Balun design for uniplanar broad band double balanced mixer

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

Indexing terms: Coplanar waveguides, Mixers (circuits), Baluns

A novel balun based on an asymmetric coplanar waveguide with finite ground plane (ASYCPWFGP) to coplanar strip (CPS) transition is presented. A return loss better than 16dB is obtained up to 50GHz. The baluns are combined with four silicon Schottky barrier crossover diodes to yield a planar double-balanced mixer (DBM) which demonstrates an ultra-broadband performance up to 40GHz.

Introduction: Double-balanced mixers (DBMS) find wide application in modern microwave systems. The MIC designers often utilise a three-dimensional or double side-structure, such as an orthogonal substrate, to obtain a practical design. However, this technique results in high fabrication cost and makes larger-scale integrations difficult. Also, the MMIC designers cannot have resorted to such a technique because it is only the top surface of the substrate they can work with. Therefore, the uniplanar balun is emerging as the most important device for MIC or MMIC DBM design. In the literature, uniplanar DBM designers have used the CPW line, coplanar strip (CPS) and slotline techniques [1 – 3] in conjunction with plated airbridges to realise RF and LO baluns which are either Marchand type baluns or double *Y*-junction type baluns. The equivalent circuit of the former is a bandpass structure whose bandwidth is limited by the quarter-wave open circuit stub of its microstrip or CPW and the quarter-wave short-circuit stub of its slotline. Previous studies have indicated that only a 5:1 bandwidth can be reached, which is not wide enough to satisfy some ultra broadband circuit applications. Similarly, the bandwidth of the double *Y*-junction balun is limited by the quarter-wave short stub of the slotline. Therefore, the operation bandwidth of DBMs based on previous balun structures are greatly constrained by theirs baluns. In this Letter a simple, ultra-broadband balun structure which is suitable for MIC/MMIC DBMs is proposed. Such a structure consists of an ASYCPWFGP line which is directly transitioned into CPS using the concept of impedance match. The resulting ASYCPWFGP to CPS balun is used to replace the transformers in the DBM. The baluns are then combined with a beam lead crossover silicon Schottky barrier diode quad to yield a completely planar DBM which can be readily produced in MIC or MMIC form.

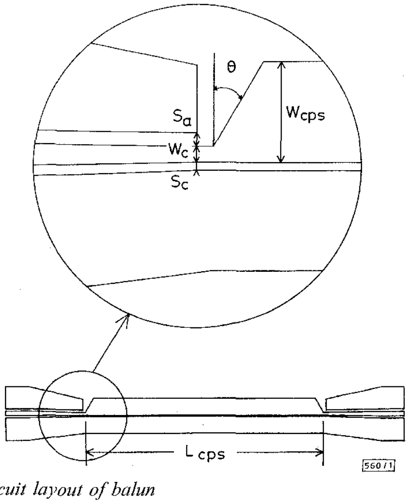

Fig. 1 *Circuit layout of balun*

Impedance level of ASCPWFGP and CPS is chosen as 55Ω. Dimensions of balun are W_c = 2.4mil, S_a = 2mil, S_c = 1.2mil, W_{cps} = 15mil, L_{cps} = 200mil and θ = 30°

Balun design: The typical DBM consists of two transformers and a crossover diode quad. The balun structure instead of the transformer is used to realise the DBM circuitry in the microwave frequency range. The circuit diagram of the balun with ASYCPWFGP to CPS transition is shown in Fig. 1. The advantages of using the ASYCPWFGP line are two-fold. First, the width of the lower gap, S_c, as shown in the Figure, can be kept the same as that of the gap of the CPS line so as to avoid discontinuity at the ASYCPWFGP to CPS junction. Secondly, the width of the other gap, S_a, and the linewidth, W_c, of the ASYCPWFGP can be adjusted to reach the impedance match condition between the ASYCPWFGP and CPS lines. Maximum power transfer between two different transmission lines (ASYCPWFGP and CPS) is thus achieved, and an ultrabroad operation bandwidth is expected. The layout of the balun is in a straight line configuration. The size can be very compact, which makes the integration between this circuit and other planar circuits easy. To meet the requirements of the testing system, the balun circuits shown in the Figure are connected in a back-to-back configuration, and the non-50Ω ASYCPWFGP is tapered to 50Ω CPW. The characteristic impedance of the CPS, which can be selected between 55 to 90Ω, is determined by the considerations of the CPS gap size and the ASYCPWFGP characteristic impedance. High ASYCPWFGP characteristic impedance will cause a large junction area and limit the working frequency. The appropriate dimensions of this circuit can be obtained by using a conformal mapping method [4]. Because the CPS is just weakly dispersive [5], the conformal mapping method has been good enough for circuit design. Fig. 2 shows the measured responses of the baluns. For a back-to-back configuration, the input return loss of the circuit is < –16dB and the insertion loss is < 5dB within the frequency range up to 50GHz.

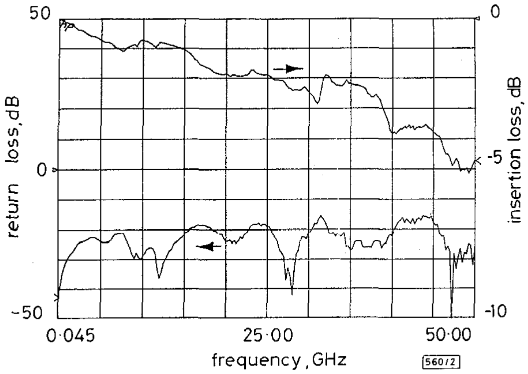

Fig. 2 *Measured response of back-to-back balun*

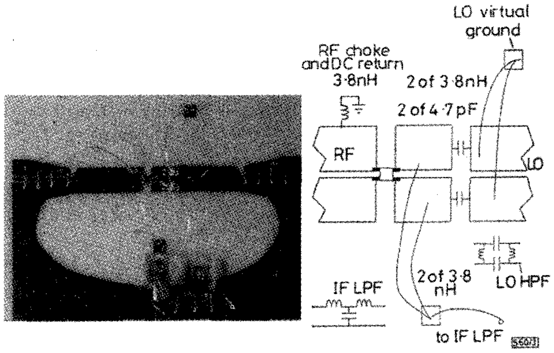

Fig. 3 *Photograph and schematic diagram of DBM near diode quad*

Crossover DBM, HPF design: F_c = 1.3GHz, L = 3.8nH, C = 4.7 pF
LPF design: F_c = 0.78GHz, L = 10.5nH, C = 4.7pF

Experiments and results: The photograph and schemetic diagram of the centre section of the DBM are shown in Fig. 3. The Metelics MSS-30 diode quad with a 15Ω Rs and a 0.07pF Cj is placed between two of the ASYCPWFGP to CPS baluns. The diode quad leads sit directly on the two CPS lines. The IF signal can be taken from the LO side. A lowpass filter of order three is used to access the IF signal. This diplexer will separate the IF current from the RF and LO ports. The LO diplexer circuit is intentionally designed as a CPS highpass filter of order three with a cutoff frequency of 1.3GHz. This highpass filter allows the lowest operation frequency of the DBM down to 1.5GHz. A 3.8nH bonding wire inductor, instead of the tranditional quarter-wavelength short stub, is used to not only separate the IF currents from the RF voltages but also provide the DC return for the diode quad. Using the wire conductor, the operation bandwidth of the circuit can be greatly extended up to the self-resonance frequency of the wire inductor. The DBM circuitry presented above was fabricated on a 25-mil-thick alumina substrate with a dielectric constant of 9.8 using conventional thin-film technology. The performances of the DBM were measured with a Cascade Microtec probe station and an HP8566B spectrum analyser. The power levels of RF and IF signals were calibrated on each frequency point using an HP435B power meter. Fig. 4 shows the measured conversion loss of the mixer driven by a 10 dBm low side LO resulting in a 100MHz IF output. Conversion loss is between 6.4 and 12dB over 1.5 to 40GHz. The RF to LO and IF to LO isolation are > 20dB in the frequency range 2 – 22GHz. The input third order intercept point of this DBM at 10GHz is 15dBm.

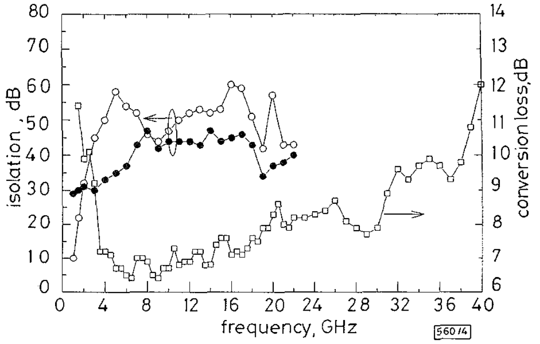

Fig. 4 *Performances of DBM circuit*

IF = 100MHz, *LO* power = 10dBm
○ LO-IF isolation
☐ Conversion loss
● LO-RF isolation

Conclusion: We have shown an ultra-broadband DBM circuit. These ultrabroad performances are mainly attributed to the use of the wideband balun and subtle arrangement of the diplexer circuits in the LO, RF and IF ports.

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Transmission line directional couplers with a generalised sinusoidal coupling coefficient

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Indexing terms: Directional couplers, Transmission lines

A generalised asymmetrical tapered sinusoidal coupling coefficient theory is presented. Using the first order approximation equations, the new theory exhibits good electrical coupling performance with reasonable coupler size.

Introduction: There is increasing interest in broadband electronic countermeasures, electronic counter countermeasures and instrumentation systems capable of covering wider frequency ranges. The development of microwave components with such wide frequency ranges has therefore become necessary. For this purpose we present a tapered directional coupler exhibiting high pass coupling response. To achieve near optimum electrical performance and a small size, a generalised sinusoidal coupling coefficient along the length of the coupler is employed.

Theory: It is well known [1 – 3] that a TEM mode directional coupler with a continuously tapered directional coupler and nonzero characteristics in the physical domain, exhibits a high pass type near equiripple complex amplitude voltage coupling response in the frequency domain. The coupling coefficient $K(z)$ along the length of the coupler is a function of the odd and even mode impedances of the two coupled lines and is expressed by

$$K(z) = \frac{Z_{oe}(z) - Z_{oo}(z)}{Z_{oe}(z) + Z_{oo}(z)} \qquad (1)$$

The first order approximation for the complex voltage coupling response in the frequency domain is obtained by using the transform

$$V_c = \frac{j\psi}{2}\int_0^1 K(x)e^{-j\psi x}dx \qquad (2)$$

where V_c is the complex voltage coupling from port 1 to port 3 (see Fig. 1), $K(x)$ the normalised coupling coefficient, $x = z/l$ the normalised displacement, z the displacement along the length of the coupler, l the length of the coupler, λ the wavelength, $\psi = 2\beta l$ and $\beta = 2\pi/\lambda$.

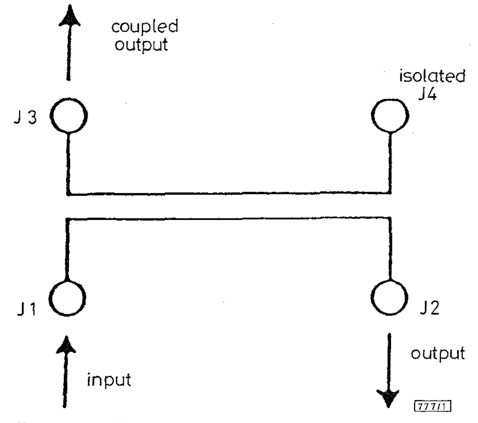

Fig. 1 *Illustration of complex voltage coupling from port 1 to port 3*

Extensive directional coupler syntheses [1 – 7] have been carried out by the use of the first order approximation for the complex voltage coupling given in eqn. 2. A number of coupling coefficient variations, such as the exponential and the cosine tapers, were employed by several workers in an effort to achieve near equiripple coupling response. In some instances, tedious and complicated numerical procedures are required [2], whereas in others [1 – 3] large coupling lengths are needed. Howard and Lin [6], by using a cosine to the fourth power coupling coefficient variation, achieved a near maximally flat coupling response with a coupler length commensurate with the much higher ripple cosine coefficient