High-Impedance Coplanar Waveguides with Low Attenuation

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Abstract—**The conventional MMIC coplanar line covers an impedance range from about 30–80 Ω. Values outside this range cannot be fabricated reliably or cause excessive losses. For several applications, however, it is desirable to use high-impedance lines (e.g., for reduced-size couplers and nonlinear transmission lines). This letter reports results from experiment and electromagnetic simulation for a coplanar waveguide (CPW) structure with an elevated center conductor realized by an air-bridge technique. We achieve wave impedances of about 100 Ω at a lower attenuation level as conventional 50-Ω CPW's of comparable size.**

I. Introduction

In MMIC's, the common coplanar waveguide (CPW) geometries span an impedance range from 30–80 Ω. For several applications, however, one needs impedance values larger than 80 Ω. They are necessary, for instance, when realizing reduced-size couplers. To achieve this, conventional lines are replaced by a combination of short high-impedance lines and lumped shunt capacitors [1]. Nonlinear transmission lines, on the other hand, require high-impedance CPW's with low attenuation for the generation of short pulses with steep edges [2]. As a further application, utilizing high-impedance lines a broadband bias supply becomes possible.

The larger the CPW impedance, the smaller the ratio between center conductor width w and slot width s. Given a constant ground-to-ground spacing, therefore, increasing the CPW impedance to values beyond 80 Ω leads to a steep increase in attenuation due to ohmic losses. Also, the impedance becomes very sensitive to the strip-width-to-slot-width ratio. Thus, small deviations in the transverse dimensions cause significant changes in impedance. This is critical because it means that uncertainties due to the fabrication process may severely influence the electrical behavior.

In view of that situation, the conventional CPW has to be modified in order to achieve a higher impedance level. Kamitsuna [3] fabricated a structure where the center conductor of the CPW is positioned on a multilayer polyimide with a thickness of 10 μm and a relative dielectric constant of 3.3. A 100-Ω transmission line is achieved, but there is a highly nonplanar surface with steep steps on the wafer. Moreover, additional process steps are necessary. Bhattacharya *et al.* [2] used an elevated CPW fabricated with normal air-bridge technology and reached an impedance of 76 Ω, which was specially tailored to a Schottky diode line. Our letter generalizes this idea and presents data useful for practical design of such lines.

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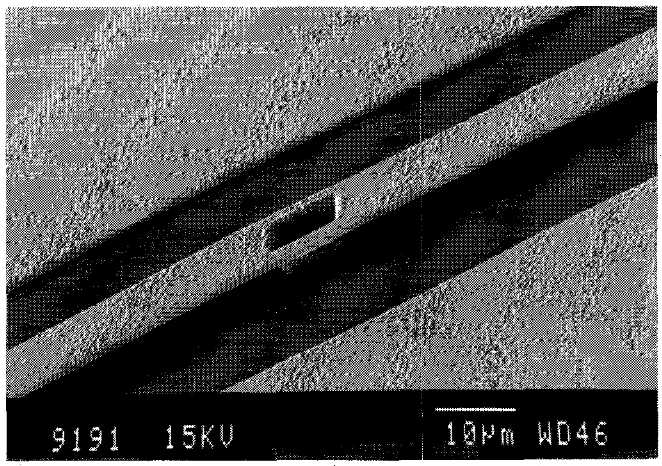

Fig. 1. REM view of the elevated CPW. The air-bridge posts have a ground area of $7 \times 10\,\mu m^2$ and the distance between two posts is about 150 μm.

II. The Modified CPW Structure

The CPW with elevated center conductor was realized as a straight line of 3 mm total length (Fig. 1). The center conductor consists of a sequence of air-bridges. Each section is about 150 μm long and has posts with a ground area of $7 \times 10\,\mu m^2$. The CPW was electroplated using the common MMIC-MESFET process at the Ferdinand-Braun-Institut. The dimensions of the air-bridge CPW are restricted by MMIC process requirements. Here, a CPW with a center conductor width w of 12 μm and a slot width s (projected to the GaAs surface) of 18 μm is used. A conventional CPW with these dimensions would have an impedance of 60 Ω, an attenuation of 0.25 dB/mm, and an effective relative dielectric constant of 6.4 at 20 GHz, calculated by using the method of [4].

First, the effect of elevation of the center conductor was estimated by means of electromagnetic simulation. For this purpose we used "em" of Sonnet Software [5], a commercial simulator for three-dimensional (3-D) electromagnetic analysis as well as an in-house (lossless) finite-difference tool [6]. Furthermore, we introduced a simple modification of the model of [4] that describes the influence of elevating the center conductor by a parallel-plate approximation. This yields a particularly fast method for modeling of this new type of CPW. The posts of the air-bridge CPW are described by an estimated equivalent length extension, thus neglecting their influence on impedance. At 20 GHz, a wave-impedance of 101 Ω, an attenuation of 0.13 dB/mm, and an effective relative dielectric constant of 2.62 are predicted with "em" [5] for the air-bridge CPW. The corresponding values, calculated with the

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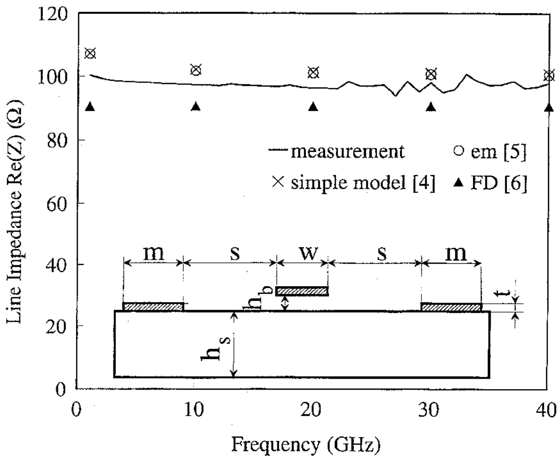

Fig. 2. Real part of CPW impedance with elevated center conductor: comparison between measurements (solid line) and simulation (symbols). The inset shows the cross section of the air-bridge CPW with $w = 12\ \mu$m, $s = 18\ \mu$m, $m = 100\ \mu$m, $h_b = 2.6\ \mu$m, $t = 2.9\ \mu$m, electric conductivity of the gold metal $\kappa = 30$ S/μm, and the GaAs substrate parameters $h_s = 500\,\mu$m, $\varepsilon_r = 12.9$, $\tan\delta = 3 \cdot 10^{-4}$.

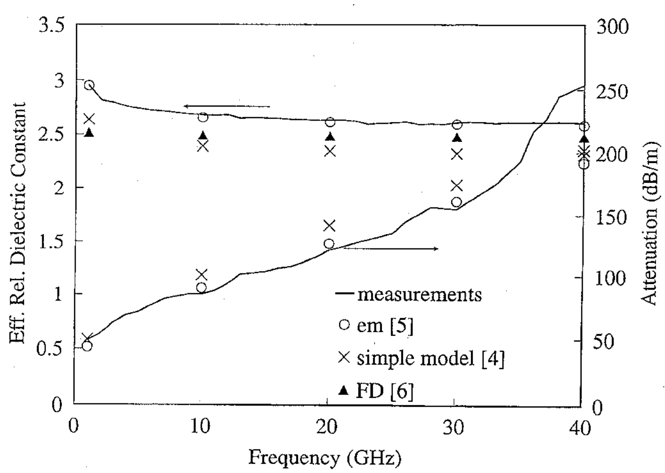

Fig. 3. Attenuation and effective relative dielectric constant of the CPW with elevated center conductor: comparison between measurements (solid lines) and simulation (symbols—for line geometry; see Fig. 2).

modified CPW model [4], are 99 Ω, 0.13 dB/mm, and 1.94. The dimensions of the air-bridge CPW are listed in the caption of Fig. 2; for the corresponding results, see Figs. 2 and 3.

III. Results

The line parameters of the realized CPW with elevated center conductor were extracted from measured S-parameters using the method described in [7]. At the ends of the lines, small capacitances were used in the deembedding procedure in order to account for the discontinuities at the ends. The measured parameters of the air-bridge CPW are shown in Figs. 2 and 3, together with the simulation results.

The CPW with elevated center conductor reaches an impedance of 97 Ω. A conventional CPW with the same ground-to-ground spacing (48 μm) and the same wave impedance (97 Ω) as the air-bridge CPW would have an only 1.5-μm-wide center conductor, which yields a (calculated) attenuation of 0.5 dB/mm at 20 GHz, compared with 0.1

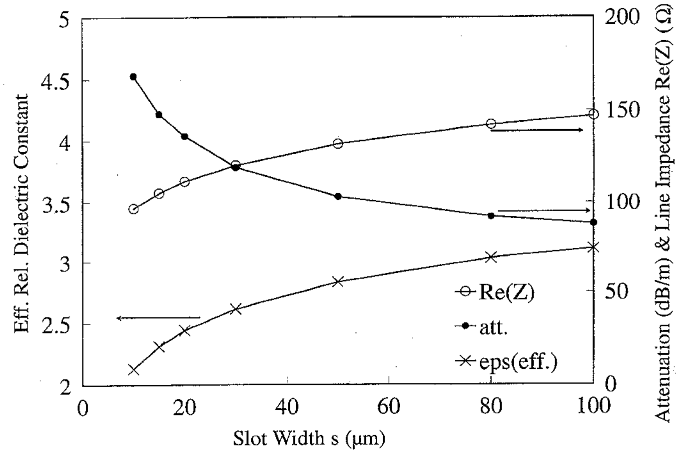

Fig. 4. Line parameters of the air-bridge CPW as a function of slot width s at 20 GHz with $w = 10\,\mu$m, $h_b = 2.5\,\mu$m, $t = 2.5\,\mu$m on a thick GaAs substrate. The values are calculated by [5]. For the structure see Fig. 2., the ground planes are chosen wide enough to assume m as infinite $[m > (w + 2 \cdot s)]$.

dB/mm measured for the air-bridge CPW. The relatively small attenuation is a great advantage of the CPW with an elevated center conductor, even if one takes into account that the reduced effective dielectric constant of the air-bridge CPW extends the line length by a factor of about 1.6.

As can be seen from Figs. 2 and 3, reasonable agreement between theory and measurement is found. Regarding $\varepsilon_{r,eff}$, the deviations of the field-oriented methods ("em" [5] and FD [6]) are small and within the uncertainty introduced by the approximative description of the post sections. The modified equivalent-circuit approach based on [4] does not reach the accuracy of the field-oriented methods but, due to its effectiveness, is still a valuable tool for practical design. For the attenuation α, "em" [5] and the equivalent-circuit model [4] yield close agreement. The deviation in characteristic impedance is about 5% for all approaches used.

With the air-bridge CPW, impedances even higher than 100 Ω can be achieved. If the slot width is increased to 20 or 30 μm, calculations predict an impedance of 110–120 Ω, for a 10-μm-wide center conductor (Fig. 4). The attenuation is reduced to 0.14–0.12 dB/mm compared with 0.25 dB/mm at 20 GHz for the 70-Ω conventional CPW.

In order to estimate the sensitivity of the line parameters of the air-bridge CPW due to process variations, we increased air-bridge height and metal thickness to 3 μm (other parameters as in Fig. 2). This leads to an increase of about 3% in wave-impedance. Dielectric constant is reduced by 10% and attenuation by less than 2%. An edge shift of the metallic layer by $+1\ \mu$m (worst case) reduces the nominal wave-impedance by 10 Ω and increases attenuation by 10%. The dielectric constant remains unchanged.

IV. Conclusion

The proposed structure of an air-bridge CPW can be realized in a conventional MESFET-MMIC process. It provides higher wave-impedances and lower attenuation compared with conventional CPW. Although 150-μm-long bridge sections are used, neither problems with mechanical stability nor reduced yield were observed. In MMIC design one needs CAD tools describing the air-bridge CPW effectively. As was shown, field-level electromagnetic simulation methods yield good accuracy. The computational costs, of course, are relatively high. Therefore, a simplified approach as developed here from [4] appears to be more appropriate for practical circuit design even if accuracy degrades slightly.

REFERENCES

[1] T. Hirota, A. Minakawa, and M. Muraguchi, "Reduced-size branch-line and rat-race hybrids for uniplanar MMIC's," *IEEE Trans. Microwave Theory Tech.*, vol. 38, pp. 270–275, Mar. 1990.

[2] U. Bhattacharya, S. T. Allen, and M. J. W. Rodwell, "DC-725 GHz sampling circuits and subpicosecond nonlinear transmission lines using elevated coplanar waveguide," *IEEE Microwave Guided Wave Lett.*, vol. 5, no. 2, pp. 50–52, Feb. 1995.

[3] H. Kamitsuna, "A very small, low-loss MMIC rat-race hybrid using elevated coplanar waveguides," *IEEE Microwave Guided Wave Lett.*, vol. 2, no. 8, pp. 337–339, Aug. 1992.

[4] W. Heinrich, "Quasi-TEM description of MMIC coplanar lines including conductor-loss effects," *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 45–52, Jan. 1993.

[5] *Sonnet Software User's Manual, version 2.4,* Sept. 1993.

[6] K. Beilenhoff, W. Heinrich, and H. L. Hartnagel, "Improved finite-difference formulation in frequency domain for three-dimensional scattering problems," *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 540–546, Mar. 1992.

[7] P. Heymann, H. Prinzler, and F. Schnieder, "De-embedding of MMIC transmission line measurements," in *IEEE MTT-S Int. Microwave Symp. Dig.*, San Diego, CA, 1994, pp. 1045–1048.