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Characterization of Parameters for Baluns at 60GHz and Aspects of their Technological Implementation

Abstract

Transmission lines for high frequency applications can be designed either in symmetrical or in asymmetrical configuration. Transformers are required to combine RF-Modules with different transmission line concepts. The transition from a symmetrical to an asymmetrical system is called BALUN (BALanced, UNbalanced). At present, the industry employs baluns with partly lumped elements that are realized as embedded passives and work up to a few Gigahertz. It is not possible, though, to use a similar approach for higher frequencies. Technology influences on transformers around 60GHz have not yet been sufficiently investigated for thick film technologies.

In order to analyze and optimize various baluns, full 3D FEM simulation was employed. The results were transferred to a test structure based on LTCC (DP943). Due to the required pattern resolution (line width: 65µm, minimum gap: 40µm) a fine line screen printing process and micro via punching (70µm) were necessary.
Two identical baluns in series are were characterized using asymmetrical test equipment. The same baluns were combined with a symmetrical amplifier with the aim of demonstrating their performance for real applications.

Introduction

In RF-Applications the signal is usually transmitted with the help of two different types of lines. While asymmetrical transmission lines are common practice, symmetrical ones are employed for differential amplifiers, antennas and digital transmission lines. It is often necessary to connect these lines to each other.

Asymmetrical Line Transmissions

In asymmetrical lines, a so called signal conductor carries the potential. The ground serves as opposite electrode and is often used as an electric screen. Examples for asymmetrical transmission lines are simple coaxial cables and patch antennas.

Symmetrical Line Transmissions

In symmetrical lines, the signal is completely independent from the ground. There are two conductors carrying each a 180° phase delayed signal. Dipole antennas and ribbon cables are examples for symmetrical transmission lines.

The transition between the two different systems is called BALUN (BALanced -> UNbalanced). Baluns are used for matching and reducing parasitic effects when switching from a symmetrical to an asymmetrical system. Principally, any possible potential offset can be obtained. Furthermore, baluns can convert impedances.

Planar Passive Galvanically Coupled Balun

A planar passive galvanically coupled balun is in the focus of interest in this paper. It shall optimize the transition between an asymmetrical coplanar line with 50Ω impedance to Symmetrical Coplanar Strips (SCS) with 100Ω impedance [2]. The working frequency is 61.5GHz with a bandwidth of 10GHz. The wavelength at 60GHz on Du Pont® 943 ceramic is 2.47mm, which results from an effective permittivity of approximately 4.1. At present, coils and capacitors, produced with thick film technology can work up to about 12GHz [1], which is due to the limited pattern resolution of screen printing technology (minimum line widths and gaps of about 40µm). It is therefore impossible to implement baluns in the frequency range of 60GHz using lumped elements (with thick film technology).
In a first step, galvanically coupled baluns are investigated since, because of the technology, the losses of field coupled baluns, such as Marchant baluns, should be higher than those of galvanically coupled ones.
The thickness of the gold starts from 5µm in all metallization layers.

Feeding Lines of the Balun

The Coplanar Wave Guide

In order to measure the S-parameters up to 67.5GHz it was necessary to first design a suitable 50Ω Coplanar Wave Guide (CPW). The pitch of the CPW (150µm) had to be smaller than that of the probe tips with a pitch of 200µm. The 50Ω CPW was designed without ground plane. Therefore, the impedance almost exclusively depends on the gap width ratio. The substrate has to be thick enough to avoid parasitic wave modes. As a consequence, a simple continuous change of the overall dimensions of the CPW is possible while the impedance value is maintained. The impedance is independent from the thickness of the substrate.

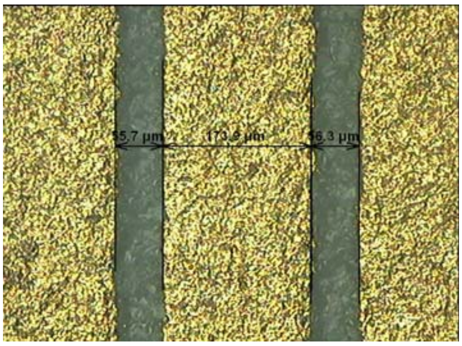


Figure 1 Top view of a manufactured CPW on DP943® in gold

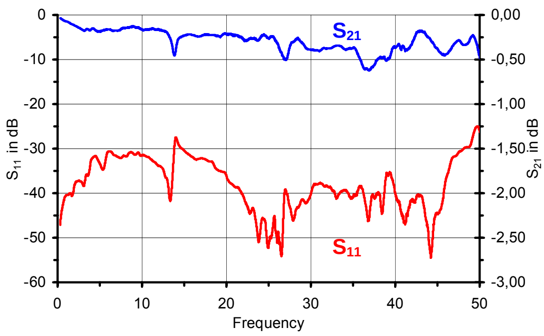


Figure 2 Measured S-parameters for the 500µm long CPW

With the help of a line calculator and the preparation of some CPWs in a matrix of test structures with stepped widths and gaps, a very well adjusted CPW was designed. The optimum input matching is found for a width of 170µm and a gap of 55µm.

The Symmetrical Coplanar Strips

The symmetrical coplanar strips (differential coupled lines) should feed a differential low noise amplifier at 61.5GHz with a differential impedance of 100Ω. This is referred to as the odd mode impedance. The even mode is not considered here since the amplifier suppresses even modes. Determining the right values for the gap and width for preparing the SCS proved to be challenging as common line calculators out on the market are not suited for calculating symmetrical lines. Hence, the SCS is simulated with a 3D electromagnetic field solver. Configuring the ports for the simulation model is also a challenging task, since HFFS® prefers propagation modes with at least one grounded electrode (due to the boundary conditions in the 3D model). The first mode computed by HFSS® is always an asymmetrical mode. In order to calculate the symmetrical mode impedance, it necessary to allow higher modes in the port calculations.

A direct test of symmetrical lines is not possible. Even 4-port measurements have to be performed with sequentially switched coaxial test ports of the network analyzer. The fact that the available measurement system up to 67GHz only allows asymmetrical coplanar measurements, is a further limitation.

The optimized dimensions of the SCS are 80µm for the width and 60µm for the according gap matching the previous CPW.

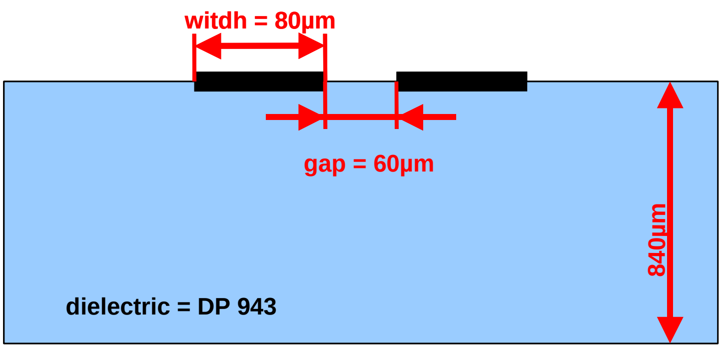


Figure 3 Profile of symmetrical coplanar strips (SCS)

Technological Aspects

In fine line printing, the quality and technological parameters depend on the printing direction. Printing in the direction of a line generally results in a better edge quality. The achievable minimum gap for printing in the direction of lines is about 20µm smaller than that of printing transverse. In order to issue fine structures with the correct dimensions, it is essential to scale the layout. There is, of course, a certain amount of shrinking of the ceramic and, furthermore, an offset between the line edge on the screen and the actual line edge on the substrate. It depends mainly on the screen and the ink drying process, but also on the printing direction. This results in different correction values for structures which are aligned to X or Y direction.

Set-up of the Balun

Almost all electromagnetic energy is equally distributed in the two gaps of the CPW at 60GHz. In the SCS the flow of energy is concentrated in a single gap. The simplest way to build a balun, is to connect the lines to each other. Certainly, this is the not the best option, though, since the discontinued energy flow from the open gap causes reflections and parasitic modes. The purpose of the Balun is to guide as much energy as possible from the open CPW gap into the other continued gap, which would result in small return losses.

In order to transfer the energy of the CPW from one gap to the other, both grounds of the CPW have to be connected at the transition. This connecting stud is a fundamental part of the Balun.
The whole transition with the stud causes a discontinuity, which affects the parasitic wave modes and reflections. There are two principal ways to match the input impedance. In order to compensate this effect, one can continue the slot and have it followed by a rigorous DC short or one can continue the slot and leave it open as shown in the picture. The two methods are identical, they only differ in the length of the continued slot.

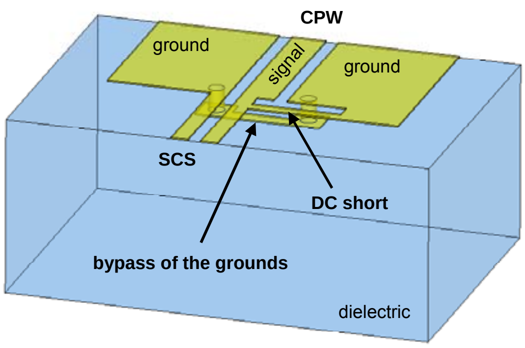


Figure 4 3D view of a Balun with a DC short

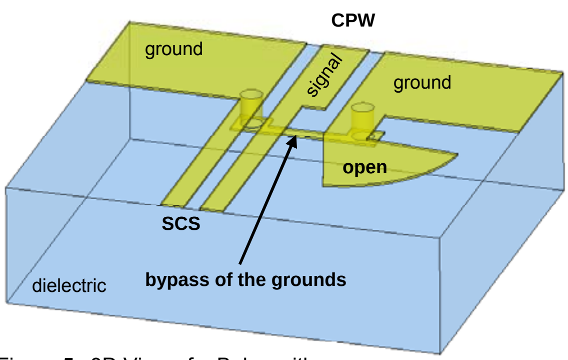


Figure 5 3D View of a Balun with an open

Parameters of the Balun

The impedances of the feeding lines have to be adjusted. The CPW should have an impedance of 50Ω and the SCS 100Ω. The gaps of the CPW and the SCS are almost identical, because of simplicity and geometrically matching.
The feeding lines, in both CPW and SCS, have critical frequencies above 100GHz. taken on their own, each of them complies with the requirements. The limiting factor is the length of the shorter one. This means, the shorter the bypass between the grounds of the CPW is implemented, the more the critical frequency of the Balun raises. As a result, the bypass cannot be shorter than the distance between the ground strips of the CPW (>290µm). In addition to this, there are other technological aspects that limiting the length of the stud, namely the thickness of the foil of 105µm and the via diameter of 75µm. According to the simulations, the critical frequency of the Balun is therefore 65GHz. The insertion losses are simulated less than 2dB within more than 30GHz.

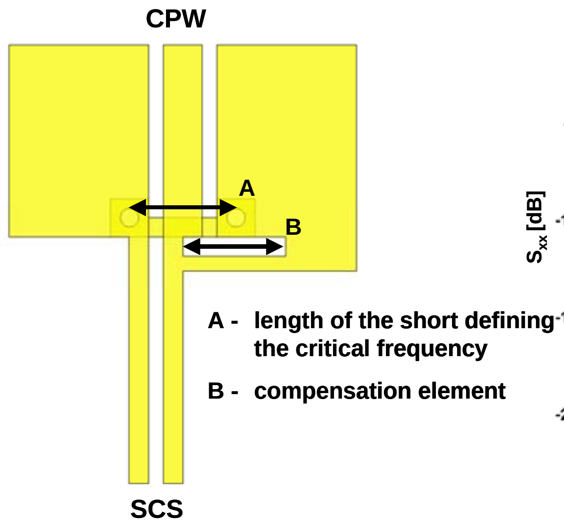


Figure 6 Top view of a Balun with a DC short

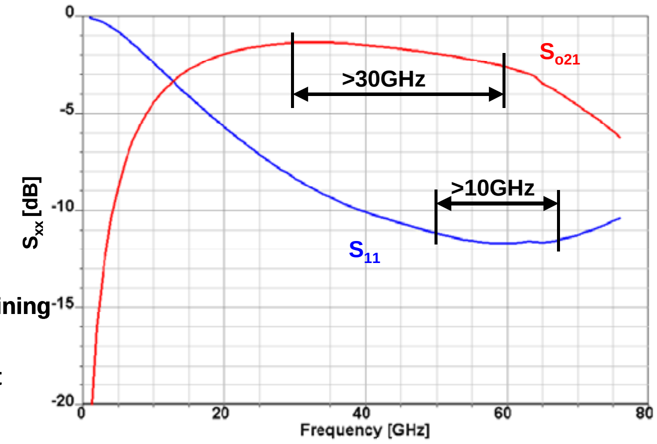
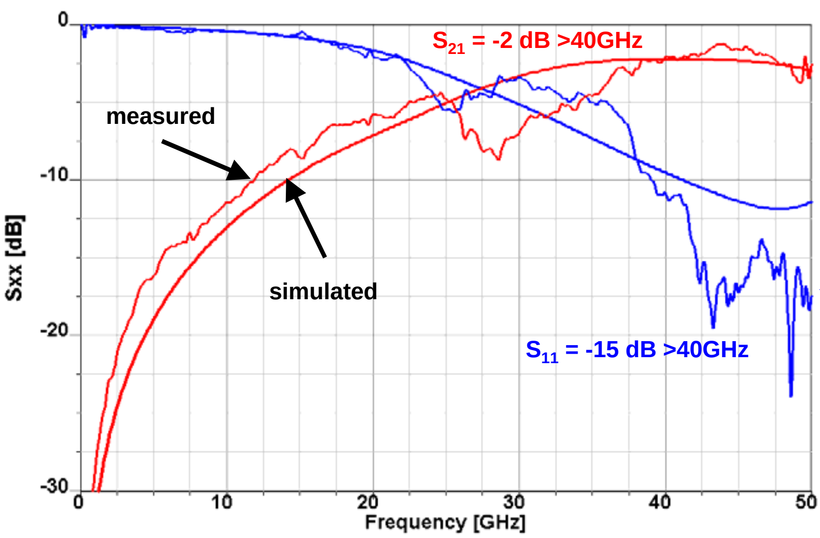


Figure 7 Simulated Balun

At the same time, the continued slot serves as a compensation element for the short one, which represents a discontinuity. As a consequence, the input is only matched within a certain frequency range. Simulations show return losses of up to 12dB across 10 GHz. The continued slot is adjusted for 61.5GHz.

Preparation and Measurements

Within the framework of investigations, it was not possible to carry out RF differential S-Parameter measurements. For this reason, the Balun structures were mirrored in order to measure them with asymmetrical test-ports. The problem of this setup is the interaction between the two Baluns. The SCS connecting the two baluns allows not only the desired differential mode, but also other, unwanted modes. The transmission performance of these passive connected Baluns depends on the length of the SCS between them. Nonetheless, this test configuration is capable to verify the simulations and the operation of the Balun. Figure 8 shows associated simulated and measured S-Parameters.



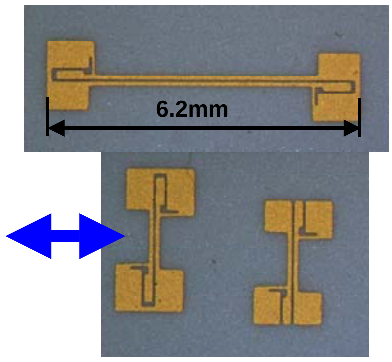


Figure 8 Simulated and measured S-parameters of two baluns connected each other

Figure 9 Manufactured baluns in symmetrical arrangement

In a further setup a differential low noise amplifier (LNA) working over a frequency range from 40GHz to 80GHz was integrated to decouple both baluns. The LNA was mounted by flip chip technology. The connecting pads have a pitch of 100µm with a size of 60*60µm².

With the Balun configuration mounted on LTCC, the signal is amplified 10dB. In comparison, on wafer measurements of the LNA shows a gain of 13dB at 50GHz [3]. The performance tests over 50GHz will follow.

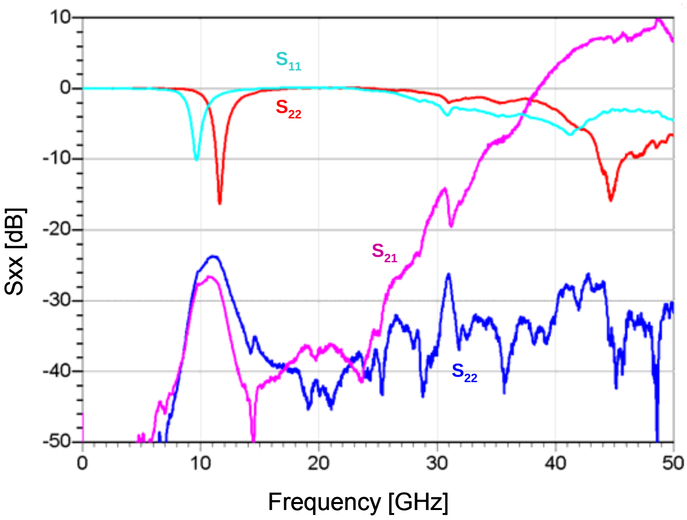


Figure 10 Measured S-parameters of a flip chip mounted LNA with baluns

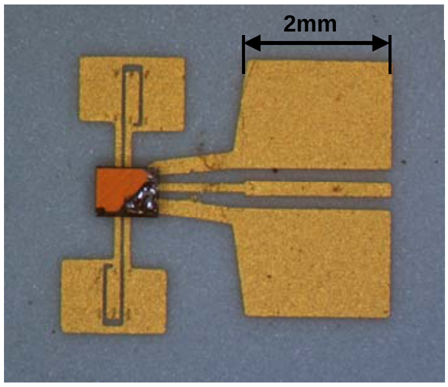


Figure 11 Flip chip mounted LNA with baluns and power supply

Conclusion

Several baluns were simulated with a full 3D electromagnetic field solver. Moreover, their feasibility was studied. Selected Baluns, whose design have been presented previously, were manufactured in standard fine line printing technology. After detailed investigations, baluns with lines of 80µm and gaps of 60µm were manufactured. DP943 gold system from DuPont® was used for the manufacturing. Applying the flip chip technology, a differential broadband amplifier with a center frequency of 61.5 GHz was mounted. The 600*700*300µm^3 large LNA has 60*60µm² connecting pads with a pitch of 100µm.

Measured and simulated results match satisfactorily, but the frequency was restricted to a limit of 50 GHz.

The measurement setup consists of two mirrored Baluns. These structures show better transmission losses than 2dB. However, the transmission performance of these passive connected Baluns depends on the length of the SCS between them. The impedance matching is supposed to be better than -15dB at 61.5GHz.
Using a differential LNA made it possible to decouple the Baluns. Although the input impedance was matched for 61.5 GHz, in the first onset a gain of 10dB at 50GHz was achieved.

Baluns up to 50GHz with a bandwidth of 15GHz are therefore realizable in standard LTCC technology. It is possible to mount flip chips with pitches down to 100um.

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