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LTCC ULTRA WIDE BAND FILTER

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ABSTRACT: *This article presents the analysis of ultra wide band (UWB) filter designed using a symmetrical three parallel coupled line resonator in low temperature co-fired ceramic (LTCC) medium. The ground plane with an aperture incorporated in it improves the coupling. Based on circuit models, the designed UWB filter has been analyzed, and the results have been confirmed by experiments. The filter has been realized with Dupont LTCC tape DuPont 951 (that has dielectric constant of 7.8). Maximum insertion loss of the experimental filter is 1.5 dB. The group variation over the pass band of the filter is within 0.2 ns. Dimensions of the experimental LTCC filter are 20 × 10 × 0.72 mm.* © 2011 Wiley Periodicals, Inc. Microwave Opt Technol Lett 53:2580–2583, 2011; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26311

Key words: *coupled line; filter; LTCC; resonator; UWB*

1. INTRODUCTION

Explosive growth in wireless communications requires filters with wide pass band characteristics for ultra wide band (UWB) systems and high data rate wireless transceivers. Design of a compact broadband filter is still a key issue in many system designs [1–5]. Multilayer structures incorporating low temperature co-fired ceramic (LTCC) or stacking several layers of microwave laminates are some of the useful technologies for realizing miniaturized filters for wide band operation. Among various approaches to design UWB filters, coupled transmission lines with defected ground has been successfully used by present authors to achieve the wide band [1].

In this article, a symmetrical three parallel coupled line resonator with defected ground has been proposed to construct a compact UWB filter in two-layer LTCC structure. LTCC is widely attracting radio frequency, microwave and millimeter wave researchers for its inherent advantages like possibility of mass production, shielding of components, possibility of using silver, gold and other material combinations (unlike in High Temperature Co-fired Ceramic), high thermal conductivity and good temperature performances. LTCC offers small package, good electrical performance, better thermal stability, and low cost. Analysis of the filter based on even and odd mode propagation characteristics of the coupled line is presented in this article. Simulation results of the developed LTCC filter are compared against the experimental results for the validation.

2. DESIGN OF UWB FILTER

LTCC technology is widely used in the fabrication of miniaturized devices such as filters, couplers, and antennas. This article also uses LTCC approach to design the compact wideband filter as shown in Figure 1. This filter is designed to operate over 3–8-GHz frequency band for multi-band orthogonal frequency multiplexing applications covering first three band groups. As shown in Figure 1, the filter consists of a three parallel coupled line resonator with an aperture on ground plane. Aperture is formed by removing part of the ground conductor under the coupled lines. As shown in Figure 2 (microstrip line with aperture on ground plane), it is clear that the aperture underneath the transmission line affects the field distribution between the line and the ground, which can be viewed as an increase in the

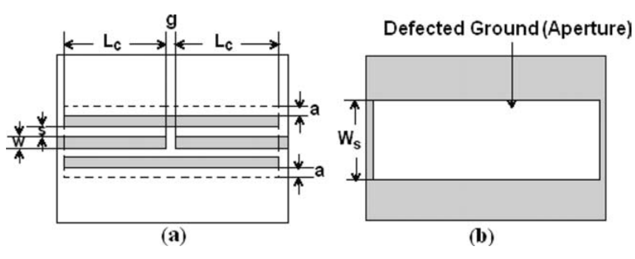

Figure 1 Two layer LTCC UWB Filter. (a) Top layer and (b) bottom layer

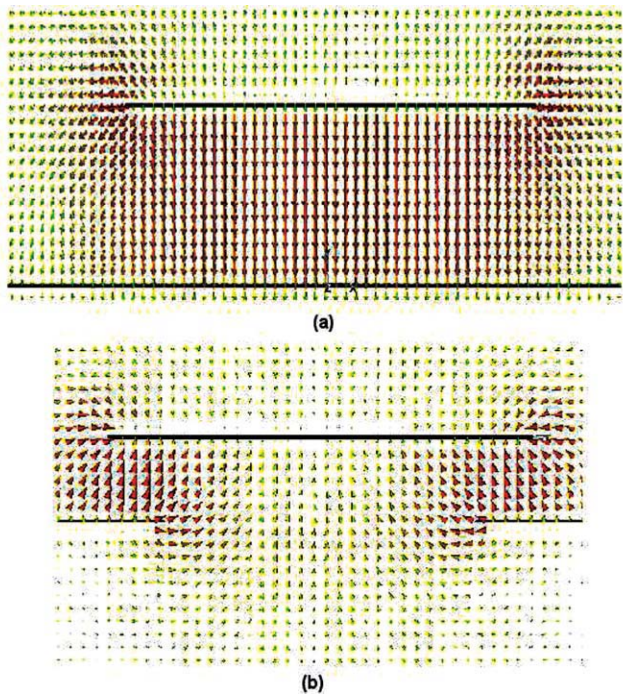

Figure 2 Field distribution. (a) Conventional microstripline and (b) Microstripline with aperture on ground. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

effective transverse distance (between the line and the ground conductor). As a result, the even mode capacitance per unit length of the coupled lines reduces resulting in an increase in the even mode impedance. At the same time, the odd mode capacitance increases resulting in reduction of odd mode impedance. Thus, using an aperture in ground plane achieves tight coupling which may be difficult to realize using conventional edge coupling due to fabrication limitations.

2.1. Circuit Analysis

The filter analysis starts with the calculation of even and odd modes of the coupled lines. Figure 3 shows the equivalent circuit of the proposed filter. Because of symmetry in filter structure, the entire structure can be analyzed by considering half of the structure with perfect magnetic conductor (PMC) as in Figure 3. PMC can also be used for multiple coupled lines to reduce it into half structure for simplifying the analysis.

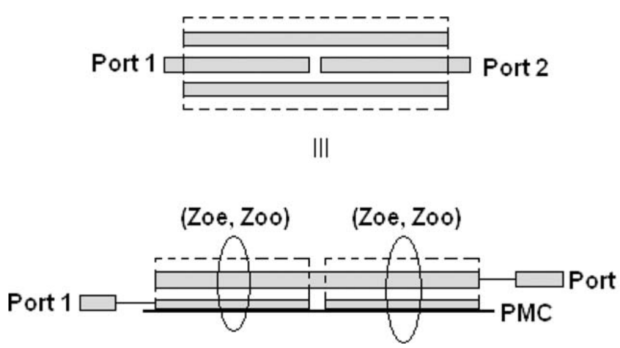

Figure 3 Equivalent circuit of the filter

TABLE 1 Geometrical Parameters of Filter

Length of coupled lines "L_c"	6500 μm
Width of coupled line "w"	250 μm
Gap "g"	700 μm
Spacing "s"	250 μm
Aperture extension "a"	200 μm
Aperture width "W_s"	1500 μm

Each coupled line section is characterized by using $[ABCD]_C$ parameters given by [6]

$$A = D = \frac{Z_{oe}\cot\theta_e + Z_{oo}\cot\theta_o}{Z_1} \quad (1)$$

$$B = \frac{j}{2}\frac{Z_{oe}^2 + Z_{oo}^2 - 2Z_{oe}Z_{oo}(\cot\theta_e\cot\theta_o + \csc\theta_e\csc\theta_o)}{Z_1} \quad (2)$$

$$C = \frac{2j}{Z_1} \quad (3)$$

where$Z_1 = Z_{oe}$ csc $\theta_e + Z_{oo}$ csc θ_o. θ_e and θ_o are even and odd mode phase velocities respectively.

2.2. Design of Filter

LTCC UWB filter is designed with the following specifications

Center frequency: 5.5 GHz
Bandwidth: 5 GHz
Tape thickness "h": 720 μm
Tape permittivity "ε_r": 7.8

The filter is designed using the following steps.

i. Finding the coupling co-efficients from the filter specifications and prototype values.
The required coupling coefficient between resonators using inverter values is 0.56.

$$Z_{oe} = 143\,\Omega$$
$$Z_{oo} = 38\,\Omega$$

ii. Finding spacing between the lines and aperture width for the required coupling coefficients.

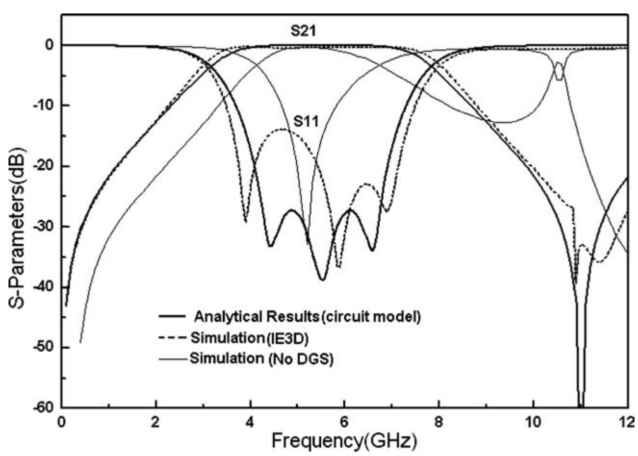

Figure 4 Analytical results of LTCC filter

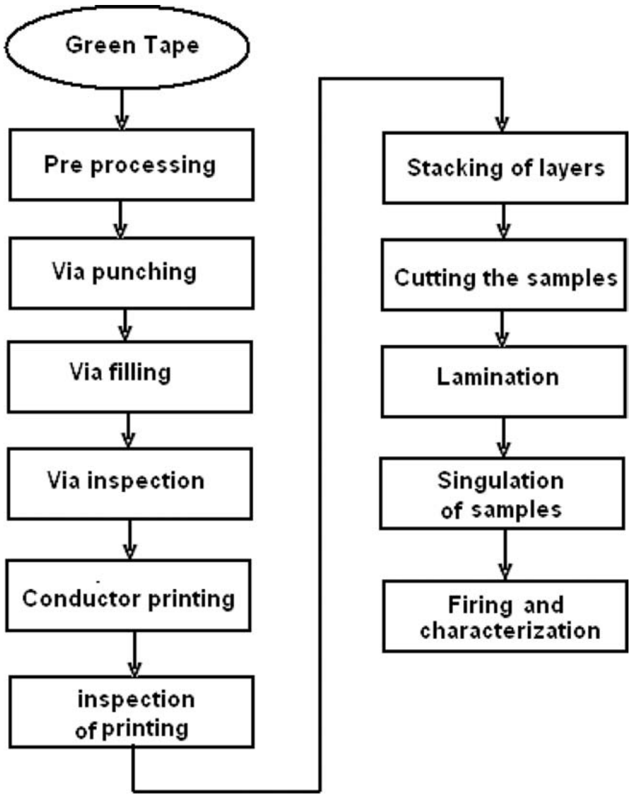

Figure 5 LTCC process used for fabrication

Physical dimensions required for the desired coupling coefficients are given below.
Width "w" of coupled lines is 250 μm. Spacing between the resonators "s" is 250 μm, the gap "g" is 700 μm and aperture width "W_s" is 1500 μm

iii. Finding the required resonator length
Resonator length "L_c" is quarter wavelength at the center frequency of the filter (5.5 GHz) which is 6500 μm

Geometrical parameters of the filter are given in Table 1. Gap effect is not considered in the analysis as it has negligible value of capacitance due to its electrical large dimensions. The analytical results (using MATLAB) are obtained by cascading individual ABCD matrix of UWB filter sections. Reflection and transmission parameters are extracted from the overall transmission matrix ([ABCD]$_T$).

$$[ABCD]_T = [ABCD]_C[ABCD]_C \quad (4)$$

Analytical results are compared against simulation results in Figure 4. The filter structure was simulated with the IE3D simulator from Zeland [7]. It can be noticed that bandwidth of the

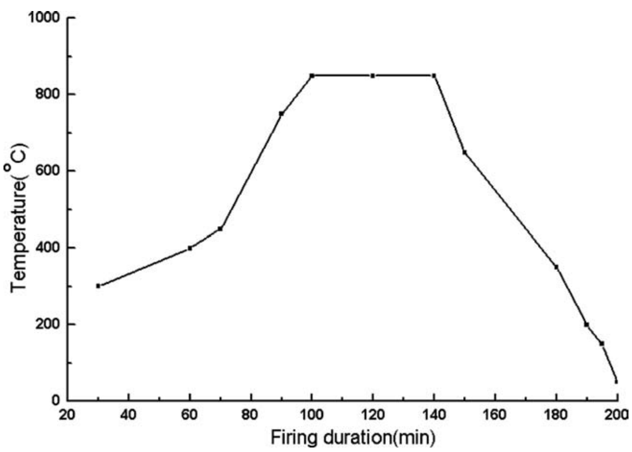

Figure 6 Firing profile of LTCC

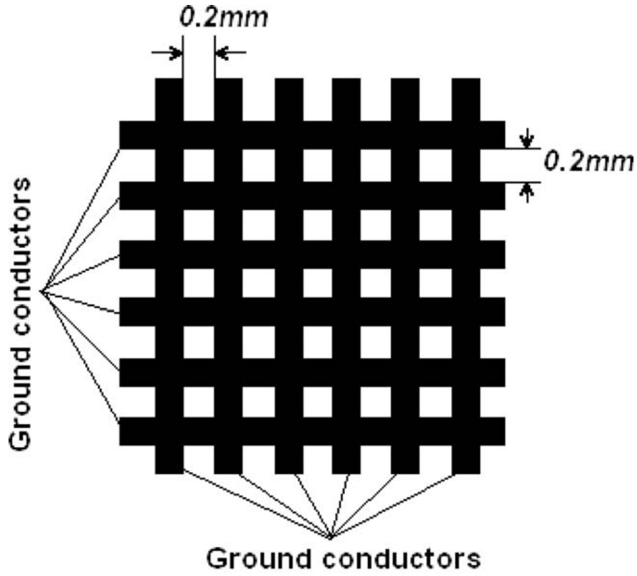

Figure 7 Meshed ground

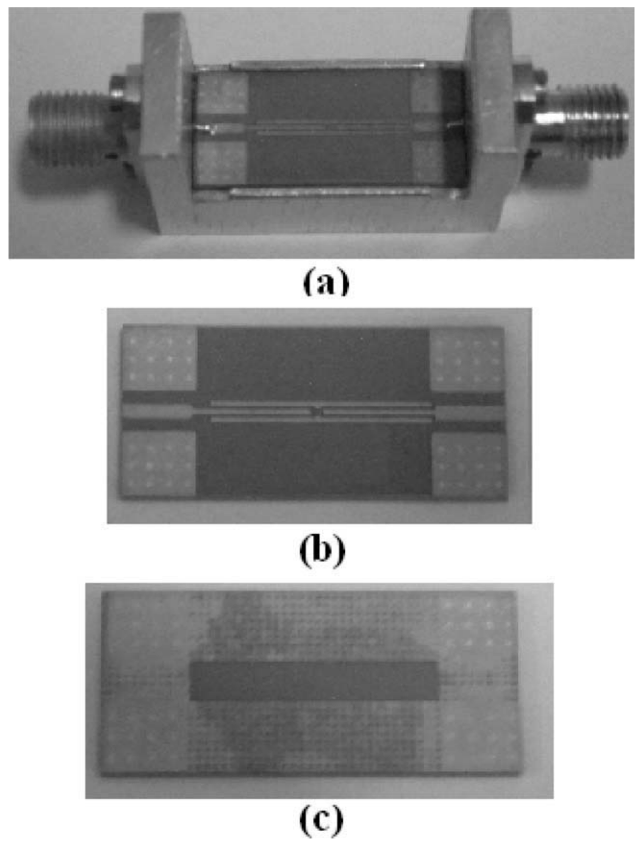

Figure 8 Developed LTCC filter. (a) Assembled filter, (b) top view, and (c) bottom view

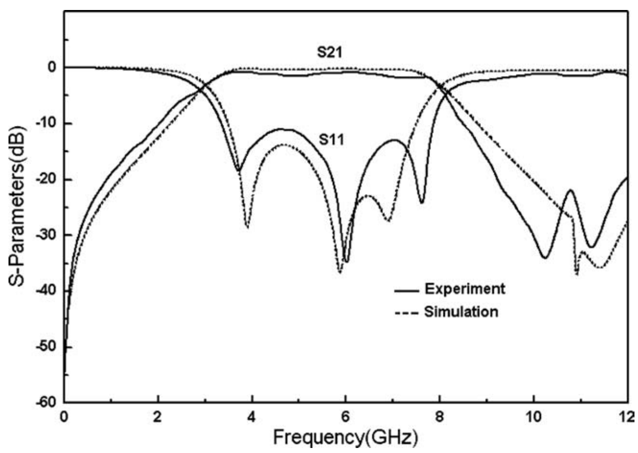

Figure 9 Measured scattering parameters of LTCC filter

proposed filter (with aperture on ground plane) is 5 GHz while the bandwidth of the filter without aperture in ground plane is 2.8 GHz. It is understood that aperture in ground plane enhanced the bandwidth by 44%.

3. EXPERIMENTAL RESULTS

An experimental filter is realized using LTCC process. The chosen LTCC process uses green tapes (DuPont 951) having thickness of 720 μm and dielectric constant of 7.8. Loss tangent of the tape is 0.014 at 10 GHz. As a first step, tapes are cut into required sizes. Holes are punched and filled. Vias having diameter of 200 μm are used for electrical interconnection between top and bottom ground layers. The fired via dimensions are 175 μm. Via filling was done using DuPont 6141 paste which is specially used for DuPont 951 tape. Conductive and resistive pastes are applied on each tape as needed. Inspection is done layer by layer before firing them, which is the key advantage of LTCC process. Then the sheets are laminated-together and fired in one step. This is done in a precisely controlled oven. Process chart used for the fabrication is shown in Figure 5. Firing takes place at low temperatures (typically at about 850°C) and the firing profile is shown in Figure 6. Silver and silver-palladium based conductors are used in the fabrication. In LTCC process, a meshed ground plane is preferred to solid ground plane for the reason of better bonding of tapes. A meshed ground with unit cell having width of 200 μm and spacing of 200 μm is used as shown in Figure 7. Lamination was done in isostatic lamination at 21MPa pressure for 10 minutes at 70°C. Figure 8a shows the developed compact LTCC filter. Figures 8(b) and 8(c) show the top and bottom views of the fabricated filter respectively. Aperture (slot) that enhances the filter's bandwidth can be seen.

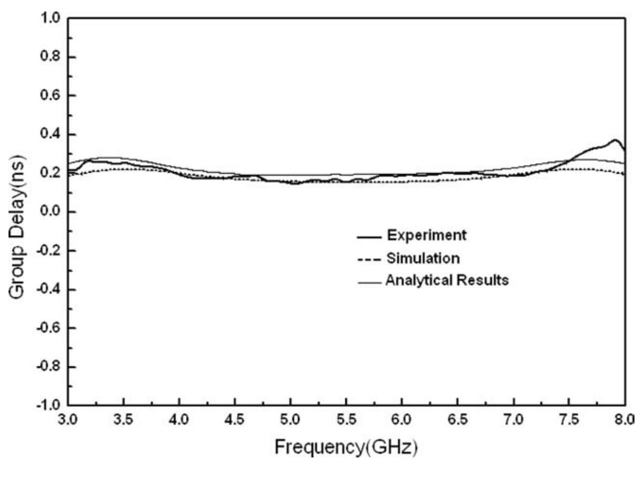

Figure 10 Measured group delay

Response of LTCC filter is measured using a vector network analyzer. A comparison is made between measured and simulation results in Figure 9. Measured pass band is from 2.95 to 8.05 GHz with a maximum insertion loss of 1.5 dB and a minimum return loss of 11 dB. Figure 10 shows the comparison between the measured and simulated group delay. Size of the realized LTCC filter is $20 \times 10 \times 0.72$ mm^3. The availability of LTCC thin tapes with high dielectric constant enabled miniaturization of the filter.

4. CONCLUSIONS

An LTCC UWB filter having pass band from 3 to 8 GHz was designed and realized in LTCC medium. It was shown that multiple parallel coupled line sections in defected ground structure topology provided the UWB characteristics. The filter was analyzed using circuit models of coupled lines and results obtained were compared against the full wave simulations and experimentation. Reasonable agreement is obtained between them. This wide band filter presented in this article can be a potential candidate filter for UWB systems due to its simple structure and good performance.

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FORMATION OF BOWTIE-SHAPED EXCITATION IN A PHOTONIC–MICROFLUIDIC INTEGRATED DEVICES

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ABSTRACT: *Narrowly confining the beam intensity in a well-defined region in the center of cell flow is a necessary step to perform*