

Folded Marchand Balun Design and Validation Using Sonnet

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Abstract: The Marchand balun has larger bandwidth than other types of combiners and has been used extensively since its introduction. The Marchand balun has also been extensively used in planar systems in both broadside-coupled and edged-coupled configurations. This paper describes the design and development of two microstrip, folded, edge-coupled Marchand baluns for use as anti-phase power combiner. The balun form-factor is thus reduced, making the circuit more compact and amenable for use in high-density printed circuit boards.

Keywords: Marchand, Baluns, Microstrip, Power Combiner, 180° Hybrid, T-Junction

1. Introduction

The need for compact printed circuit baluns for testing differential circuits is well documented [1]. Because testing integrated circuits is expensive, cost reduction is an important goal for semiconductor companies [2-3]. These pressures seem particularly acute for RF and wireless device manufacturers since consumers have embraced the idea of higher performance and more functionality at a lower price [4-5]. The project described in this paper involves continuing improvements to a low-cost high-volume load board, which originally used two anti-phase power combiners switched using RF relays [6]. Those balun combiners were targeting a frequency range from 1.7-3.6 GHz. The folded Marchand balun presented here aims to replace those combiners with a single structure and provide improved broadband performance, improved reliability, and simplified calibration. The design is an evolution of the planar Marchand baluns shown by Tsai [7] in 1993 and Sun and Lee [8] in 2001. Marchand's original design was implemented as a coaxial to two-wire wideband conversion transformer [9]; for today's printed circuit boards (PCBs), the baluns need to be planar.

2. Edge-Coupled Planar Marchand Baluns

The typical Marchand balun uses a $\lambda/2$ transmission line as the single-ended port and two $\lambda/4$ coupled sections as the differential port in a configuration similar to that presented in [7]. Fig. 1 shows the microstrip edge-coupled implementations of the planar balun prior to folding. The balun shown in the top portion of Fig. 1 is similar to that presented in [7]. The balun shown at the bottom of the figure is an improved version introduced by [8].

In both cases, the $\lambda/2$ section is left with an open circuit termination; while the two $\lambda/4$ sections are short-circuited. The standing wave will produce a voltage minimum at the center of the $\lambda/2$ section, resulting in a current maximum. Since the two $\lambda/4$ sections are placed on opposite sides of the voltage

minimum, the voltage coupled will be of equal amplitude but opposite phase. The improved balun uses symmetrical $\lambda/4$ sections and air-bridges to increase the edge coupling between the transmission line segments and thus improve the frequency range of the amplitude and phase balance.

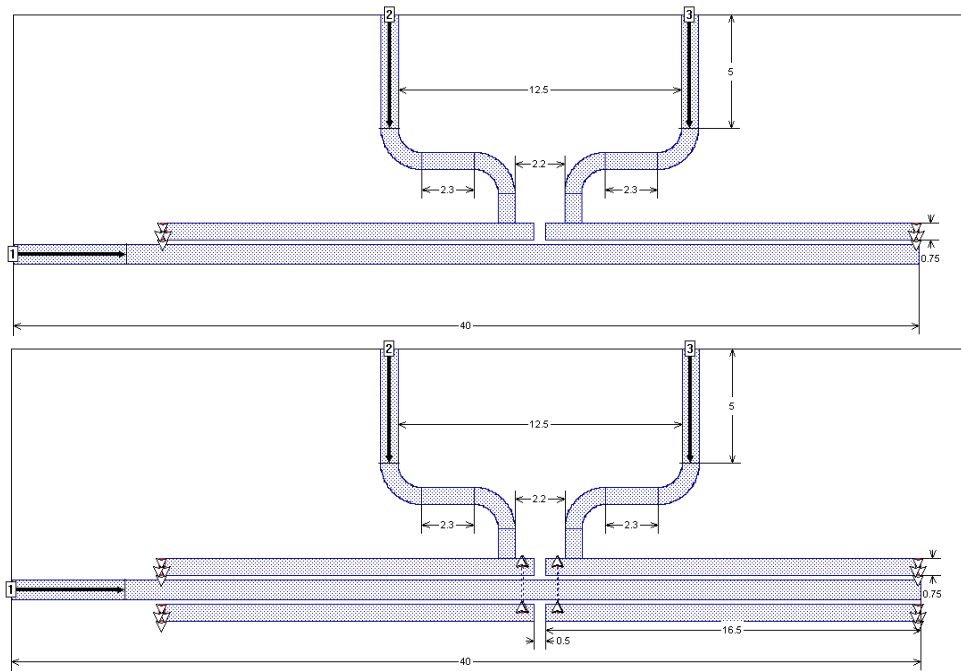


Fig. 1. Typical planar edge-coupled Marchand balun using microstrip lines (top) and an improved version using air bridges, similar to [8], (bottom).

The baluns were designed for a center frequency of 2.4 GHz in order to accommodate the desired frequency range of 1.7-3.6 GHz. Using FR-4 with an ϵ_r of approximately 4.4 and a dielectric thickness of 60 mils, λ_g was calculated to be approximately 69 mm. The line geometries were chosen to be the same as in [8] for comparison purposes, thus the $\lambda/2$ transmission line is 0.75 mm wide, the $\lambda/2$ sections are 0.85 mm wide, and the gap between is 0.2 mm. The metal used is 1-oz. copper. As these designs will be prototyped and tested at a later date, the simulated geometries include provisions for SMA edge connectors with a 5 mm long center pin.

Fig. 2. shows a comparison of the amplitude balance of the baluns, measured as the difference between S_{21} and S_{31} , noting that it is essentially identical up to about 2.6 GHz. Above 2.6 GHz, the symmetrical balun's crossover design compensates for amplitude mismatches to within 1 dB well beyond 4 GHz. Both baluns, however, have less than 3 dB amplitude imbalance to 4 GHz. Both baluns have excellent phase balance, measured as the absolute phase difference between S_{21} and S_{31} , of within 5° of the ideal 180° up to 4 GHz. Fig. 3. shows the insertion loss performance of the baluns. Both baluns are close to the 3 dB power split for some range of frequencies. Note, however, that the air bridge balun shows better balance performance, especially in the 1-2.5 GHz range.

The balun can be analyzed as a three port power divider/combiner. It is well known that a three port network cannot be lossless, reciprocal, and matched at all ports at the same time [10]. For these balun design, the engineering compromise was to sacrifice the input match at ports 2 and 3, while striving to achieve reciprocity, low insertion losses, and maintain good amplitude and phase balance between the input and output ports.

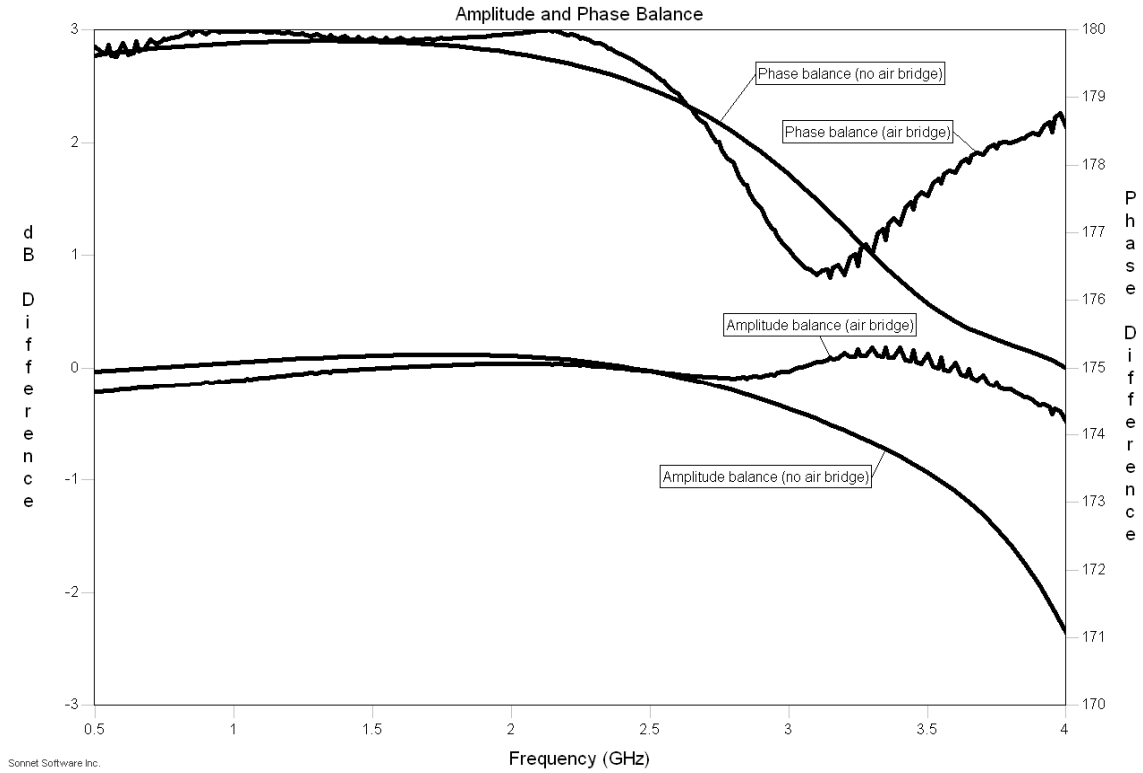


Fig. 2. Amplitude and phase balance comparison of the planar Marchand baluns.

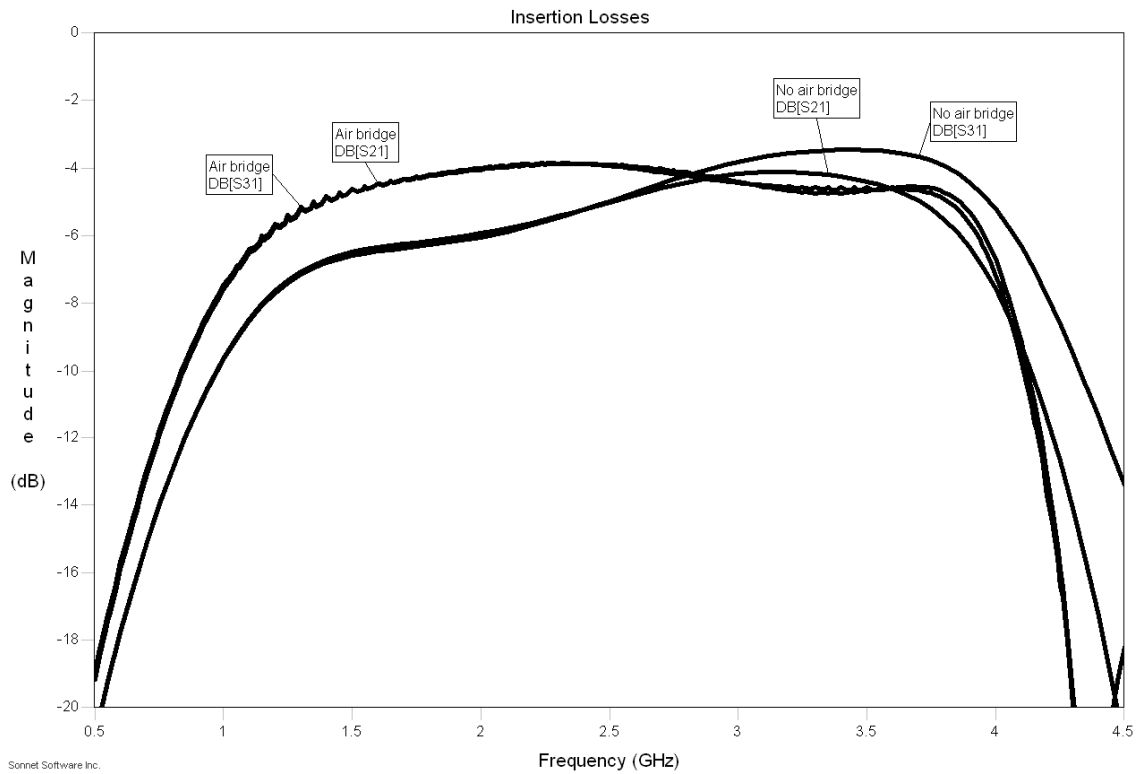


Fig. 3. Insertion loss comparison of the planar Marchand baluns.

3. Folded and Meandered Planar Marchand Baluns

Although the balun configurations shown in Section 2 perform well, they are still relatively physically long. Consequently, they may not be suitable for use in densely occupied circuit boards, such as automated test equipment load boards [11]. These applications require more compact form factors, thus the idea of folding a planar Marchand balun was formed.

The development began with the air bridge balun because it showed somewhat better performance. This balun has a form factor of 12 mm by 40 mm. Several folded geometries were designed and simulated. However, it was found that, in order to maintain complete symmetry, the number of turns or bends in one direction had to be the same as in the opposite direction; i.e., a square or round balun could not be developed if the endpoints of the $\lambda/4$ sections were to line up properly with the inner $\lambda/2$ microstrip line. The final two realizations fold and meander the transmission lines into a nearly square geometry and into a mirrored triple S configuration, as shown in Fig. 4. Both new baluns fit within a board area of 20 mm by 20 mm, which may be more amenable for congested PCB designs.

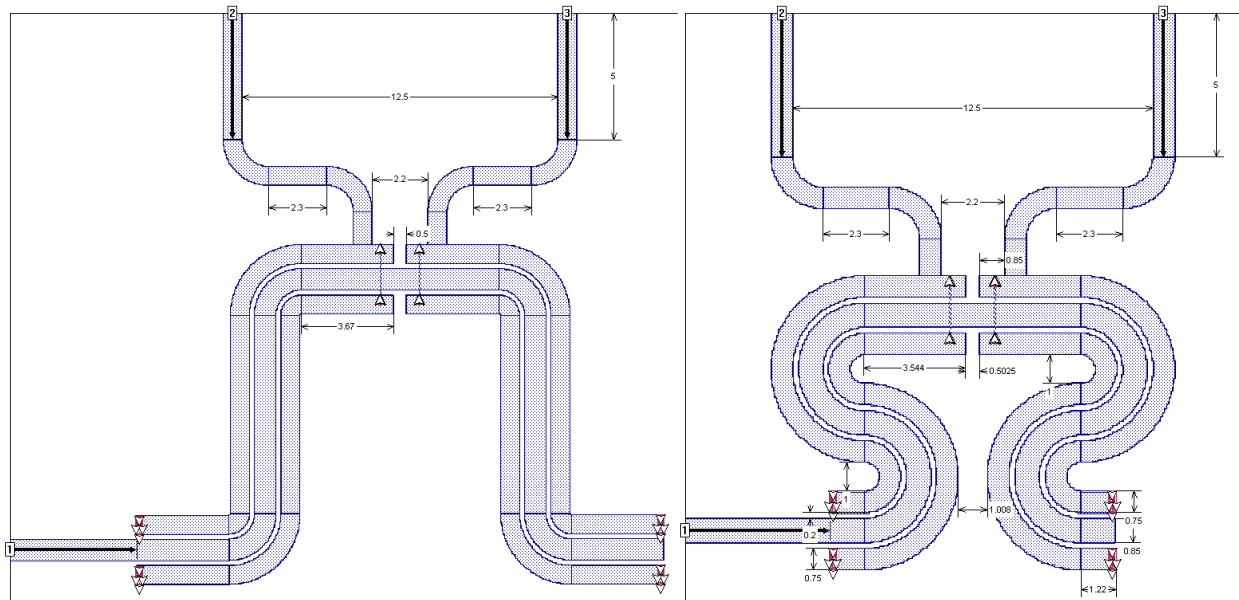


Fig. 4. Folded square (left) and meandered (right) planar Marchand baluns.

4. Simulation Results

The baluns shown in Fig. 4 were configured as three port structures in Sonnet™. The results of the simulations from 0.5 – 4.5 GHz are shown in Figs. 5 and 6. The folded square balun shows excellent amplitude and phase balance up to 3.7 GHz, however, it also shows high insertion losses (greater than 6 dB) above 3.3 GHz. The folded meandered balun shows more variation in the amplitude and phase balance. The amplitude balance, however, is within 2 dB from 1 – 4.3 GHz. The phase balance is within 11° up to 4.3 GHz. The overall frequency response of the meandered balun shows more differences in S_{21} and S_{31} than the folded square balun. These differences are probably the result of mutual coupling between the transmission lines as they were meandered.

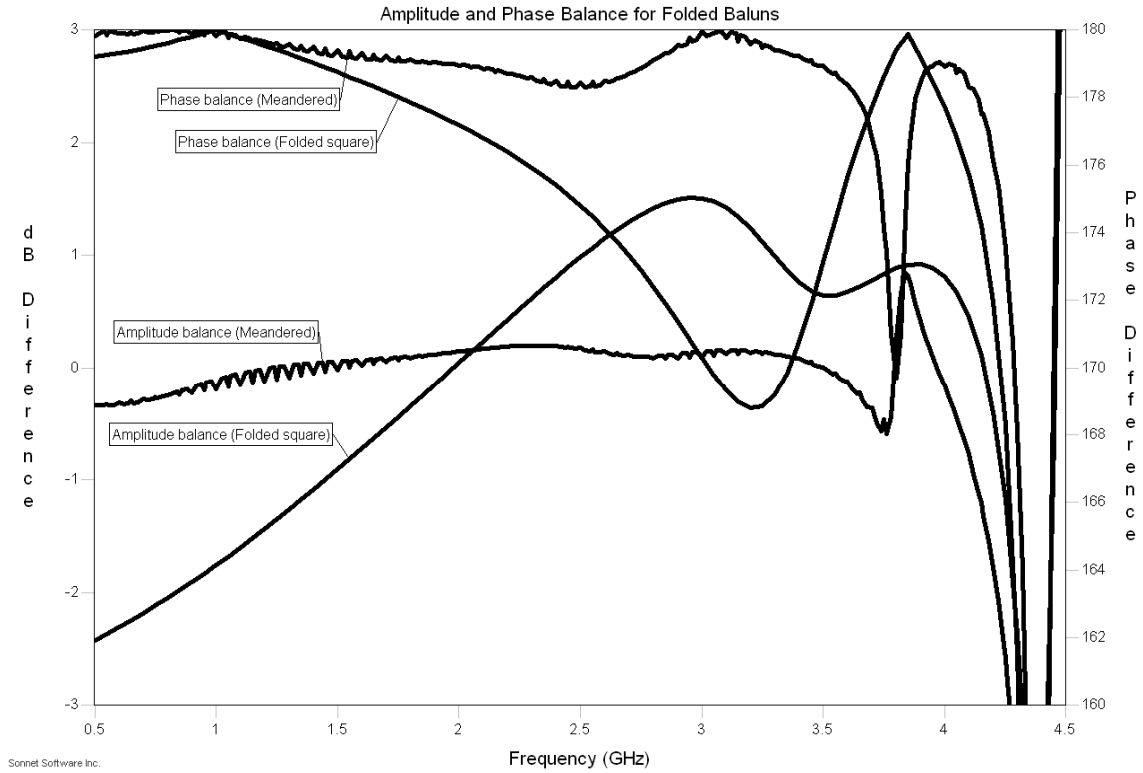


Fig. 5. Amplitude and phase balance of the folded planar Marchand baluns.

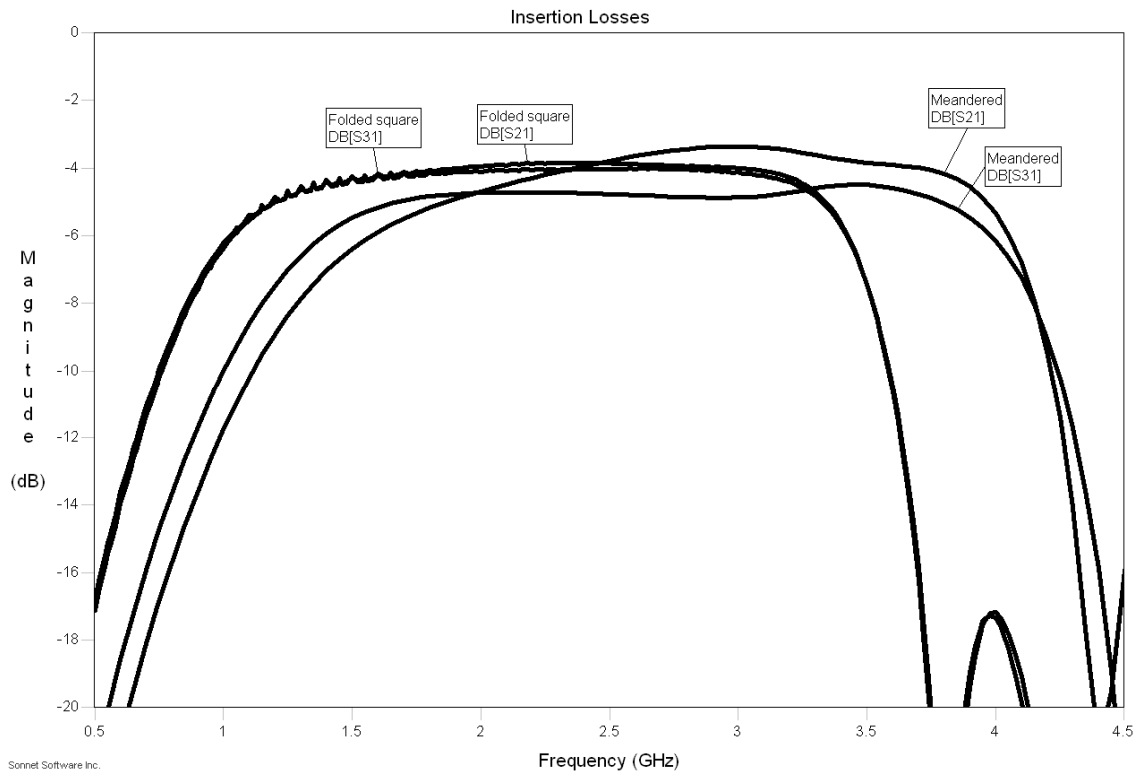


Fig. 6. Insertion loss of the folded planar Marchand baluns.

5. Conclusions

Baluns are very useful impedance transformers that can also be used as power divider/combiners and they are commonly used for connecting differential circuits to single-ended circuits. For PCB applications, planar baluns are required. This paper discussed the design of two folded, planar, edge-coupled Marchand baluns for use in congested PCB applications. These balun designs evolved from those presented in [7] and [8], which showed very good performance but that were of compact form-factors. The folding and meandering of the transmission lines composing the anti-phase baluns caused some performance degradation but offered a nearly square form factor of about 20 mm by 20 mm. The designs were implemented as three-port devices and simulated using Sonnet™. The results showed that acceptable performance can be achieved in with a compact balun for the desired frequency range.

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