REALISATION OF RF BAND-PASS FILTERS IN AN LTCC MODULE STRUCTURE

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Abstract

Realisation of passive multilayer pass-band filters in a low-temperature co-fired ceramic (LTCC) module structure for radio frequencies was studied. The filter structure consisted of a planar inductor, capacitors and microstrip lines printed on LTCC sheets by gravure-offset-printing technique. The filter consisted of three layers. The conductor lines of the inductor were about 100 µm wide, which enabled to make a high inductance value in a relatively small area. The relative permittivity value of each sheet was varied depending on the function of that layer.

The transmission parameters (S_{21}) *of the filter were measured by a network analyser at frequencies from 0.2 to 5 GHz. The electrical values of the components of the filter were measured by an LCR meter at the frequency of 1 MHz. The measured transmission parameters were used as goal data in the APLAC circuit simulator in order to find the values of the lumped elements for the equivalent circuit. The centre frequency of the band pass was 1.2 GHz with the bandwidth of about 50 MHz. The insertion loss was less than 1 dB and the attenuation at the band stop was over 10 dB. The calculated quality factor at the centre frequency was higher than 20.*

1. INTRODUCTION

The use of low-temperature co-fired ceramic (LTCC) materials is becoming an interesting alternative for telecommunication applications [1]. Number of the manufacturers involved in the LTCC technology is increasing all the time, which increases the availability of the materials. Also, the properties of LTCC materials are improving. Good electrical properties and the possibility to integrate passive components inside the LTCC module are important aspects when dealing with the high-frequency applications [2]. These passive components can be used as basic building elements to make a passive filter.

The most common manufacturing method to make passive components on the LTCC sheet is screen-printing technique. In order to avoid the limitations of the technique in printing of narrow conductors the gravure-offset-printing technique has been developed [3]. With this technique it is possible to print narrow conductor lines down to 50 µm. In this study the technique was utilised to print the passive components of the RF band-pass filter.

2. REALISATION OF THE FILTER

2.1. Design

The structure and component values of the 3-stage Butterworth band-pass filter (Fig. 1a) were used as a basis of the design [4]. This structure was modified (Fig. 1b) by taking into account the aspects of the realisation. For example, the series capacitance (C2 in Fig. 1a) was divided to both sides of the series inductor to eliminate the need of via holes from the inductor. Also the inductances to the ground layer (L1 and L3) were removed in order to simplify the realisation of the structure.

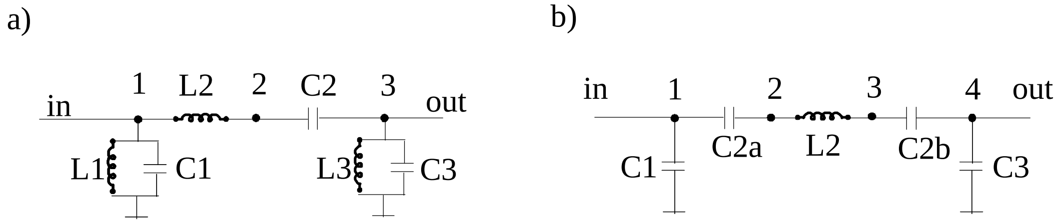

Figure 1. a) A prototype Butterworth band-pass filter and b) a modified band-pass filter.

The filter was made on the basis of this modified structure. The structure of this three-layer filter is shown in Fig. 2 where the node numbers correspond to the nodes in the equivalent circuit of the filter shown in Fig. 3. This equivalent circuit takes into account, e.g., capacitive parasitics caused by the small distance between the inductor and ground layer.

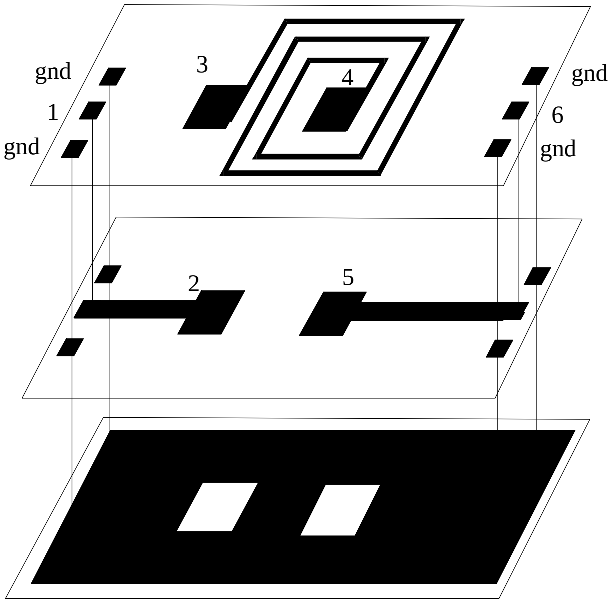

Figure 2. The structure of the filter consists of three layers.
The lines between different layers describe via holes.

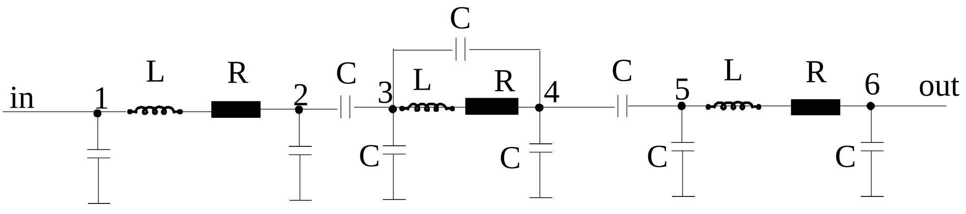

Figure 3. The equivalent circuit of the filter.

The simulation showed that the inductance and resistance of the microstrip lines were small enough to be neglected from the equivalent circuit as shown in Fig 4. The geometrical dimensions for the layout of the microstrip lines, capacitor pads and inductor were calculated and are given in Table 1. In the design of the inductor previous experimental work was utilised to define its size, number of turns and line width and space. The shrinkage of the LTCC materials during sintering was naturally taken into account in the design. In addition to the values shown in Table 1, the calculated value of the parasitic capacitance between the inductor and ground layer (C20 and C30 in Fig. 4) was 1.5 pF. With these values the centre frequency was 1.25 GHz and the 3 dB bandwidth was below 100 MHz.

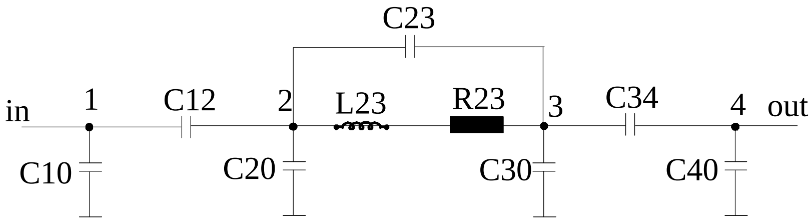

Figure 4. The simplified equivalent circuit of the filter.

Component	Nodes	Value	Width [mm]	Length [mm]
Microstrip	C10=C40	2 pF	0.200	0.970
Series capacitor	C12=C34	645 fF	0.880	0.880
Series inductor	L23	22.5 nH	0.100	19.0

Table 1. The designed values and fired dimensions of the components. The relative dielectric constant of the microstrip line layer was 100 in the calculations.

2.2. Realisation

The conductor layers were printed on 110 µm thick unfired commercial LTCC sheets (D-41010-70C (ε_r=8) and D-41210-70C (ε_r=100) from ESL). The ground plane on the bottom layer and the inductor layer on the top surface were printed on the sheet with a lower permittivity to reduce the effect of parasitics. The inductor consisted of 2.5 turns and its size in the layout was 2.7 x 2.7 mm^2. The microstrip lines were printed on the sheet with the higher permittivity to increase the capacitance value between the microstrip line and ground plane, which corresponds to the values C10 and C40 in the equivalent circuit of Fig. 4.

The conductors were printed by the gravure-offset-printing technique by using commercial Ag thick-film pastes with modified properties optimal for this printing technique. Accuracy of the printing machine was ±10 µm. Via holes of 100 µm diameter were made by a Nd-YAG-laser into unfired sheets. The printed sheets were laminated at a temperature of 70 °C and at a pressure of 20 MPa. The laminated structure was co-fired at 400 °C for 10 hours followed by a conventional thick-film firing process at a peak temperature of 850 °C for 10 minutes.

3. RESULTS AND DISCUSSION

3.1. Simulation

Each lumped element has some effect on the filter behaviour and this was studied by simulating the structure with the APLAC circuit simulator. The simulation showed that the inductance and resistance of the microstrip lines had only a small effect on both the centre frequency and the attenuation of the band pass. The series inductance (L23) and the parasitic capacitance between the inductor and ground plane (C20 and C30) had the most powerful effect on the filter behaviour. A change of 2% in the parameter value already affected the centre frequency of the band pass. Also the series capacitance (C12 and C34) and the parasitic parallel capacitance between the turns of the inductor (C23) had an effect on the quality of the band pass.

3.2. Geometrical measurements

The geometrical properties (width and thickness of conductors, etc.) were measured by an optical microscopy and a DEKTAK^{3}ST surface profiler meter. The line width of the fired conductors in the inductor pattern was 100 µm ±10%. The average horizontal shrinkage of the LTCC substrate during firing was about 12% and the vertical shrinkage was 18%. The surface roughness (R_a) was less than 1.5 µm and the thickness of the three layer substrate was 255 ± 10 µm on the 30 x 30 mm^2 area in the LTCC module consisting only of low permittivity sheets. When the high permittivity sheet was included, the surface roughness and thickness variation unfortunately increased.

3.3. Electrical measurements

The resistivity of the conductors was 5×10^{-8} Ωm and the thickness of fired conductors was 6 µm in average. The inductance of the series inductor measured by the LCR meter (HP 4284A) was between 21.5 and 23.9 nH. The LCR meter was also used to track possible faults in the filter structures, i.e., the discontinuities in the via holes.

The transmission parameters (S_{21}) were measured by the network analyser (HP 8719C) at the frequencies from 0.2 to 5 GHz. The S_{21} parameters of the band-pass filter at the frequencies from 1.1 to 1.3 GHz are shown in Fig. 5. The centre frequency was 1.20 GHz with a negligible attenuation. The 3 dB bandwidth was 52 MHz, which resulted in the quality factor, Q, of 23 calculated by the equation

$$Q = \frac{F_r}{\Delta F} \tag{1}$$

where F_r is the centre frequency of the band pass and ΔF is the 3 dB bandwidth. The simulation results of the same filter from the equivalent circuit of Fig. 4 are also shown in Fig 5.

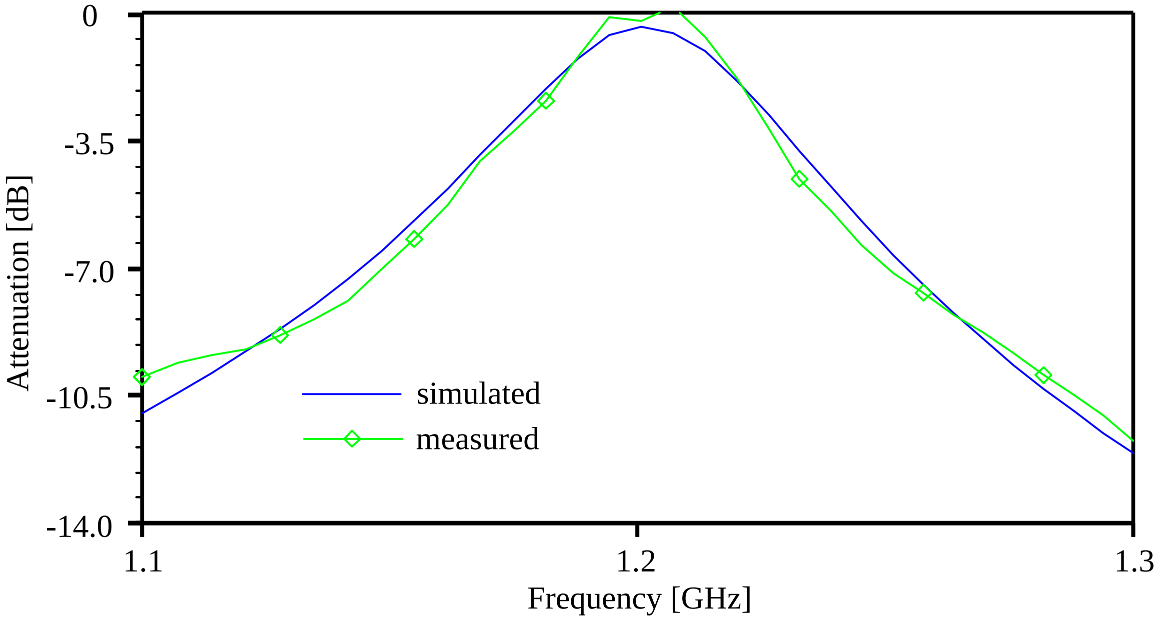

Figure 5. The measured and simulated transmission parameters of the band-pass filter.

The simulated component values obtained by using the measured transmission parameters as goal data are given in Table 2 where also the calculated values are shown, for comparison. The component codes are shown in Fig. 4. The parameter values of L23 and C23 were taken from the LCR meter measurements and kept constant in the simulation.

Component	Simulated	Calculated
C10	1.86 pF	2.0 pF
C12	606 fF	645 fF
C20	948 fF	700 fF

Table 2. The simulated and calculated component values.

3.4. Discussion

The centre frequency was 1.25 GHz with the designed values while the centre frequency of the realised filters was between 1.19 and 1.21 GHz. The measured 3 dB bandwidth was 55 MHz in average. The attenuation of the realised filters was less than 1 dB. Of course, some samples failed having considerably higher attenuation. The problems in most of these cases were related to poor metallisation of via holes.

The simulation results matched quite well with the calculated component values. Some differences between the calculated and simulated component values existed due to the printing process where the variation of line width and alignment accuracy could cause changes in the component values.

CONCLUSIONS

The realisation of a passive band-pass filter in an LTCC module structure was studied. The filters were operating at the centre frequency of 1.2 GHz with a low attenuation. The component values simulated together with the measured transmission parameters were in good agreement with the calculated values. Some differences between these two values arose mainly from the printing and alignment steps.

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