A Very Small, Low-Loss MMIC Rat-Race Hybrid Using Elevated Coplanar Waveguides

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Abstract—**A very small, low-loss MMIC rat-race hybrid using elevated coplanar waveguides is proposed. A 15-GHz-band rat-race hybrid is designed and fabricated in a 0.50 mm × 0.55 mm chip area. The proposed hybrid requires less than half the area used when constructing miniaturized MMIC hybrids from TFMS lines. Furthermore, coupling loss of the proposed hybrid is reduced by approximately 2 dB in comparison to that of previously reported ones.**

I. Introduction

Hybrid couplers are often used as 90°- and 180°-power dividers or combiners in microwave circuits. However, these need $1/4\lambda$ or longer transmission lines and consume MMIC chip area. Therefore, their size must be reduced in order to adapt to MMIC's. One solution is to use thin film microstrip (TFMS) lines on a GaAs substrate [1]–[4]. This reduces the size of the hybrid by about 1/10 in comparison to those constructed from microstrip lines using a GaAs substrate. However, these hybrids exhibit a relatively large insertion loss due to the narrow conductor width of the TFMS lines. Another solution is to use a combination of short high-impedance transmission lines and shunt lumped capacitors [5]. This is very useful in reducing the transmission line length needed. In the rat-race hybrid, size was reduced by 80%. This hybrid is constructed using three $1/8\lambda$ 100 Ω coplanar waveguides (CPW's) and MIM capacitors. The 100 Ω CPW needs a wide gap between the ground planes so it still consumes MMIC chip area. TFMS lines could also be applied in this procedure. However, further increases in insertion loss are caused by reducing conductor width in order to achieve such high-impedance transmission lines.

In this letter, very small, low-loss MMIC rat-race hybrids using elevated coplanar waveguides [6] are proposed to overcome these problems.

II. Characteristics of Elevated Coplanar Waveguides

The characteristic impedances of CPW's are determined mainly by W/G ratio (W is the center conductor width, G is the gap width). Therefore, to increase the CPW characteristic impedance, G must be expanded and W reduced. Obviously, this results in a wide circuit and increases insertion loss. The elevated CPW can overcome these problems. The calculated characteristic impedance vs. the line width $L (L = W + 2G)$ of elevated CPW's is shown in Fig. 1. The conventional "planar" CPW ($H = 0$) is also shown in this figure. In this calculation, the conductor width W was set to 9 μm and the relative dielectric constant of the dielectric layer was 3.3. For example, a 100 Ω characteristic impedance is obtained at a line width L of 40 μm, at an $H = 10$ μm, while a very large L over 120 μm is required for conventional "planar" CPW's ($H = 0$). Therefore, the size of high-impedance CPW's is reduced using elevated CPW's without reducing the conductor width W.

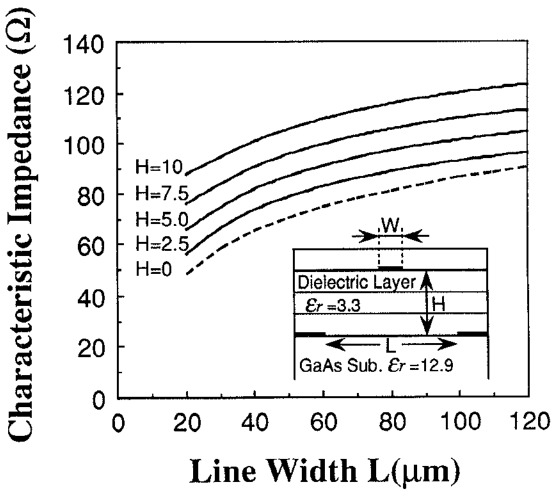

Fig. 1. Calculated characteristic impedances vs. line width L of elevated CPW's with a different dielectric film thickness H. That of the conventional "planar" CPW's ($H = 0$) is also shown in this figure. In this calculation, the conductor width W was set to 9 μm.

It is very interesting to compare these elevated CPW's with TFMS lines. Using TFMS lines, 100 Ω transmission lines are achieved at the smaller width of $W = 5$ μm and an $H = 10$ μm. Therefore, the elevated CPW is expected to reduce the insertion loss of high-impedance transmission lines in multilayer MMIC's. These transmission lines are fabricated using multilayer polyimide layers on a GaAs substrate. The measured S_{21} of the 100 Ω elevated CPW ($W = 9$ μm, $H = 10$ μm, $G = 40$ μm) is shown in Fig. 2. That of the 100-Ω TFMS line ($W = 5$ μm, $H = 10$ μm) is also shown in this figure. The length of both transmission lines is 0.8 mm with 0.25 mm-50 Ω input/output CPW's on both sides for on-wafer measurement. Using the elevated CPW, insertion loss is reduced approximately 0.2 dB. This offset is increased when compared with the guided wavelength, because the effective dielectric constant of the 100 Ω elevated CPW (2.9) is larger

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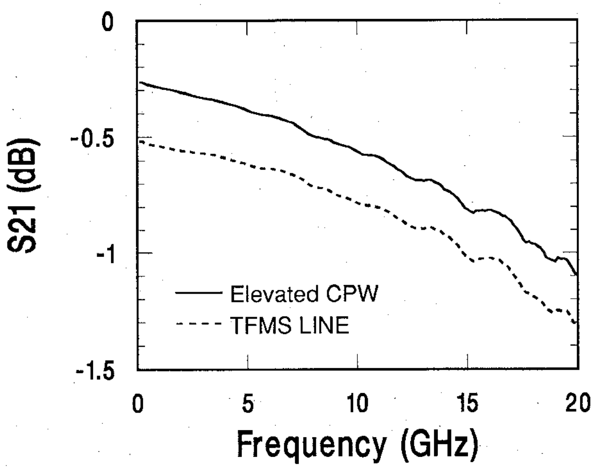


Fig. 2. Measured S_{21} of the elevated CPW ($W = 9$ μm, $H = 10$ μm, $L = 40$ μm) and the TFMS line ($W = 5$ μm, $H = 10$ μm). The line length and the characteristic impedance of both transmission lines are 0.8 mm and 100 Ω, respectively. These have 0.25 mm-50 Ω-input/output CPW's on both sides.

than that of the TFMS line (2.4). This is due to the effect of an electromagnetic field passing through the GaAs substrate ($\epsilon_r = 12.9$). Therefore, elevated CPW's are very capable of reducing both the chip area and insertion loss of MMIC's using high-impedance transmission lines.

III. 15-GHz-Band Rat-Race Hybrids

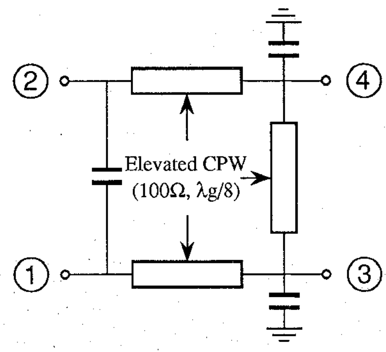
15-GHz-band rat-race hybrids were designed using the previously mentioned elevated CPW's and MIM capacitors. The circuit diagram and photomicrograph of the rat-race hybrid are shown in Fig. 3. This hybrid consists of three 1/8λ 100 Ω elevated CPW's, two shunt and one series lumped capacitors instead of three 1/4λ and a 3/4λ 70 Ω transmission lines. The port interchange (① and ②) was made at the series MIM capacitor [5]. These 1/8λ 100 Ω elevated CPW's were connected at their intersection through via holes to the shunt MIM capacitors existing just under the via pads. Therefore, they are closely connected.

Measured performance is shown in Fig. 4. This rat-race hybrid exhibited a coupling loss ($|S_{21}|$, $|S_{41}|$) of 4.2 dB ± 0.8 dB, return loss ($|S_{11}|$) better than 17 dB and isolation ($|S_{31}|$) better than 18 dB in the frequency range 13–17 GHz.

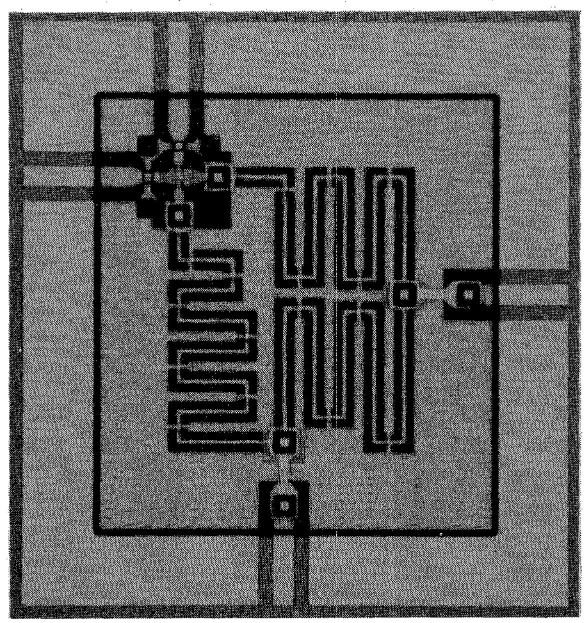
The intrinsic chip size of this hybrid is 0.50 mm × 0.55 mm. The circuit area was reduced to less than half that required for previously reported hybrids constructed using TFMS lines [4]. Furthermore, performance was significantly better than these previously reported (coupling loss of 6 dB ± 1 dB [4]).

IV. Conclusion

A very small, low-loss MMIC rat-race hybrid using high-impedance elevated CPW's is proposed. Elevated CPW's are very effective in reducing both the size and insertion loss of high-impedance transmission lines. Adapting this elevated CPW, excellent low-loss 15-GHz-band rat-race hybrids were achieved, reduced in size less than 0.3 mm^2. Elevated CPW's are expected to achieve other functional circuits using the same procedure combining with lumped capacitors and multi-stage wide-band microwave circuits in MMIC's using high-impedance transmission lines.



(a)



(b)

Fig. 3. Circuit diagram and photomicrograph of a 15-GHz-band rat-race hybrid. (a) Circuit diagram. (b) Photomicrograph.

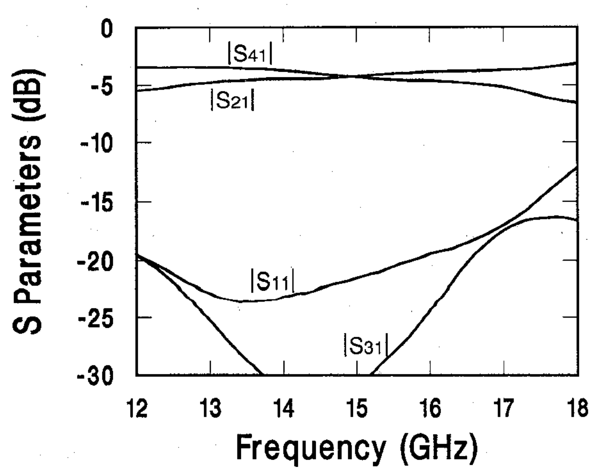


Fig. 4. Measured performance of the 15-GHz-band rat-race hybrid.

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