the high atmospheric attenuation (10-15 dB/km) in this frequency band.

The low loss and low dispersion of the Planar Goubau Line (PGL) that we have optimised, combined with a simple fabrication process, make it a good candidate for Ultra-Wide Band (UWB) applications. The characterization of PGL structures requires coplanar waveguide probe pads. In order to perform on-wafer measurements, a transition from the excitation access to the PGL line has also been optimized. In the first time, we study the variation of PGL attenuation versus the silicon thickness and the silicon permittivity. A commercial full wave simulator HFSS (High Frequency Structural Simulator) based on the Finite Element Method (FEM) has been used to do a parametric study. The study of the variation of PGL attenuation versus the permittivity substrate and the silicon thickness proves that the cut-off frequency of this high-pass filter can be shifted to a lower frequency. Then, we focused on the reflection and transmission parameters, with a comparison of the simulation and measurement results for the back-to-back transition and the extraction of the single transition S-parameters by a thru-line technique.

II. DESCRIPTION AND BEHAVIOR OF THE PGL

The PGL (figure 1) is designed on a high resistivity (60 Ω.m) silicon substrate (ε_r=11.6) with a strip width of 100µm and a gold metallization thickness of 1.6 µm.

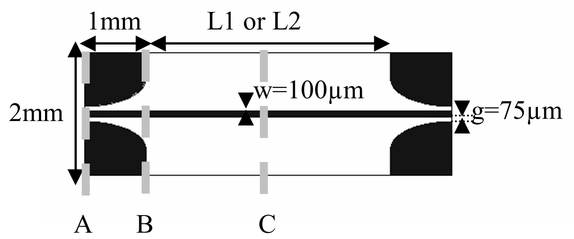

Fig.1: Top view of the coplanar to PGL transition

In [2], the influence of substrate permittivity and substrate thickness on the electromagnetic propagation of the Goubau wire is studied from 100 GHz to 10 THz : to decrease losses, the permittivity must be low (close to permittivity of air) and the substrate thin in THz band. In the 57-64 GHz band, whereas the increase of the substrate thickness decreases the attenuation, the opposite behaviour is observed with the substrate permittivity as its increase improves the transmission. A Silicon substrate thickness equal or higher than 300µm (Figure 2) and a substrate permittivity higher than 8 (Figure 3) permit to maintain the propagation losses below 0.07dB/mm according to simulation results. So, the increase of the substrate thickness and the increase of the substrate permittivity imply a decrease of the cut-off frequency of this high-pass filter.

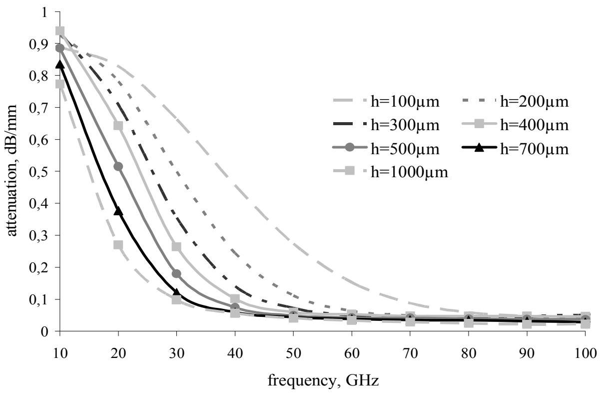

Fig.2: Attenuation (dB/mm) of the PGL versus the frequency (10-100GHz) for different thicknesses of Silicon and a strip width of 100µm

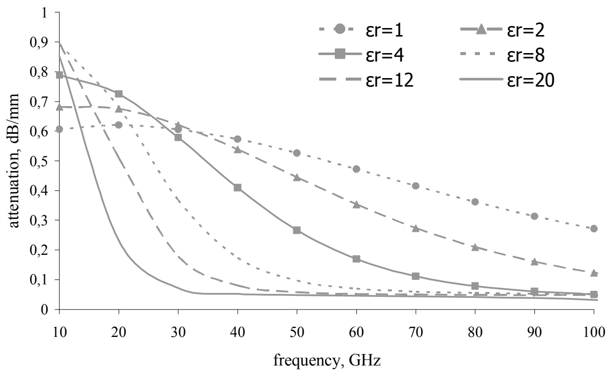

Fig.3: Attenuation (dB/mm) of the PGL versus the frequency (10-100GHz) for different permittivities of substrate (h=500µm) and a strip width of 100µm

The presented attenuation is weak compared to other open structures on low resistivity Silicon [3,4] that exhibit a 0.4dB/mm measured attenuation at 60GHz. A parametric study on the conductivity (Figure 4) of the strip metallization proves the negligible effect of this parameter on the attenuation, in contrary to the variation of the strip width (Figure 5) and of the metallization thickness (Figure 6) : at 60GHz, the attenuation is lower when the metallization thickness is high (the skin depth is equal to 0.33µm at 60GHz) and the strip width is large at 60GHz : the attenuation decreases from α= 0.068 dB/mm for w=50µm= $h_{Silicon}$/10 to α= 0.035 dB/mm for w=400µm= $h_{Silicon}$/1.25.

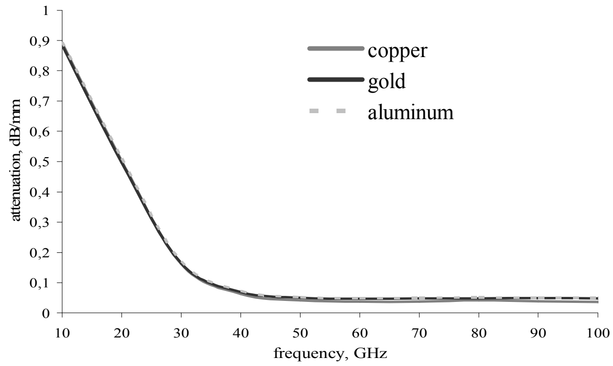

Fig.4 : Attenuation (dB/mm) of the PGL versus the frequency (10-100GHz) for different conductivities of the strip (tstrip=1µm, $h_{Silicon}$=500µm, w=100µm)

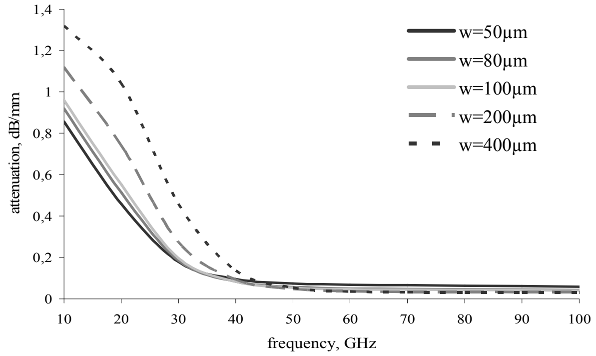

Fig.5: Attenuation (dB/mm) of the PGL versus the frequency (10-100GHz) for different strip widths (tstrip=1µm, $h_{Silicon}$=500µm)

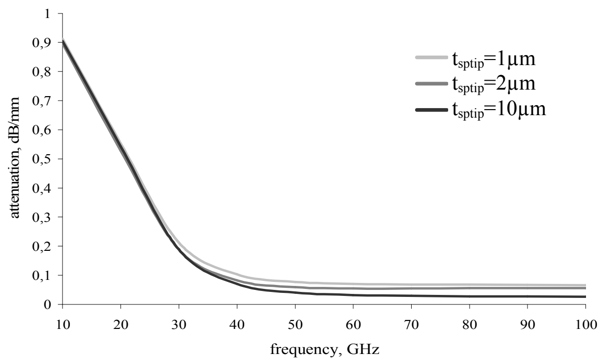

Fig.6 : Attenuation (dB/mm) of the PGL versus the frequency (10-100GHz) for different thicknesses of the strip ($h_{Silicon}$=500µm, w=100µm)

In order to qualify and to quantify the losses, we plot in figure 7 the total losses α, the metallic losses α_c and the dielectric losses α_d. We note at 60GHz the predominance of the metallic losses in comparison with the dielectric losses and the radiating losses (α- α_c - α_d). We report in figure 8 the cross-field E for a PGL (w=100µm) on 500µm of Silicon in the free space and we observe different distributions of the field versus the frequency. When the frequency increases from 30GHz to 90GHz, the field is more and more confined around the strip and the radiating losses are reduced (Figure 7).

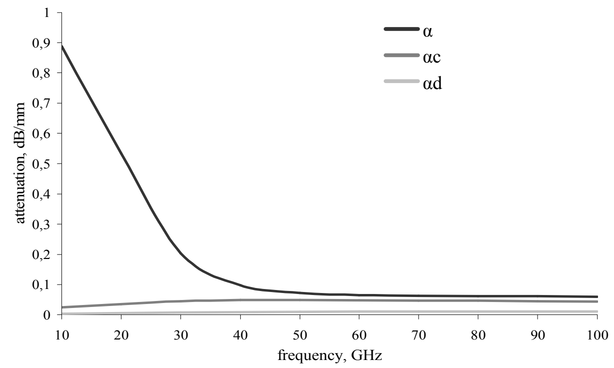

Fig.7 : Attenuation (dB/mm) of the PGL versus the frequency (10-100GHz) (t_{strip}=1µm, $h_{Silicon}$=500µm, w=100µm) in considering total losses α, metallic losses α_c or dielectric losses α_d

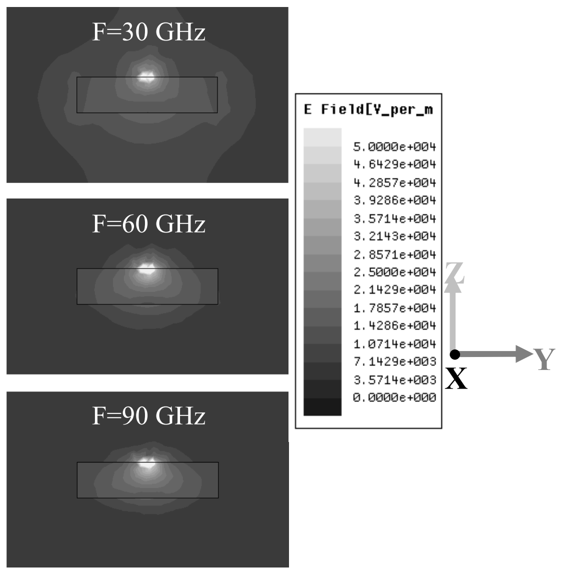

Fig.8: Cross-section E-field distribution of the PGL on high-resistivity Silicon ($h_{Silicon}$=500µm, w=100µm) at 30GHz, 60GHz and 90GHz

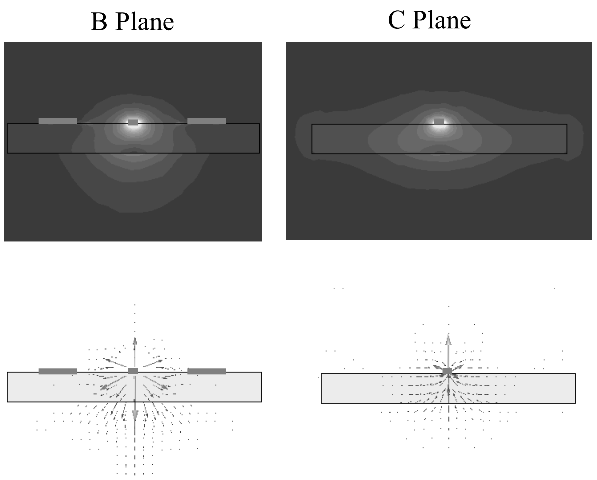

Fig.9: Cross-section E-field distributions along the coplanar-tapered PGL transition for $h_{Silicon}$=350µm (B Plane and C Plane of figure 1)

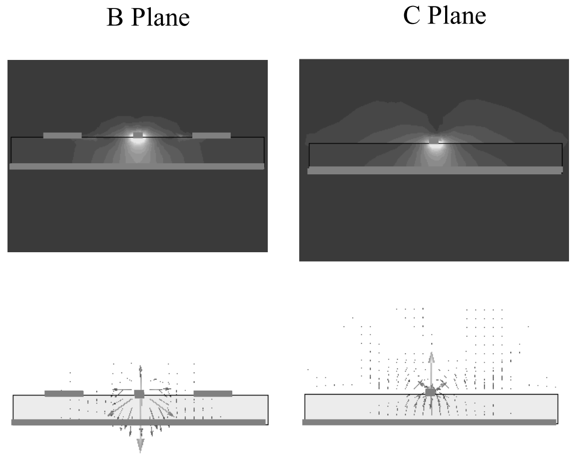

Fig.10: Cross-section E-field distributions a long the coplanar-tapered PGL transition for $h_{Silicon}$=350µm with ground plane (B Plane and C Plane of figure 1)

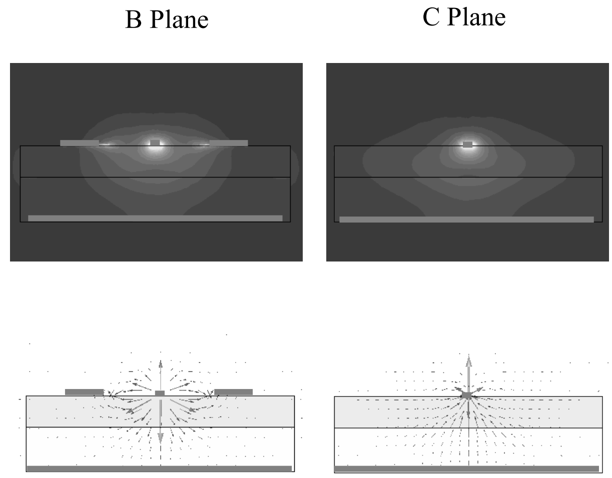

Fig.11: Cross-section E-field distributions along the coplanar-tapered PGL transition for $h_{Silicon}$=350µm, h_{Glass}=500µm with ground plane (B Plane and C Plane of figure 1)

In figures 9, 10 and 11, we have considered three cases for the PGL associated to a transition: a first case with a 350µm Silicon substrate (figure 9), a second case with a 350µm silicon substrate in presence of a metallic plane (figure 10) and the third case with a 350µm silicon substrate over a 500µm glass substrate in presence of metallic plane (figure 11). The metallic plane corresponds to the chuck, on which is positioned the PGL to be measured, and the addition of the glass substrate is dedicated to limit the influence of the chuck. The electric field distribution along the transition is shown in all the figures 9, 10 and 11. In figure 10, the disturbance of the PGL by the proximity of the metallized plane can be observed, and we can see in figure 11 that an added glass substrate can limit the effect of this metallized plane: if we compare the figures 9 and 11, we observe a Goubau mode.

III. MEASURE OF COPLANAR TO PGL TRANSITION AND PGL

Measurements were performed with a PNA Microwave Network Analyser and a probe station equipped with millimetre probes and calibrated with a LRM (Line Reflect Match) method. The coplanar to PGL transitions have been realized on silicon of 350µm height. To avoid the disturbance of the PGL by the proximity of the metallized chuck, a glass substrate of 500µm thickness is added below the silicon. This additional glass substrate is taken into account in HFSS simulations, causing for the studied PGL the same attenuation as for the PGL on a 500 µm-thick silicon substrate placed in free-space. The measurements on the probe station of the scattering parameters on the back-to-back structures with the additional glass substrate allow the extraction of the coplanar to PGL transition parameters.

The S-parameters of the transition [5] between the coplanar measurement access and a PGL of width w=100µm, have been extracted from measurements and reported in figure 12. The measured return loss of the transition is lower than -10dB on the 57-64 GHz frequency band (figure 12) and the insertion loss is equal to 1.36dB at 64 GHz. We can see that the transition is disturbed by the measurement setup.

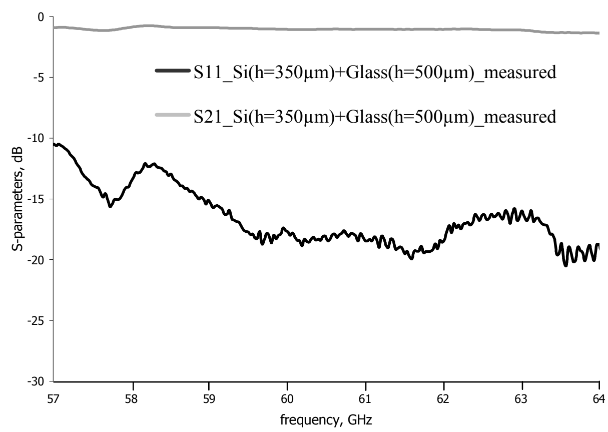

Fig.12: Return loss and insertion loss of coplanar to PGL transition, extracted by (TL) using measured data

The PGL attenuation (figure 13) is obtained by averaging the attenuation of different lengths of line in order to limit the stochastic errors (temperature variations, positioning of probes).

Six different lengths of line (2, 4, 6, 10, 20 mm) with the same coplanar-PGL transition have been designed with a redundancy of each structure. Each back-to-back structure presents a correct transmission (│S11│<-15 dB). The average attenuation α presented in figure 13 is calculated from these 20 extracted attenuations. Over the 57-64 GHz frequency band, the measured attenuation varies between 0.05 dB/mm and 0.071 dB/mm, with a mean value of 0.064 dB/mm.

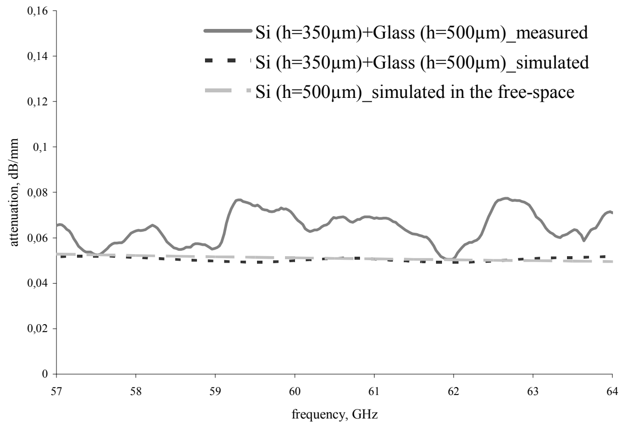

Fig.13: Measured and simulated attenuation (dB/mm) versus the frequency (57-64 GHz)

IV. CONCLUSION

In this paper, a PGL structure on high resistivity Silicon is optimized and presents a very low attenuation with a measured average value of 0.064 dB/mm in the 57-64GHz band. The attenuation parameter is lower than the ones presented by other open structures. The comparisons between simulations and measures are quite close. The attenuation could be easily reduced by a thicker line metallization. We are prospecting the possibility to realize filters and antennas.

REFERENCES

[1] T. Kuri, K. Kitayama, A. Stohr, and Y. Ogawa, Fiber-optic millimeter-wave downlink system using 60GHz-band external modulation, Journal of Lightwave Technology 17 (1999), 799-806.

[2] A. Treizebre, B. Bocquet, Y. Xu, R. G. Bosisio "New THz excitation of planar Goubau line," *Microwave and Optical Technology Letters*, vol.50, no.11, pp.2998-3000, Nov.2008.

[3] K. Elgaid, D. L. Edgar, D. A. McCloy, I. G Thayne, "CPW interconnects for MMIC applications on low resistivity CMOS grade silicon using micromachined SU8 negative resist," European Microwave Conference, Milan, Italy, Sept 2002, pp.1-4.

[4] G. E Ponchak, A. N. Downey, "Characterization of Thin Film Microstrip Lines on Polyimide", *IEEE Transactions on components, packaging and manufacturing technology*, Part B, vol.21, no.2, pp. 171-176, May 1998.

[5] S. Bulja, D. Mirshekar-Syahkal : "Novel wideband transition between coplanar waveguide and microstrip line," *IEEE Transactions on Microwave Theory and Techniques*, vol58, no.7,pp.1851-1857, June 2010.