Lumped-Element Compensated High/Low-Pass Balun Design for MMIC Double-Balanced Mixer

Hwann-Kaeo Chiou, Hao-Hsiung Lin, and Chi-Yang Chang

Abstract—**We report a novel lumped-element balun structure for both monolithic and hybrid circuit applications. The proposed structure utilizes two filters to compensate the amplitude and phase errors at the two balance outputs of a traditional out-of-phase power splitter. This circuit requires no multilayer or suspended substrates techniques; therefore, wide applications on many circuits operated especially, in the low microwave band, are expected. Two monolithic microwave integrated circuit (MMIC) mixers were built to demonstrate the electrical feasibility.**

Index Terms— **Compensated high/low-pass balun, lumped-element balun, MMIC double balanced mixer.**

I. Introduction

MICROWAVE baluns are realized in either distributed or lumped circuits. The formers have shown their capability in many hybrid-based circuit designs. However, because of their nonplanar structure and large size, few of them are adopted in the conventional monolithic microwave integrated circuit (MMIC) processes. Conversely, the lumped-circuit baluns, for their compact size, play important roles in MMIC circuits. The lumped circuit baluns are summarized in three main categories—active balun [1], planar-transformer balun [2], and lumped-circuit 180° hybrid balun [3]. In this letter, we propose a novel lumped-element balun based on the compensated filter structure. The proposed circuit uses four lumped circuit filters to synthesize the balun. Two filters are designed as a traditional out-of-phase power splitter. The amplitude and phase errors at the two outputs are equalized by the two other compensating filters. The compensated balun shows good amplitude balance and frequency-independent antiphasal characteristics. It requires no multilayer or suspended substrates techniques and can be easily applied on many circuit designs, especially in low microwave band.

II. Balun Design

Fig. 1 shows the basic structure of a pi–pi type compensated high/low-pass balun. Two filters are connected in parallel to form a three-port high/low-pass out-of-phase power splitter. The filters, like the 180° lumped-element hybrid, model the quarter and three-quarter wavelength transmission lines. The impedance transformation ratio between the unbalanced and balanced ports is simply determined by the characteristic impedances of the filters. In the filter structures with lower order, for instance $N = 3$, the equal amplitude is valid only at the 3-dB cutoff frequency. Increasing the order of filters will improve the bandwidth of the amplitude balance but the phase error will increase. Therefore, baluns with very wide band cannot be achieved using the traditional out-of-phase power splitter. However, this problem can be solved by adding two compensating filters at the outputs of the balun. The output of the high-pass arm is shunted with a low-pass filter while the output of low-pass arm is shunted with a high-pass filter. Because of the electrical duality between the high-pass and low-pass filters, the amplitude and phase balances are simultaneously achieved. There are four possible balun topologies, namely pi–pi, tee–tee, pi–tee, and tee–pi baluns. The pi–pi-type balun exhibits the best amplitude and phase balances. Its balance outputs inherently provide dc return path and the last series inductor or capacitor in compensated filters can be removed in real circuit implementation. Therefore, the pi–pi type balun is suitable for monolithic microwave integrated circuit (MMIC) DBM design.

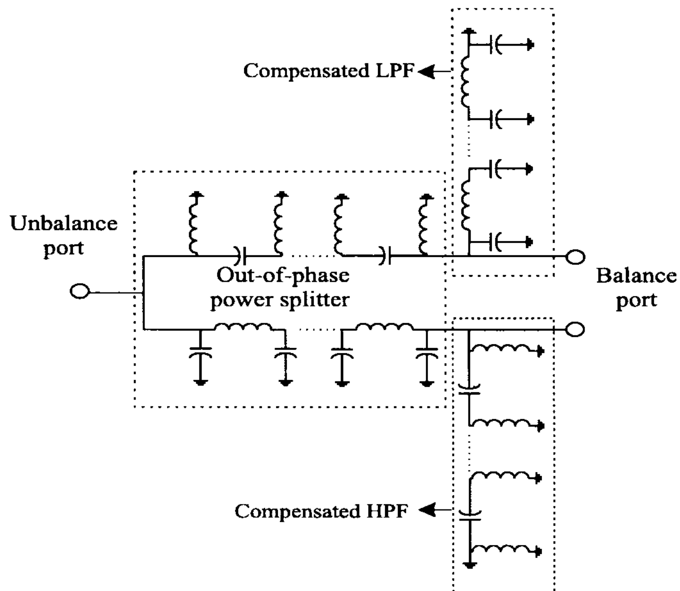


Fig. 1. The schematic diagram of pi–pi type compensated high/low-pass balun.

III. Experiment and Results

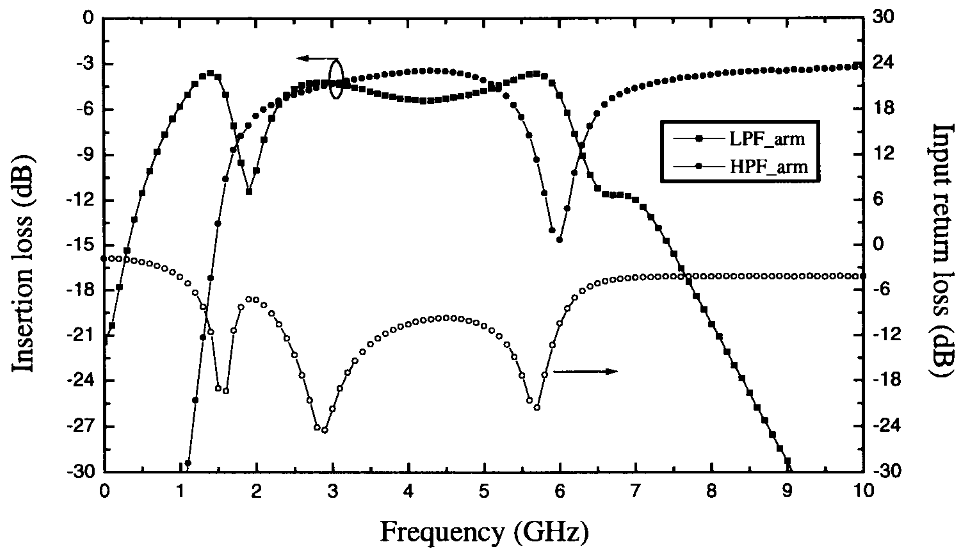
A compensated pi–pi high/low-pass balun is fabricated in MMIC form to prove the design concept. A five-order low-pass filter is equivalent to two 45° transmission lines in cascade. Two cascaded −45° lines are applied in high-pass arm. Comparing the ABCD matrix elements between the transmission line and lumped filter, the values of the

Manuscript received March 6, 1997. This work was supported by the National Science Council of R.O.C. under Contract NSC-85-2622-E-002-009.

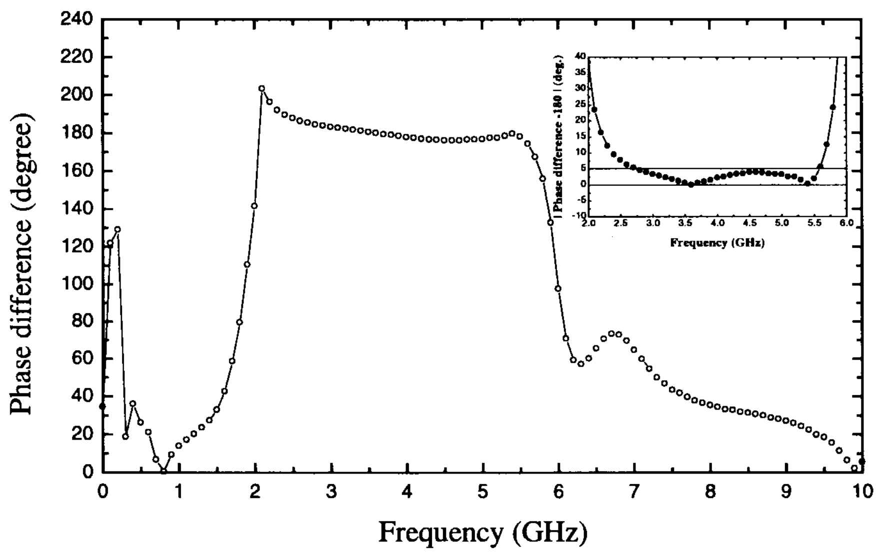
H.-K. Chiou and H.-H. Lin are with the Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan, R.O.C.

C.-Y. Chang is with the Department of Communication Engineering, National Chiao Tung University, Hsinchu 300, Taiwan, R.O.C.

Publisher Item Identifier S 1051-8207(97)05415-9.



(a)



(b)

Fig. 2. The measurements of compensated high/low-pass balun: (a) amplitude balances and (b) phase balances.

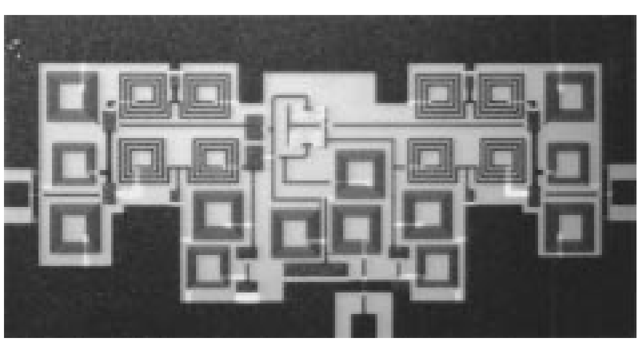
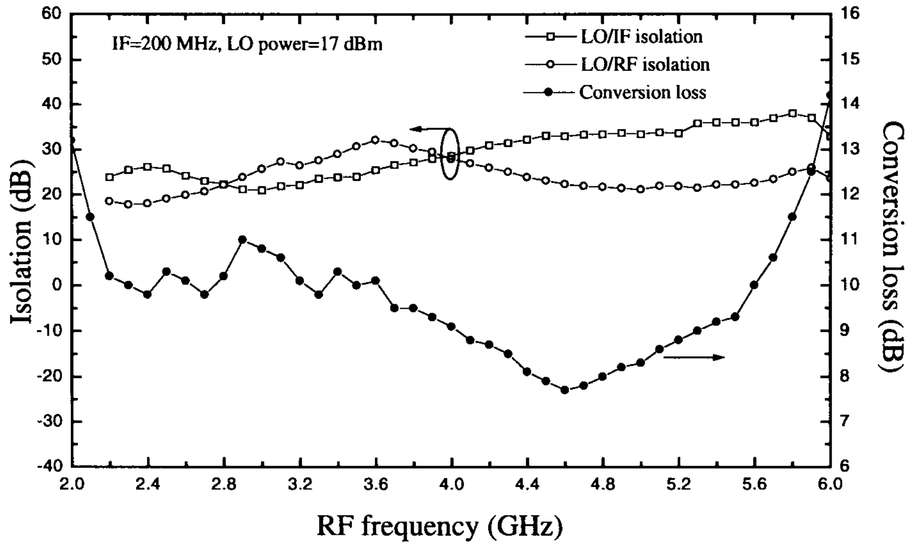


Fig. 3. The photograph of the compensated high/low-pass DBM. The chip dimensions are 1.5×2.7 mm^2.

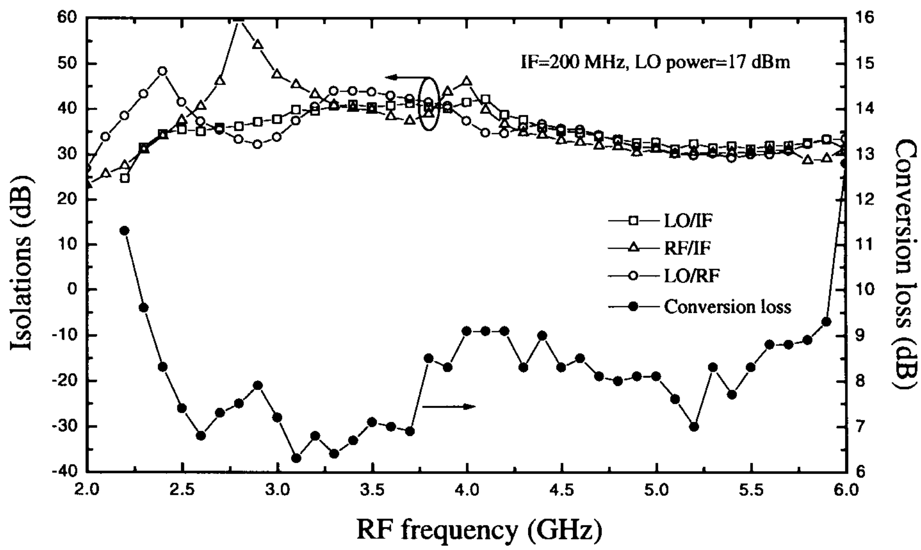
capacitors and inductors of the filters are easily obtained. The 45° transmission line centered at 4-GHz correspondends to a pi-type LPF with one 2-nH inductor and two 0.23-pF capacitors. In the pi-type HPF arm, the value of the inductors are 6.8 nH and that of capacitor is 0.8 pF. Each filter has characteristic impedance of 70.7 Ω, which transforms 50-Ω unbalance impedance into 100-Ω balance impedance. For the parasitics effects, the MMIC spiral inductances are not exactly equal to the designed values. The performances of the balun are slightly degraded. However, the balun still remains the good amplitude and phase balance responses over a 1 : 2.5 bandwidth ratio. Fig. 2(a) shows the amplitude responses of the balun. The insertion loss of both HPF and LPF arms have a -4.4 ± 1.0 dB from 2.25 to 5.7 GHz. The input return loss is better than -10 dB. The out-of-phase property is shown in Fig. 2(b). The absolute phase error is less than 5° across the band.

IV. MMIC DBM Design

Two double balance mixers realized with compensated and uncompensated baluns were designed for comparison. The center frequency of the baluns was chosen at 4 GHz which



(a)



(b)

Fig. 4. The performances of the DBM's: (a) uncompensated DBM and (b) compensated DBM.

covers two unlicensed ISM bands at 2.4 and 5.7 GHz. The photograph of the compensated high/low-pass DBM is shown in Fig. 3. Two MMIC baluns combined with four 1 μm $\times$ 25 μm N-ion implanted field-effect transistor (FET) diodes form a complete double-balance mixer. The IF signal is picked up via a low-pass filter of order three. As shown in Fig. 4(a), the conversion loss of a uncompensated mixer is between 7 and 12 dB from 2 to 5.9 GHz. The isolation is better than 20 dB over the same frequency band. The performances of the compensated mixer is shown in Fig. 4(b). As can be seen, a conversion loss improvement of 1 to 3 dB is achieved. The port to port isolations are better than 25 dB across the band. Comparing to the uncompensated mixer, the conversion loss and isolation are significantly improved. The better LO/RF isolation implies that the phase and amplitude balance of both LO and RF baluns are better as well.

V. Conclusion

A lumped-circuit balun based on compensated high/low-pass filters has been proposed. The prototype circuit shows good amplitude balance and almost frequency-independent antiphasal properties. Two MMIC mixers have been built to demonstrate the electrical performances. Both conversion loss and isolations are improved significantly by using the compensated high/low-pass balun.

References

[1] A. M. Pavio and R. M. Halladay, "A distributed double-balanced dual-gate FET mixer," in *IEEE GaAs IC Symp. Dig.*, 1988, p. 177.
[2] T. H. Chen, K. W. Chang, S. B. Bui, and H. Wang, "Broadband monolithic passive baluns and monolithic double-balanced mixer," *IEEE Trans. Microwave Theory Tech.*, vol. 39, pp. 1980–1986, Dec. 1991.
[3] S. J. Parisi, "180-degree lumped-element hybrid," in *1989 IEEE MTT-S Dig.*, pp. 1243–1246.