ENHANCED COUPLED, EVEN MODE TERMINATED BALUNS AND MIXERS CONSTRUCTED THEREFROM *

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ABSTRACT

A new mixer circuit technology, based upon what we call the *Planar Balun,* which is appropriate for microstrip or suspended-substrate mixer construction, is introduced. The multilayer Planar Balun is an even-mode-terminated structure which provides coupling in which odd-mode impedance and velocity can be controlled without greatly affecting even-mode characteristics. The Planar Balun and mixer circuitry are described, and comparisons are made with other baluns. Wideband mixer performance and balun voltage distribution are shown. A Planar Balun mixer fabricated in a 0.25-inch-square surface mount package is demonstrated.

INTRODUCTION

A new circuit concept called the Planar Balun permits a new degree of flexibility and performance in designing mixers and modulators. The key features of mixers based on the Planar Balun concept include microstrip packaging; thick, rugged single-sided ceramic substrates; superior performance over extremely wide bandwidths; small size; even-mode termination; and suitability for use in surface mount packages. With the Planar Baluns, the amplitudes at the two antiphasal outputs are extremely well-equalized. The combination of enhancements to coupling with even-mode termination, and amplitude equalization yields mixers which have superior balance over greater bandwidths when compared to previously-developed mixers. The achievement of decade-plus mixer bandwidth in a microstrip-type environment while maintaining excellent mixer performance is now possible through the use of the Planar Balun technology.

*(patent pending)

PLANAR BALUN FEATURES

The purpose of the mixer balun is to provide one unbalanced input and two equal-amplitude antiphasal outputs while offering resistive termination to even-mode propagation. In the Planar Balun, multilayer thin-film circuitry is used on one side of a ceramic substrate. The circuit comprises edge-coupled transmission lines with a dielectric overlay, second-layer metal-overlay capacitors, and transmission line-resistor networks tied to each separate capacitive overlay. This structure functions with or without a backside substrate ground plane, hence the substrate can be either suspended or, more importantly, can be attached directly to a housing in microstrip fashion.

The use of edge-coupled lines in the presence of a local ground plane is made possible with overlay capacitor plates, the capacitances of which are made to vary along the balun length. These overlay capacitors are fundamental in the enhancement of coupling. Depending on the capacitance chosen for a particular balun cell, the designer can trim the value of odd-mode impedance and velocity without greatly affecting the even mode. This tapering of odd-mode impedance is crucial in matching the input to loads as complicated as the R port of a double-balanced mixer. The capacitive overlays also provide local virtual ground points which act to shield the circuitry from ground proximity effects.

Even-mode propagation is controlled by the use of transmission lines interconnecting each overlay capacitor to a resistor. Each transmission line-resistor combination trims the even-mode impedance at each circuit cell location. This has the effect of de-Q-ing the undesirable half-wavelength even-mode resonances. Even-mode energy which may be driven in reverse into the balun outputs by the diodes of a mixer is resistively terminated. The Planar Balun provides features which are vital in achieving improved mixer balance and response flattening over broad bandwidths. *This also allows for broad mixer bandwidth even in a microstrip environment.*

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CIRCUIT DESCRIPTION

The balun comprises multiple circuit cells, as shown in Fig. 1. The cross section of one balun cell is shown in Fig. 2. After cascading all cells, the two input terminals of the first cell provide the input and ground terminals. The two output terminals of the last cascaded cell are the balanced output terminals. The overall balun is made up of eight sections, as shown in Fig. 3.

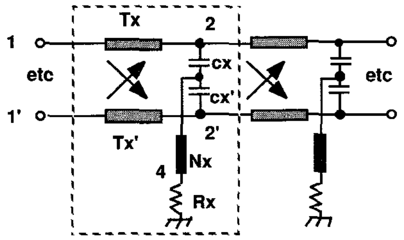

Fig. 1 Planar Balun circuit cell.

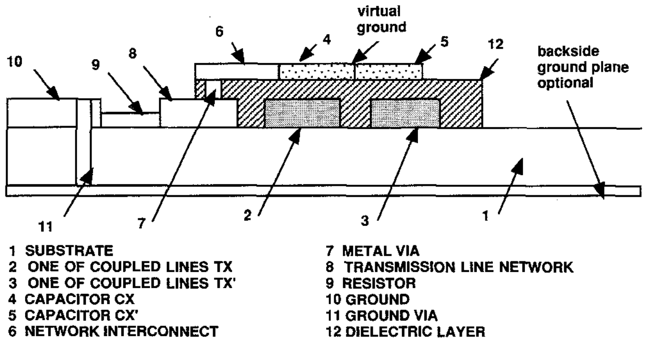

Fig. 2 Cross section of a circuit cell.

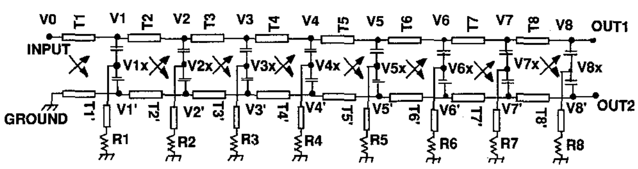

Fig. 3 Schematic diagram of a Planar Balun.

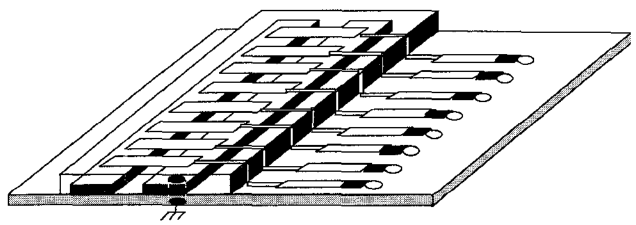

Fig. 4 Physical layout of a Planar Balun.

Figure 1 shows a circuit cell with edge-coupled pair Tx and Tx', overlay adjoining capacitors Cx and Cx', and transmission line Nx which interconnects the virtual ground node between the overlay capacitors to resistor Rx. The physical construction of the circuit cell is shown in Fig. 2. The 12 major elements of this construction are also listed. A backside ground is optional, but must be included in the design procedure if it is to be used in the construction. The backside ground plane may be omitted, except for a ground perimeter necessary to ground the resistors. Physical construction of a Planar Balun is shown in Fig. 4.

COMPARISON OF THREE BALUN TYPES

The primary criteria for evaluating the superiority of one balun type over another are the relative degree of amplitude equality and the degree to which there exists a 180-degree phase relationship between the outputs. Comparison of suspended broadside-coupled baluns, edge-coupled baluns, and the Planar Balun have been made. Figures 5(a), (b), and (c) show the S_{21} and S_{31} responses of the three types. In the first two cases, it is apparent that the through line carries more power than the coupled line at low frequencies. At some higher frequency, there is an equal-

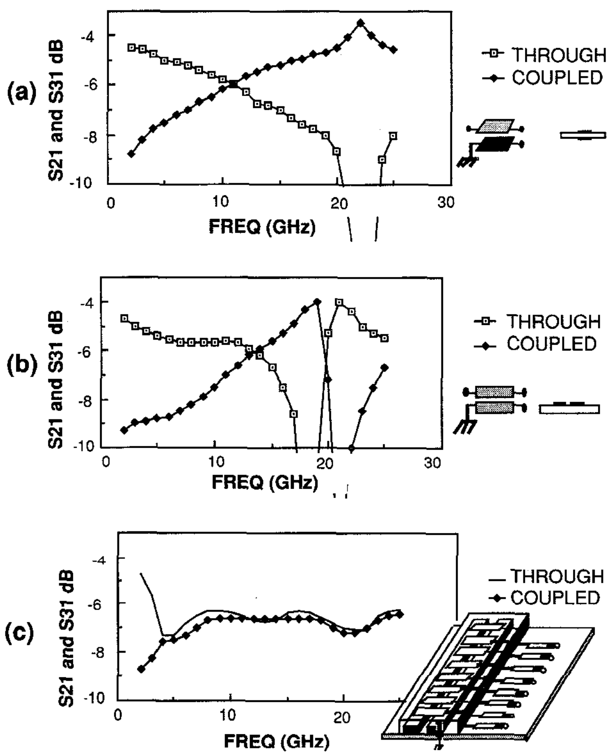

Fig. 5 Responses of (a) broadside coupled (b) edge coupled and (c) Planar Balun.

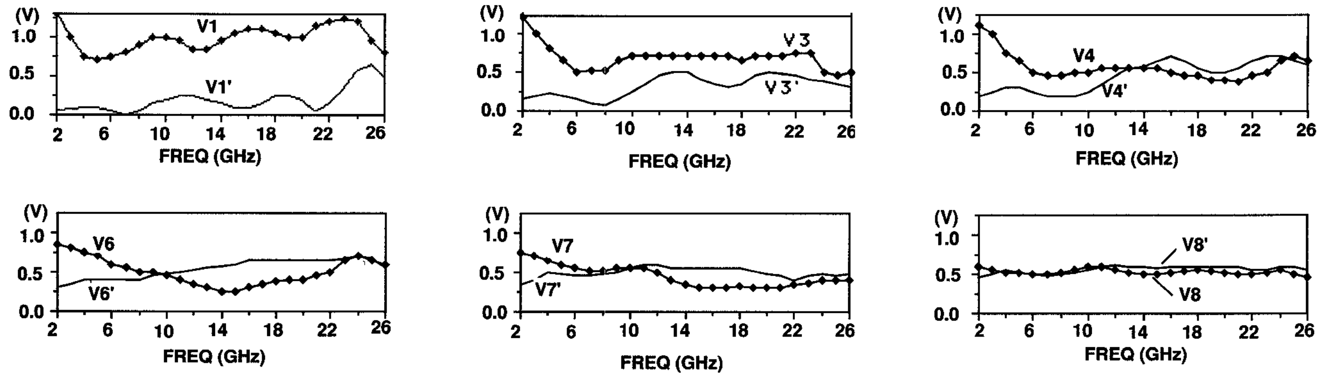

Fig. 6 Node voltages along Planar Balun (see schematic in figure 3).

power crossover point, which is followed by an overcoupled region at high frequencies. When the physical length of the first two baluns corresponds to:

$$\text{Length} = n \times \lambda_{oe} / 2$$
$$n = 1, 2, 3, \ldots$$

a resonance occurs in the S parameters with extreme overcoupling. In a mixer application, all responses are severely upset at these resonance points. *In contrast, the Planar Balun responses of Fig. 5(c) show equalized amplitudes and the even-mode termination feature has eliminated the resonances.* The phase responses of all three baluns are approximately the same if ground planes are far removed. The physical length of each alumina balun compared was 200 mils and Z_{oo} was near 25Ω.

PLANAR BALUN MEASUREMENTS

The Planar Balun is amplitude equalized. The networks driving the resistors are quarter-wave transformers, and the resistors are all the same value. As the frequency range is swept, the loading of the transformer-resistor lines, as they appear on each individual overlay capacitor, alternates from high to low impedance. Where the capacitive overlays are nearly virtual ground to the odd mode (near the outputs) only light loading occurs. Toward the input end the overlays have higher odd-mode voltages, and more odd-mode loading occurs. At lower frequencies the transformers are electrically short and a small amount of odd-mode current is drawn from the through side of the balun and passed into the resistor. The result is that amplitude equalization is reinforced. The even mode is periodically heavily loaded by each shunt resistor network. By varying each transformer length and overlay capacitance, the Planar Balun responses can be optimized.

Figure 6 shows the voltage on each main balun line at each cell with a 2-V-peak, 50Ω input voltage source. As seen at cell 1, one-half of the 2-V source appears and the other side is near ground. Moving down the balun, cell by cell, it appears that the coupling voltage first increases at high frequencies. As total balun length increases, coupling occurs at the lower frequencies. At the output the voltages are nearly identical across the band at 0.5 V. Figures 7 and 8 show the overlay voltages at each cell position with and without resistors. Note the higher voltages and severe peaks occuring without the resistors. It is therefore evident that the resistor networks are required to lower the voltage at each cell overlay and eliminate even-mode resonances.

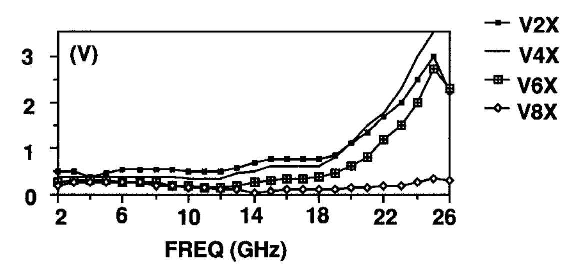

Fig. 7 Planar Balun voltages on overlay capacitors with balun resistors removed.

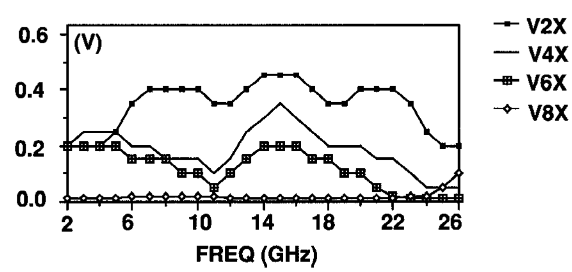

Fig. 8 Planar Balun voltages on overlay capacitors with balun resistors in place.

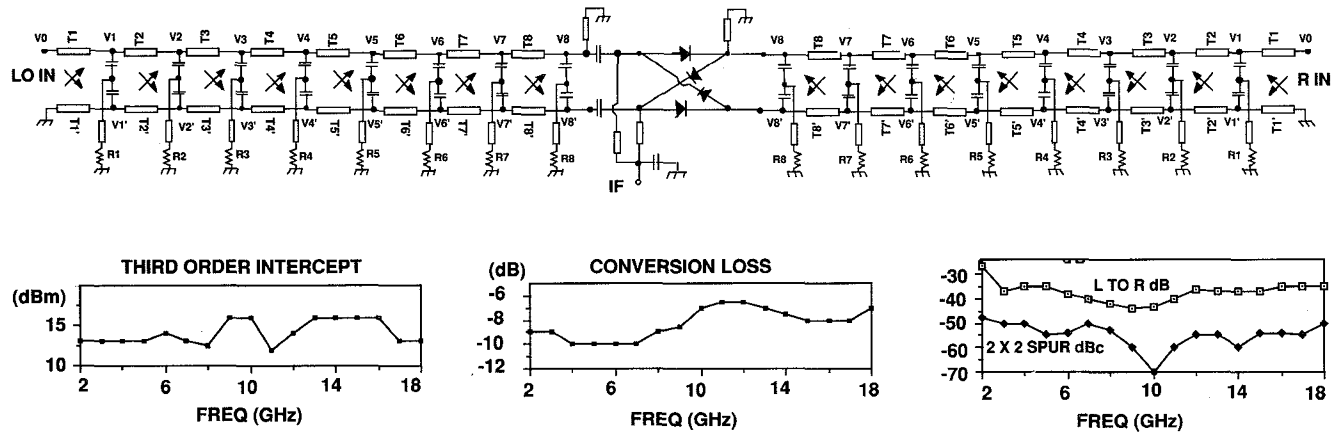

Fig. 9 Schematic diagram and measured responses of a mixer using Planar Baluns.

MIXER APPLICATIONS

Figure 9 shows a mixer with the Planar Balun used on the RF and LO ports. The IF port is formed by diplexing the LO and IF frequencies using reactive filtering. Two IF ground returns are formed by the grounded side of the R balun input and by a shorted stub on the R balun through path.

The phase and amplitude integrity of both baluns, along with the diode match within the Schottky monolithic ring quad are immediately seen in L-to-R isolation and 2Rx2L spurious suppression. Figure 9 also shows the measured performance of the mixer, and provides a good indication of the large bandwidths that can be obtained using Planar Baluns. Also seen are L-to-R isolation across the band in the 30 to 40 dB range and 2Rx2L spurs which are 50 dBc or better. The nonlinear mechanisms of compression and intermodulation are relatively flat with frequency.

SUBSTANTIATION OF MICROSTRIP-LIKE APPLICATIONS

Figure 10 shows the package outline for a mixer design similar to that previously described, but achieved in a microstrip environment. This package is the 0.25-inch-square Avantek *PlanarPak* surface-mount package. The bandwidth of this mixer measured 2 to 20 GHz with nearly the same conversion loss shown in Fig. 9. The primary difference between this and the previously-described design is that in this version, phase compensation circuitry was included to maintain the phase linearity of each balun.

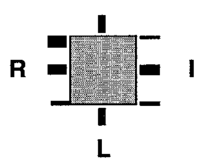

Fig. 10 Quarter inch Planar Pak mixer using planar baluns.

CONCLUSIONS

The Planar Balun technology demonstrates many desirable performance features. Comparisons with other balun types have been made and the performance improvement of the Planar Balun is further reinforced. Both suspended and microstrip-like mixers have been built by the author using Planar Baluns. The measured results on the mixers indicates that Planar Baluns offer the potential of improved performance with wider bandwidths than mixers built with other types of baluns. This has made possible a passive mixer technology mountable in microstrip surface mount packages as small as 0.25-inch square.

ACKNOWLEDGEMENTS

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