A Novel 15 to 45 GHz Monolithic Passive Balun for MMICs Applications

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Abstract — **This paper presents the design and performance characteristics of a novel broadband monolithic passive balun that has been developed for MMIC's applications. The new balun utilizes a multi-dielectric layer structure to achieve a broadband performance of up to 3:1 in a simple coplanar configuration. A return loss better than 15 dB, with a maximum insertion loss of 4.5 dB including the 3 dB power splitting loss from 15 to 45 GHz has been realized. The developed balun also achieves better than 0.35 dB and 1.5° of amplitude and phase imbalance over the same frequency band. This performance is specially important to the intended use with wideband double balanced mixers, and amplifiers.**

I. Introduction

Baluns perform the function of transforming an unbalanced line like a coaxial cable or microstrip line to a balanced line with equal amplitude and 180° out of phase outputs. This component is essential in a variety of important microwave applications such as balanced mixers, push-pull amplifiers, multipliers and phase shifters. As monolithic microwave integrated circuits advance the need for broadband monolithic passive baluns that can be fabricated with the same technology becomes more evident. The design of broadband monolithic passive baluns has been the subject of many investigations in recent years [1]-[4]. A monolithic version of the well-known Marchand balun was implemented monolithically using CPW structures, and an amplitude and phase imbalances less than 1.5 dB and 10° respectively over the band from 1.5 to 6.5 GHz has been reported [5]. However that balun requires considerable amount of space because of the four sections of quarter wavelength transmission line involved in the design.

In this paper the design, implementation, and results on a new 15 to 45 GHz multi-layer monolithic passive balun are described.

II. Balun Design

The coaxial version of the monolithic wideband balun presented in this paper, was originally proposed by Roberts in 1957 [6] with its schematic illustrated in Fig. 1. Where Z_a, Z_b, and Z_{ab} represent the characteristic impedance of lines *a*, *b*, and the coupled line *ab* respectively. The symbols θ_b and θ_{ab} are respectively the electrical lengths of transmission lines *b* and *ab*. The balun was used with VHF and UFH applications and showed a broadband performance of 2.8:1.

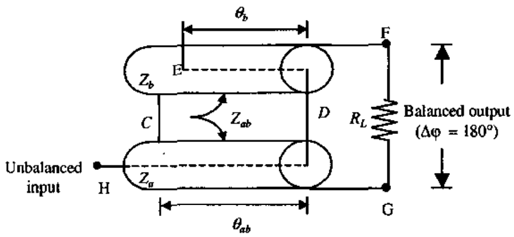

Fig. 1 Schematic of the coaxial wideband balun

To implement this balun monolithically for used in K_a-band applications, the configuration should be further investigated. Fig. 2 illustrates a simplified model of the balun developed for the purpose of impedance analysis. The terminals *F*, *G*, *E*, *C* and *H* are the same as in Fig. 1. The input impedance (Z_{in}) looking into the terminals *A*-*B* can be expressed directly by:

$$Z_{in} = -jZ_b \cot\theta_b + \frac{jR_L Z_{ab} \tan\theta_{ab}}{R_L + jZ_{ab} \tan\theta_{ab}} \qquad (1)$$

On letting the electrical lengths of line segments b and ab be equal, i.e., $\theta_b = \theta_{ab} \doteq \theta$, and the characteristic impedance $Z_{ab} = R_L$ then substituting in Eqn. 1 the following expression is obtained:

$$Z_{in} = R_L \sin^2\theta + j(\cot\theta)(R_L \sin^2\theta - Z_a) \quad (2)$$

and the input impedance becomes perfectly matched at two widely separated frequencies that are given by the solution of:

$$\sin^2\theta = \frac{Z_a}{R_L} \quad (3)$$

These frequencies are symmetrically disposed about a center frequency corresponding to θ = 90°.

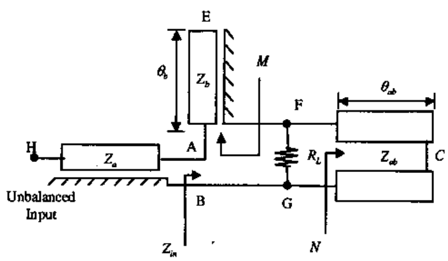

Fig. 2 Simple transmission line model for the proposed balun

Fig. 3 illustrates the developed monolithic implementation of the proposed balun. The circuit relies on a multi-layer dielectric to form transmission lines Z_a, Z_b, and Z_{ab}. As shown in Fig. 3 the proposed deign used both coplanar waveguide (CPW) and microstrip transmission lines. The unbalanced input is fed through a 50 Ω CPW line and the balanced output is taken through a balanced coplanar-strip (CPS) output line (Z_{ab} = 60 Ω). The output line is formed from the ground planes of the two microstrip lines a and b (Z_a=Z_b=50 Ω) constructed using the top metal. The characteristic impedances of these transmission lines are designed such that the balun transforms a 50 Ω unbalanced input to any arbitrary balanced output (a value 60 Ω balanced output was chosen for this design) over a frequency band from 15 to 45 GHz. The electrical lengths θ_b and θ_{ab} are chosen to be 90° at a center frequency of 30 GHz, which corresponds to a physical length of 926 μm of the output CPS line ab and 1226 μm for the mircostrip line b. As can be seen the construction is arranged to allow line b to be housed in one of the arms of the balun. Thus the overall physical length is only one-quarter wavelength. Fig. 4 shows a cross section in the balun, the two metals are separated by a dielectric material with ε_r=4 and thickness of 1.5 μm. The whole circuit sits on a GaAs substrate (ε_r=12.9) of 200 μm thickness

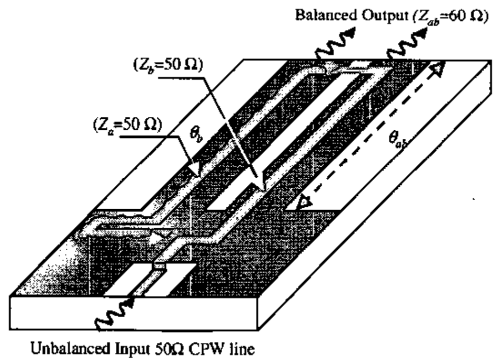

Fig. 3 Circuit construction of the proposed balun

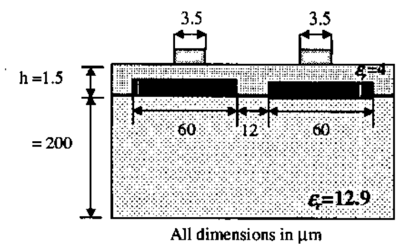

Fig. 4 Typical balun structure cross section

III. Balun Performance

The results of the electromagnetic simulation of the balun are shown in Fig. 5 through 7. The commercial software IE3D from Zeland was used to analyze and study the balun performance. The return loss of the input port is better than 15 dB over the band from 15 to 45 GHz as illustrated in Fig. 5. Also the two frequencies at which the impedance is perfectly matched are evident at 20 GHz and 39 GHz, and this is in agreement with the theoretical prediction based on the transmission line model mentioned in the previous section. Most importantly, the insertion loss including the 3 dB power splitting loss is almost flat around 4.5 dB over the band from 15 to 45 GHz, which indicates that the actual balun loss is equal or less than 1.5 dB. These losses comprise mainly the losses in the narrow strips that were used to implement the microstrip lines. The simulated values for the phase and amplitude imbalances between the two balanced ports plotted as a function of frequency are shown in Fig. 6 and Fig. 7. In order to examine the effect the substrate thickness has on the balun performance, three different substrates thicknesses were considered. It is evident from Fig. 6 and Fig. 7 that better performance can be obtained with thicker substrates. This is because a thicker substrate results in higher even mode impedance, which is a key issue in balun design. As shown in Fig. 6 an amplitude imbalance better than 0.35 dB is achieved for a 600 µm substrate thickness and it goes up to 0.8 dB for 100 µm substrate. Also as illustrated in the phase imbalance is better than 1.5° from the 180° phase difference for the case of 600 µm substrate and it goes up to 4° for the 100 µm substrate.

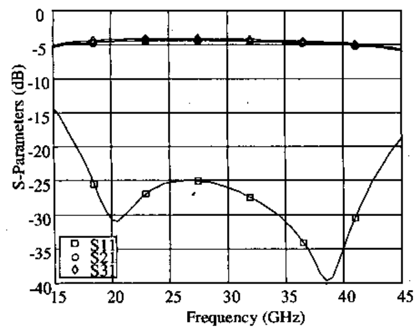

Fig. 5 Balun simulated return and insertion loss

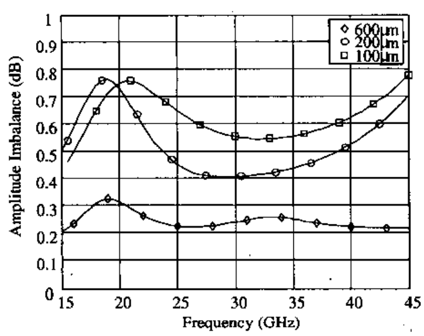

Fig. 6 Balun simulated amplitude imbalance

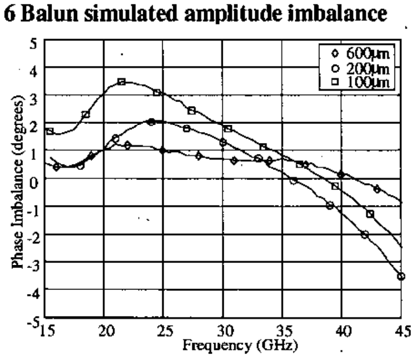

Fig. 7 Balun simulated phase imbalance

IV. Experimental Results

To physically measure the amplitude and phase imbalance, between the output ports, a 50 Ω CPW line must be added to each of the balanced outputs. Inorder for the balun to operate as deigned it must see a 60 Ω balanced load across its output terminals. However, adding the output 50 Ω CPW lines will change the terminating impedance seen at the balun's output, which will in turn, affect its performance. To overcome this problem a 75 Ω resistance will be connected in parallel with each of the 50 Ω CPW output balanced lines so that the overall impedance seen across the balanced terminals will be equal to the required 60 Ω. A photograph of the developed balun is shown in Fig. 8. The balun was fabricated on NORTEL InGaP/GaAs HBT process on a 200 µm substrate. The balun along with the probe pads measures 0.7mm x 1.4 mm. However, in a typical balanced mixer configuration the actual area occupied by this

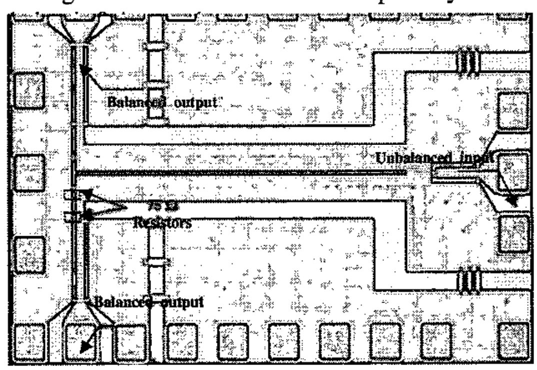

Fig. 8 Photograph of the fabricated 15 to 45 GHz monolithic balun (0.7 mm x1.4 mm)

The measured and simulated return and insertion loss of the balun with CPW output lines are shown in Fig. 9. As can be seen, there exists close agreement between measured and the simulated performance of the balun. A measured return loss better than 12 dB was achieved over the entire band from 15 to 45 GHz with almost a flat insertion loss around 7 dB. It can be noticed that the insertion loss is higher than that for the normal balun (Fig. 5). This is because of losses encountered with the 75 Ω resistances added with the output CPW lines (evaluated approximately to be 2.5 dB). The measured and simulated phase and amplitude imbalance of the fabricated balun are shown in Fig.10 and Fig. 11, respectively. Again, a close agreement between the measured and the simulated results has been achieved with measured amplitude and phase imbalance less than 1 dB and 5.5° respectively over the 15 to 45 GHz frequency band. It is also evident that there is a difference between the simulated phase and amplitude imbalances presented in Fig. 6 and Fig. 7 for the normal balun without the output CPW line. This difference arises mainly from the CPS to the CPW transition used at the output.

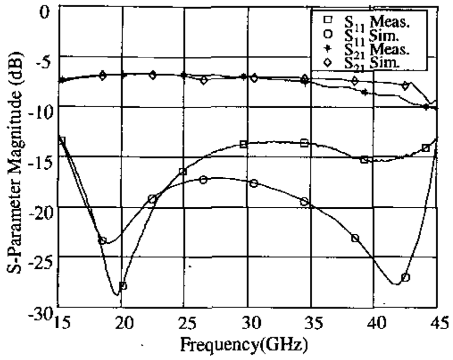

Fig. 9 Measured and simulated return and insertion loss for the fabricated balun

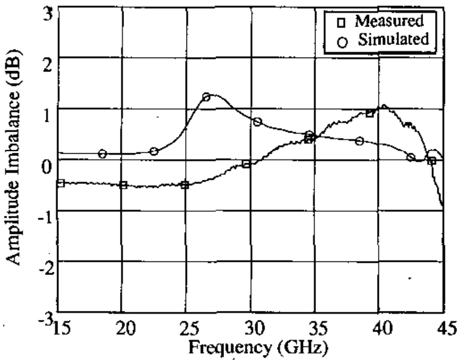

Fig. 10 Measured and simulated amplitude imbalance for the fabricated balun

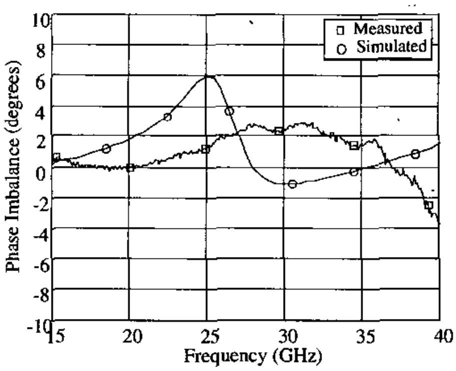

Fig. 11 Measured and simulated amplitude imbalance for the fabricated baluns

V. Conclusion

A novel broadband monolithic passive balun has been designed, implemented and tested. The balun was fabricated using NORTEL GaAs process. Good agreement between the simulated and the measured performance of the balun is obtained, with good amplitude and phase imbalance performance over a wide frequency band from 15 to 45 GHz. The newly developed balun is sufficiently compact in size and is an attractive configuration for future use in MMICs applications at the K_a-band such as balanced mixers, multipliers and push-pull amplifiers particularly in view of the wide bandwidth it offers. The developed balun has already been used in the design of a 20 to 40 GHz wideband double-balanced direct conversion mixer and excellent performance has been obtained.

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