Design and manufacture of a directional coupler in LTCC

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Abstract

In this work, the design and fabrication process of a stripline 90 degree hybrid coupler using LTCC technology are presented. The main specifications required for the device developed were 1.03 GHz central operation frequency, isolation higher than 23dB and a maximum size of 15 mm x 10 mm. To obtain a starting point of physical parameters for the simplified DC configuration a transmission lines calculation program was used and design optimization was performed by simulation. Final design was developed according to specifications required, mentioned above, using LTCC material with k = 7.8 and 12 um thickness TF ink. The fabrication process required twelve LTCC 951 Dupont layers. Coupling lines and the earth planes were screen printed using Dupont 6148 Ag conductive paste. Standard lamination and firing process was applied.

Keywords: Hybrid, Coupler, LTCC, Microwave, Stripline.

Introduction

Directional couplers, with parallel coupled transmission lines, are frequently used in microwave applications to split signals and take a sample in order to measure its amplitude and power levels. A 3 dB, 90 degree coupler, commonly known as Quadrature Hybrid Coupler, is a four-port device that is used to equally split an input signal with a 90° phase shift between output ports. Microstrip and stripline edgewise structures are commonly used to implement the coupled lines, but when a tight coupling is needed, greater than about -8 dB, the spacing between the strips becomes prohibited small and the conventional edgewise configuration becomes impractical so the broadside stripline configuration is adopted in such cases [1]. For this configuration multilayer structures are needed, and Low Temperature Co-fired Ceramic LTCC process is a novel technology to fabricate three dimensional structures [2]. In this work, the design and fabrication process of a stripline 90 degree hybrid coupler using LTCC technology are presented.

Analysis and Design

The design was based in the characteristics of a commercial device but for our application an optimization in 1030 MHz was required so it was designed to work at that frequency. The main electrical specifications required for the device, according to its application, are detailed in Table 1.

Table 1. Hybrid 3 dB, 90º Specifications

Parameter	Value
Central frequency	1030 MHz
Bandwidth	>20 MHz
Reflection Coef. (S11)	<-25 dB
Isolation	>23 dB
Insertion Loss	<0.4 dB
Phase offset	<2º

Due to the high coupling level required (3 dB), the Broadside stripline configuration was used (Fig.1). In this configuration the coupled strips are vertically located in different layers. To define the first geometry approximation of the prototype, optimized for the central frequency, the analytical formulas for Broadside-Coupled strips were used [1].

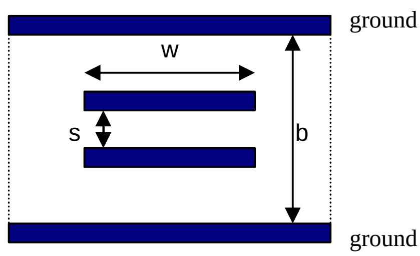

Figure 1.Schematic of broadside stripline structure

The design was then parameterized and optimized by simulation. The strips thickness (w), the spacing between them (s) and the device thickness (b) were tuned to improve the design according to the specifications. The result, using a dielectric material with k=7.8, was a substrate structure with the dimensions showed in Fig. 2.

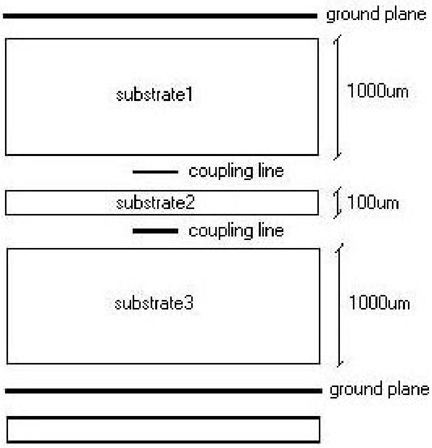

Figure 2. Substrate structure required

DuPont LTCC Green Tape was used for the substrate. In order to know the behavior and the final dimensions of the LTCC due to the stretching in the laminate process it was characterized for different thickness material, laminating pressures and temperatures. The result was 100 um and 216 um thickness LTCC layers after co-firing. According to that, for the structure of Fig.2, the substrate2 is easy obtained with one 100 um layer. Substrate1 and substrate3 could be made pilling up ten 100 um layers, but it presents the disadvantage of aligning and press a lot of layers. On the other hand, an approximation can be made by piling up four or five 216 um layers, resulting in 864 um and 1080 um substrates respectively. Both approximations were evaluated adjusting the width of the strip lines in the design to meet the specifications. The best result was obtained from a structure with 1080 um for substrates 1 and 3 and 220 um width for the strip lines.

The maximum amount of coupling occurs when the length of the coupling lines is ¼ of the wavelength (l=?/4) [3]. In our design the central frequency is 1030 MHz, so the length of the coupler must be l=18.19 mm. Due to the limited size required for the device (15mm x 10mm maximum) several layout designs were analyzed to fit the coupled lines into the substrate. The different options analyzed for the layout are shown in Fig. 3. The isolation for *Layout1* and *Layout2* designs was considerably below the required values but it was improved with the *Layout3* model, so it was selected for the fabrication process. The final dimensions and an schematic of the prototype with the port numbers adopted is showed in Fig. 4

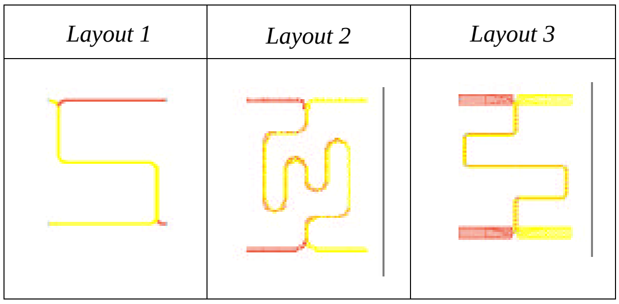

Figure 3. Layout designs

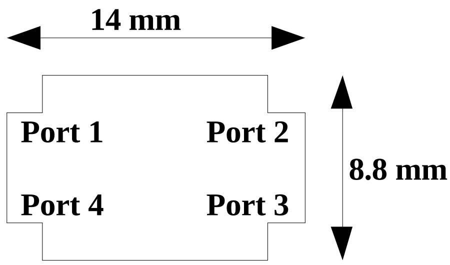

Figure 4. Prototype schematic

Fabrication Process

The mask designed for the fabrication process includes three variants identified as A, B and C, two devices of each one. The idea of the variants was to analyze ant test the results of using different size, position and shapes for the coupler terminals.

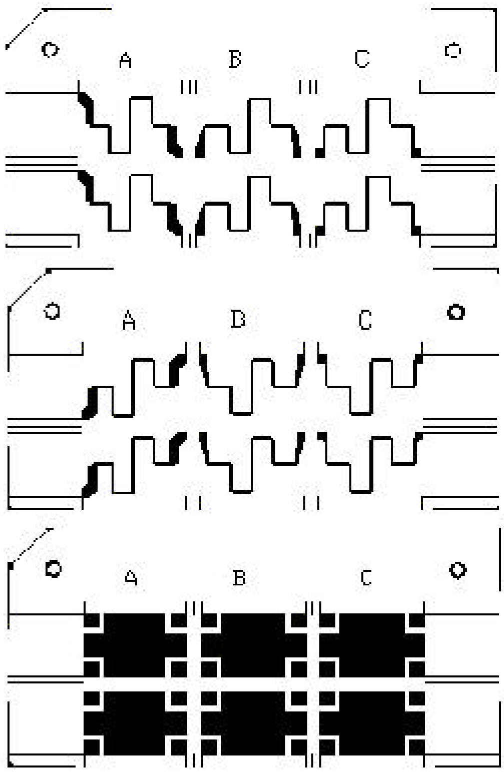

Figure 5. Masks Design

The complete mask is composed of three layers (Fig. 5), one layer for each coupler strip and another one for the ground planes.

DuPont LTCC Green Tape 951 PX (k=7.8) was used for the substrate and twelve layers were needed to complete the structure. The lamination pressure in the screen printing process was of 60 kg/cm^2 at 80°C during 3 minutes. DuPont 6148 PT silver thick film paste was used for the strip lines. Tapes were micromachined using a CNC (Computer Numerical Control) milling machine. After lamination, the device was sintered using typical LTCC temperature profile [2]

Characterization

The devices were characterized using a Vector Network Analyzer Rohde & Schwarz, model ZVRE. A test board, using Rogers RO4350 material, was designed and fabricated to connect the device under test (DUT) to the measurement system (Fig.6). The SMA connectors used in the test board were previously characterized in their own boards (Fig.7.) in order to verify their reflection coefficients. A CNC rapid prototype system was used for the test board fabrication. The connectors selected for the board were SMA Mouser connector 530-142-0701-841, 0.042" board thickness, 0.375" wide.

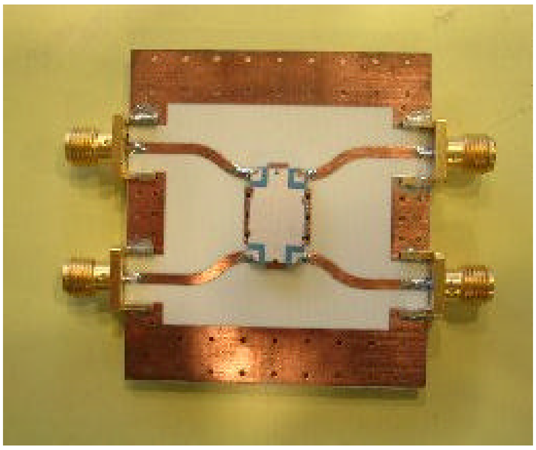

Figure 6. Test board and DUT

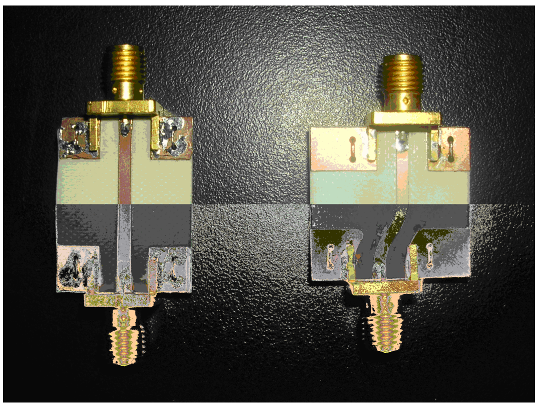

Figure 7. Connectors test boards

In order to be able to safely recover the DUT and the test board after characterization, only the four coupler ports were soldered to the board and the ground plane connection was made by mean of pressure applied to the top of the device using a press system assembled for that purpose. In that way the DUT could easily be removed after testing without damaging the component and allowing the reusability of the test board.

Results

Several prototypes of each variant type were characterized and a good repeatability in the results was obtained. The best results were found with the "variant A" and the results of the characteristic parameters measured for this device are detailed in Table 2. The performance of this prototype is showed by mean of its characteristic curves from Figures 8 to 12.

Table 2. Prototype results

Parameter	Value
Central frequency	1030 MHz
Coupling	4.71 dB
Reflection Coef. (S11)	-18.56 dB
Isolation	28.13 dB
Insertion Loss	0.49 dB
Phase	90.66

From the results in Table 1 and the characteristic curves obtained we can see that the coupling is around 1,7 dB below the required value, the isolation is around 28db so it meet the specification and it results in a directivity of 23 db (Directivity = Isolation - Coupling) and the phase and insertion loss are close to the required values.

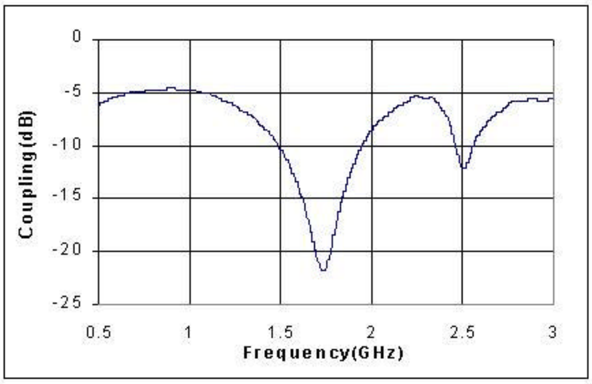

Figure 8. Coupling factor

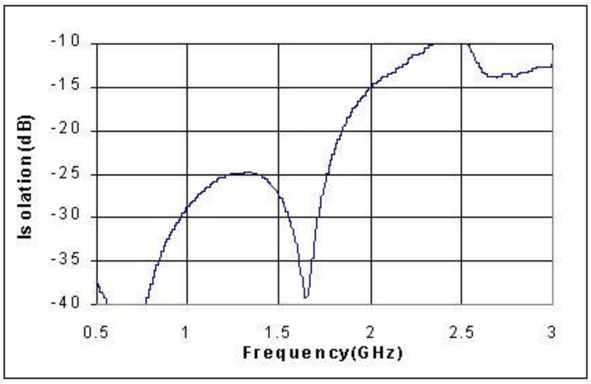

Figure 9. Isolation

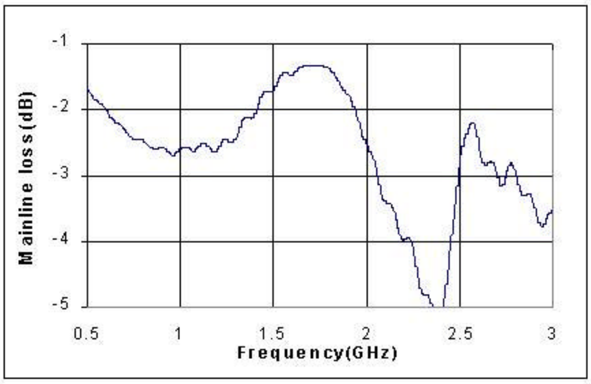

Figure 10. Mainline loss (S21)

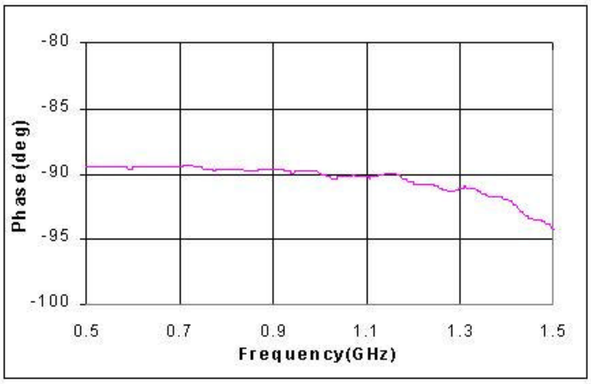

Figure 11. Phase

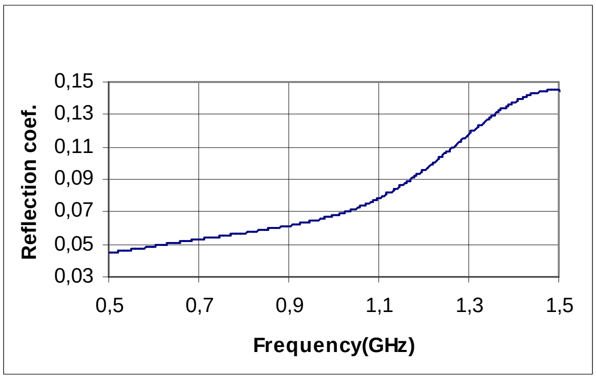

Figure 12. Reflection Coefficient (S11)

Conclusions

A 3 dB Hybrid Coupler was designed and fabricated using LTCC technology. Several prototypes were characterized and evaluated with results close to the specifications required and good repeatability was obtained. Some parameters must be improved in the design in order to adjust them to the values required by the specifications. To reach the coupling of 3 dB the spacing between strip lines must be reduced, so thinner LTCC layers will be tried in the next prototype. The devices with bigger sizes for the coupler terminals presented better isolation and some mismatch in the phase (around 3º) was found in all prototypes when using the coupler in the reverse direction so it must be improved in the next design.

References

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