Graphical Design of Air-Gap Stacked Marchand Balun

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Abstract — **A new Marchand balun for MMIC is proposed which uses air-gap stacked structures and does not need any dielectric process. To design the newly proposed Marchand balun, simple graphical design method was used, which is based on Tsai and Gupta's generalized coupled lines model. The simple design results were compared with a general full-wave analysis. In this case, HP-Momentum simulator was used.**

I. Introduction

Balun is a widely used component in many microwave circuits, such as balanced mixers, amplifiers, multipliers, etc. However, wideband MMIC balun was hardly realized because the size is too big to fit into the MMIC chips. Pavio [1] implemented a Marchand balun [2] in a multilayer dielectric form for the MMIC chip. Although the results were good, it required very thick dielectric layer (20 μm) to achieve the tight coupling. Chen, *et al.* [3] used the same approach in a wideband mixer. The thickness of the dielectric layer was still 3 μm thick, which cannot be realized commercially available MMIC foundry process [4]. Unfortunately, the multi-layer monolithic version of this balun has suffered from loss on the order of 2 dB [2]-[3]. This is due to the very narrow metal lines which must be used. These narrow metal lines are required because the silicon nitride (SiN), which was used as the inter-metal dielectric, is restricted to values less than 3 μm.

In this paper, we proposed a new Marchand balun for MMIC using air-gap stacked structures. Because the proposed balun uses air-gap ($\varepsilon r = 1$) instead of silicon nitride ($\varepsilon r = 7$), the metal lines can be wider, which leads to smaller loss than the SiN based balun. This paper describes generalized network model for air-gap stacked microstrip coupled lines, graphical design of air-gap stacked Marchand balun and the comparison between simple model and full-wave analysis.

II. Generalized Network Model

Although balun is widely used in microwave circuits, very little information for design method of Marchand balun exists. These days, this balun is typically designed based on a general full-wave analysis program. Considering the computing time required by a general full-wave analysis, this approach can be quite inefficient given a poor initial design. In this section, we propose a graphical design method based on Tsai's network model and low frequency field-simulation data.

The graphical design procedure consists of three steps. First, we extracted capacitance and inductance matrix per unit length for the simulated coupled line with various size at low frequency using commercial field simulator. In this case, HP-Momentum was used [5]. Secondly, we made a coupler model using the Tsai's network model for general coupled lines and the work of Tripathi for each parameters [6]-[7]. Thirdly, the coupled line section, which is composed of the Tsai's network model, was optimized for Marchand balun operation.

Fig. 1 shows the schematic of air-gap stacked microstrip coupled-lines to define the physical parameters, which was proposed by the authors [8]-[9]. The design parameters of the AGSM coupled-lines are the widths of lower and upper conductors (W_1 and W_2, respectively) and the overlap width between the two conductors, because the gap between the two conductors is determined by the thickness of photoresist in the standard air-bridge metal process, in which the gap is 2.5 μm and GaAs substrate thickness is 75 μm.

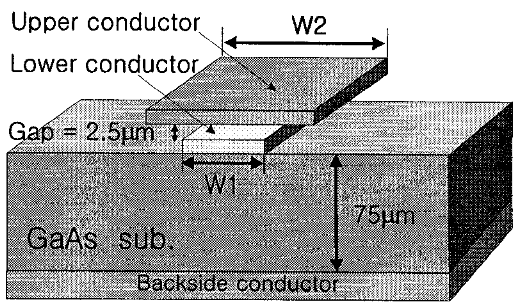

Figure 1. Schematic of the air-gap stacked microstrip lines

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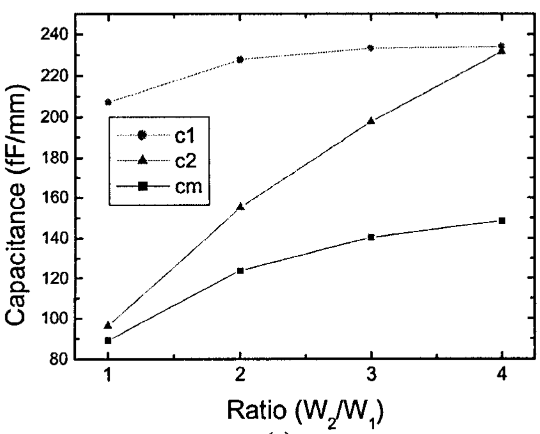
The AGSM coupled-lines capacitance and inductance matrixes are extracted using HP-Momentum simulation at 1 GHz. Fig. 2 is the capacitance and inductance parameters for various dimension of upper metal width, where the lower metal width is fixed to 20 μm.

As we can see in Fig. 2(a), the C_1(self-capacitance of lower conductor) and C_m(mutual-capacitance of the two conductors) increase slowly but C_2(self-capacitance of upper conductor) increases rapidly when W_2 increase with constant W_1. The C_2 is smaller than C_1 because the electric field from the upper conductor to ground is screened by the lower conductor. The L_2 and Lm decrease rapidly but L1 decrease slowly when the W_2 increase as shown in Fig. 2(b).

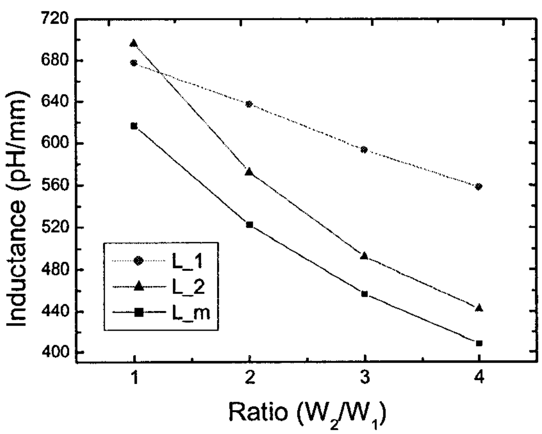
While the C_m is proportional to the overlap dimension between upper and lower conductors, the L_m is proportional to the product of L_1 and L_2. Therefore the C_m is almost constant and the L_m is linearly increase when the W_2 increase. From these L and C-parameters, the equivalent Z-matrix model of AGSM coupled-lines based on Tripathi's quasi-TEM analysis was constructed.

III. GRAPHICAL DESIGN OF AIR-GAP STACKED MARCHAND BALUN

Prior to design of balun, 3-dB coupler was designed as a simple example. To design 3-dB coupler using equivalent Z-matrix model, the Z-parameters were transformed to S-parameters.

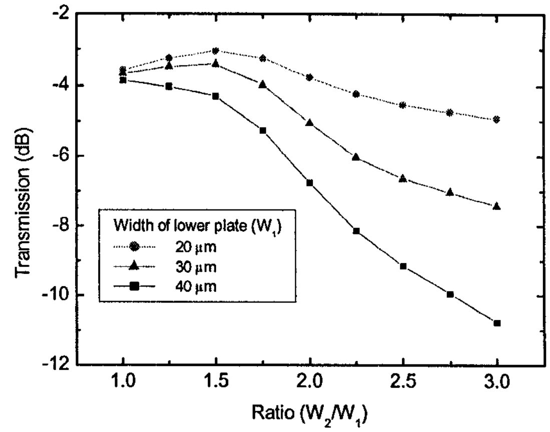


(a)

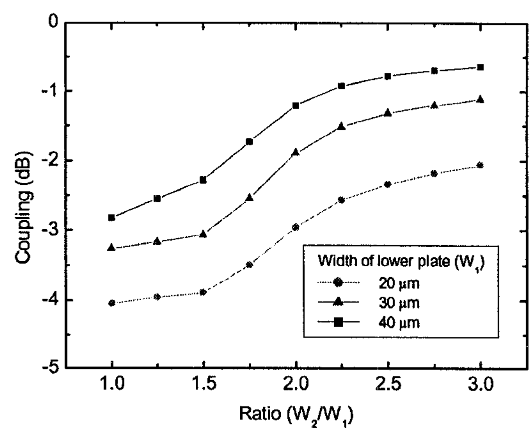


(b)

Figure 2. Extracted capacitance (a) and inductance (b) characteristics of AGSM coupled –lines with



(a)



(b)

Figure 3. S-parameters of AGSM coupler with length of 0.85 mm at 27 GHz. (a) transmission and (b) coupling

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Fig. 3 shows the S-parameters for various dimension of AGSM coupled-lines. From the transmission (a) and coupling (b) characteristics, the width (W_1) of 20 μm and ratio (W_2/W_1) of 1.75 are optimum dimension in the condition that coupling of better than –3.5 dB and transmission of better than –3.5 dB. The matching and isolation are better than –15 dB in the optimum dimension.

The optimum dimension AGSM 3-dB coupler, which has the length of 850 μm, W_1 = 20 μm and W_2 = 35 μm, was simulated as a function of frequency in the range of 1 ~ 40 GHz as shown in Fig. 4. The equivalent Z-matrix model and the HP-Momentum simulation result have almost the same characteristics in transmission and coupling. From this results, the graphical method can be used as a useful pre-simulator.

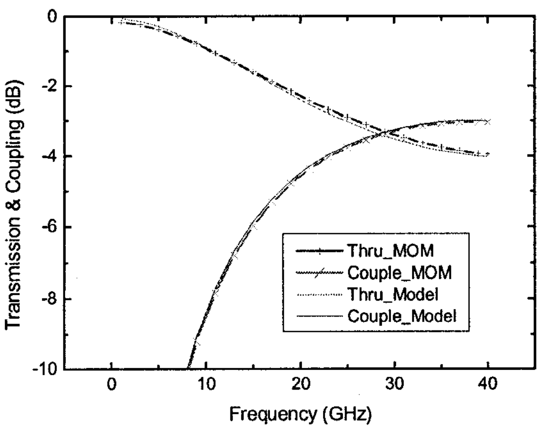
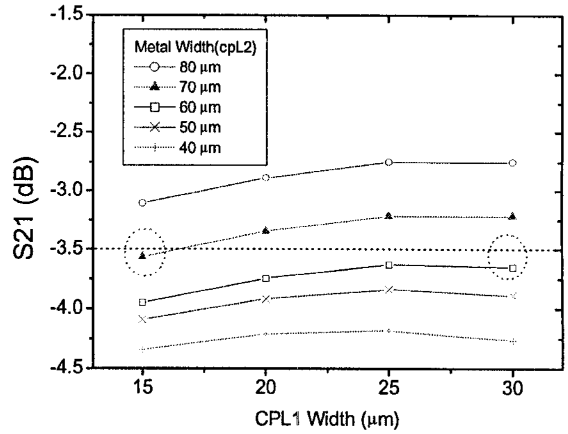
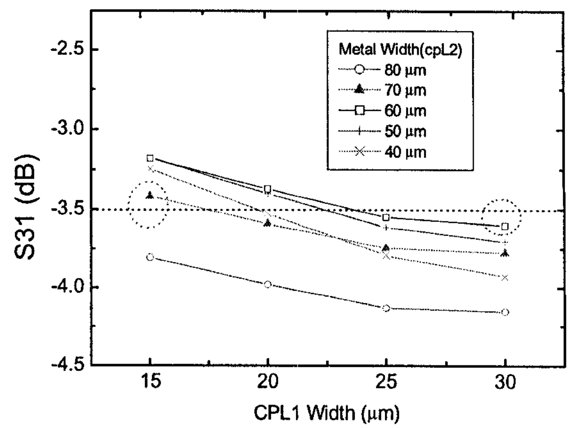


Figure 4. Comparison of S-parameters between Z-matrix model and HP-Momentum simulation data of the AGSM 3-dB coupler

The wideband Marchand balun centered at 27 GHz was design using two couplers based on equivalent Z-matrix model. Fig. 5 shows the S-parameters of Marchand balun for various dimension at 27 GHz, where the lower metal widths are fixed as W_1(cpl-1) = 15 μm and W_1(cpl-2) = 40 μm and the lengths are fixed to their quarter wavelengths at 27 GHz. From the S21 (a) and S31 (b) characteristics, the type-1(left-side), which has W_2(cpl-1) = 15 μm and W_2(cpl-2) = 70 μm, and the type-2(right-side), which has W_2(cpl-1) = 30 μm and W_2(cpl-2) = 60 μm, are satisfying the condition that S21 and S31 better than -3.5 dB. However, the type-1 has better performance considering the matching characteristics. With the initial condition of type-1, the Marchand balun dimension is optimized as W_1/W_2(cpl-1) = 13/17 μm and W_1/W_2(cpl-2) = 40/60 μm, where the lengths are fixed to their averaged quarter wavelength for c-mode and π–mode.



(a)



(b)

Figure 5. S-parameters of balun for various widths at 27 GHz.

Fig. 6 shows S-parameters of optimized Marchand balun by using Z-matrix model and HP-Momentum simulation. The HP-Momentum simulation shows that the optimized Marchand balun has only less than 1 dB loss in a wide frequency range of 27 ~ 40 GHz.

The designed Marchand balun was fabricated using GaAs P-HEMT MMIC technology of our group [10]. Fig. 7 shows the microphotograph of the fabricated AGS Marchand balun. For 2-ports measurement, the other port of balanced signal was terminated by on-chip 50-Ω resistor.

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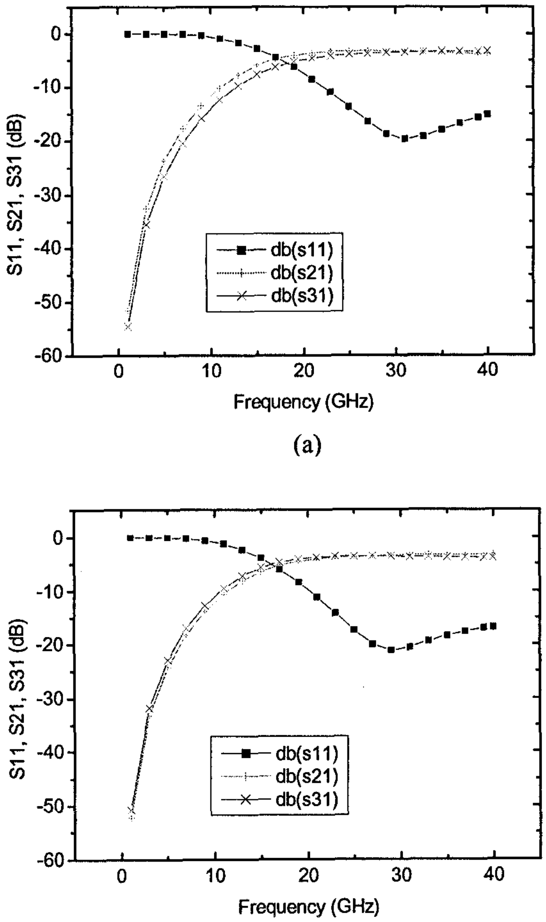
The AGS Marchand balun was tested by using Cascade Microtech on-wafer probing station and HP8510C Network Analyzer.



(b)

Figure 6. S-parameters of optimized Marchand balun. (a) using Z-matrix model and (b) using HP-Momentum simulation

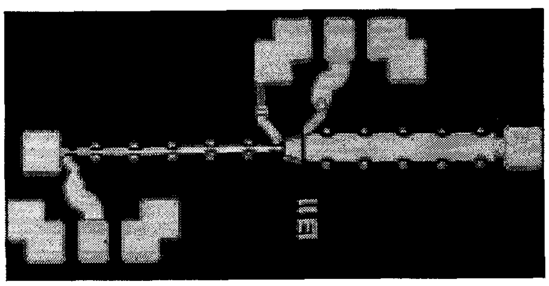


Figure 7. Microphotograph of the AGS Marchand balun

The measured S21 and S31 at 22 GHz are −2.5 dB and −4.0 dB, respectively. The S21 and S31 are unbalanced which may be due to over-coupling. The unconsidered real structure, such as air-bridge posts, have some effect on the balun performance. Therefore, prediction of this complex structure needs complicated analysis which feedback the experimental results.

IV. CONCLUSION

An air-gap stacked Marchand balun for MMIC is proposed and does not need any dielectric process. To design the proposed Marchand balun, simple graphical design method was used, which is based on Tsai and Gupta's generalized coupled lines model. The simple design results are matched well with HP-Momentum simulation. The fabricated Marchand balun have some unbalancing problems. However, the simple graphical design method can be used as a useful pre-simulation.

REFERENCES

[1] A. M. Pavio and A. Kikel, "A monolithic or hybrid broadband compensated balun," *1990 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 483-486, Jun. 1990.

[2] N. Marchand, "Transmission line conversion transformers," Electronics, vol. 17, no. 12, pp. 142-145, Dec. 1944.

[3] T. H. Chen, K. W. Chang, S. B. Bui, H. Wang, G. S. Dow, L.C. T. Liu, T. S. Lin, and W. S. Titus, "Broadband monolithic passive baluns and monolithic double-balanced mixer," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-39, no. 12, pp. 1980-1986, Dec. 1991.

[4] M. C. Tsai, "A new compact wideband balun," *1993 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 141-143, June 1993.

[5] HP-Momentum Release 2, Hewlett Packard, Inc., Fremont, CA., Jul. 1997.

[6] C. M. Tsai and K. C. Gupta, "A generalized model for coupled lines and its application to planar balun synthesis," *1992 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 873-876, June 1992.

[7] Lutz, Y. Hahm, A. Weisshaar, and V. K. Tripathi, "Modeling and analysis of multilevel spiral inductors for RFICs," *1999 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 43-46, Jun. 1999.

[8] G. H. Ryu, D. H. Kim, J. H. Lee, and K. S. Seo, "A novel 3 dB coupler for MMIC using air-gap stacked microstrip lines," *IEEE Microwave Guided Wave Lett.*, vol. 10, no. 1, pp. 1-3, Jan. 2000.

[9] G. H. Ryu, D. H. Kim, J. H. Lee, and K. S. Seo, "A novel low impedance line for MMIC using air-gap stacked structure," *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, pp. 43-46, Jun. 2000.

[10] S. G. Yang, D. H. Kim, and K. S. Seo, "DC and RF characteristics of 0.25 μm non-recessed gate GaAs P-HEMT fabricated by self-aligned gate process," Electron. Lett., vol. 34, no. 14, pp. 1431-1433, Jul. 1998.