Multilayer Low Pass Filter Using LTCC Technology

Xi-Dan Chen, Ying-Li Liu, and Yuan-Xun Li

Abstract—The implementation and characteristics of a compact lumped-element three-order low pass filter are presented in this paper. The filter with 120 MHz cut off frequency, as well as more than 20 dB of the attenuation above 360 MHz frequency band is successfully manufactured in an LTCC substrate with 40 μm layer thickness. The overall size of the filter is 2.0 mm×1.2 mm×0.9 mm. A good coincidence between the measured results and the full-wave electromagnetic designed responses is observed.

Index Terms—low pass filter, low temperature co-fired ceramic (LTCC), lumped-element filter, multilayer RF circuits.

1. Introduction

The latest wireless products demand ever-greater functionality, higher performance, and lower cost in smaller and lighter formats. These demands have been satisfied to date by major advances in integrated circuit and high-density packaging technologies. One of the important developments is low temperature co-fired ceramic (LTCC) which has two obvious potential advantages. First, miniaturization is possible by vertical deployment of filter elements since there are many dielectric layers available. Second, it can reduce the component and assembly cost by effective passive integration [1].

At present, LTCC provides an ability to embed passive components in layers while the active elements are mounted onto the surface layer, which can realize the combination of the passive and active components for RF modules such as power amplifier modules [2]-[5], transceiver modules [6],[7], voltage controlled oscillator modules [8].

Multilayer low pass filter is one of the simplest passive modules of LTCC. We will implement and measure a conditional three-order Butterworth filter by using one inductor and two capacitors, the key step of implementation is accurate control of the passive components of the filter. The proposed filter is fully integrated into a general LTCC substrate and has a very simple structure and small size for wide application and low-cost realization.

2. Circuit Implementation

2.1 Circuit Model

The conditional three-order Butterworth filter configuration is implemented based on the lumped-element L-C filter circuit shown in Fig. 1.

Fig. 1. The π section filter circuit.

Based on the synthesis method using circuit simulator advanced design system (ADS), a π section filter circuit with 120 MHz cut off frequency and more than 20 dB of the attenuation above 360 MHz frequency band has been designed. The corresponding component values in Fig. 1 are \( L, C_1, C_2 \) are 132.63 nH, 26.53 pF, 26.53 pF respectively. The curves in Fig. 2 show the transmission and reflection responses of the π section filter circuit.

Fig. 2. Responses of the filter circuit: (a) transmission response (b) reflection response.
2.2 Component Implementation

After the simulation of the circuit model, the next step taken is to implement those components in a multilayer LTCC. An important part of the design circle is the extraction of accurate component model for use in high frequency structure simulator (HFSS). Lumped equivalent circuit, an electromagnetic generated S-parameter database have been investigated. With the collection of the electrical responses of various component shapes and sizes, proper HFSS models can be chosen for different available values.

For 132.63 nH, the inductor fabricated is square spirals. They are 2.5 turns and the physical configuration uses the green tape of PPT LSF120 with the relative permeability constant of 60. The metal loss of silk ink with LTCC ($R_s = 0.0024 \, \Omega/m$) and the dielectric loss of the green tape ($\tan \delta = 0.005$) have been taken into account during the simulation. The helical type inductor topology is shown in Fig. 3 (a) and the frequency dependent inductance is shown in Fig.3 (b).

For 26.53 pF capacitor, FERRO ULF140 is utilized with the dielectric constant of 14 and dielectric loss about 0.0015. Fig. 4 shows three dimensional configuration of the capacitor. The two different types of plates connect to two opposite sides. Silver is printed on the two opposite sides as electrodes. When an inductor is added to form a filter, the capacitor will be separated to two parallel capacitors.

Fig. 5 shows the frequency dependent capacitance. It can be seen that in the same frequency range, the capacitance has a smaller fluctuation than the inductance.

Fig. 5. Effective capacitance of the designed capacitor.

Having had these simulations, the initial physical layout of the proposed filter can then be easily set up. A fine tuning is required to accommodate the parasitic effects of each lumped element, mutual coupling effects between elements, and finalize the layout design by employing full-wave simulation tool. Fig. 6 shows final three dimensional LTCC layout of the filter. Two metal ground plates, which are connected to each other via holes, cover the structure on the top and the bottom.

Fig. 6. Three dimension LTCC layout of the filter.

Fig. 7. Responses of the physical layout: (a) Transmission responses and (b) Reflection responses.
Characteristics of the filter simulated by HFSS software are presented in Fig. 7 (a) and (b). From the responses of the three dimensional configuration, a cut off frequency 120 MHz, more than 20 dB of the attenuation above 360 MHz frequency band can be obtained, which well satisfy with the filter performances and agree well with the responses of the filter circuit.

3. Experimental Data

For LTCC process technology, the compatibility of system materials with respect to shrinkage, thermal expansion coefficient and chemical compatibility must be considered, different shrinkage rates of the fired specimens make the materials distort during co-firing, which causes deviation from the designed parameters. The pre-cofiring tape must be larger than that of the designed model. Fig. 8 (a) and (b) show the inductor films. Note that the films should be designed to connect the electrodes for packaging easily. Capacitor films are shown in Fig. 8 (c) and (d). All tapes are realized in the 0805 size of standard packaging laminated filter.

The three-order laminated low pass filter with 120 MHz cut-off frequency is successfully manufactured using LTCC technology, and the samples are shown in Fig. 9. The overall dimension is 2.0 mm×1.2 mm×0.9 mm without input and output pads for measurement.

Fig. 8. Films for the filter components: (a) and (b) films of inductors (c) and (d) films of capacitors.

Fig. 9. The filter samples.

The measurement is carrying out by connecting one probe station to the two external ports of the device. The experimental data of the filter characteristics is performed by using Agilent 8722ES vector network analyzer. The collected data is then calibrated to the desired reference plane by the thru-reflect line (TRL) technique through carefully designed calibration standards embedded in the same LTCC tile. The measured responses of the fabricated filters are shown Fig. 10 (a) and (b).

Fig. 10. Responses of the prototype: (a) transmission responses and (b) reflection responses.
From Fig. 10 (a) and (b), the three-order $\pi$ section filter reveals about 22.5 dB insertion loss at 360 MHz. A good coincidence between simulated and measured data is observed. Nevertheless, the measured cut off frequency is about 130 MHz, which is different from the estimated frequency. It is believed that the deviation comes from the additional inductive and capacitive parasitic effects caused by vias and fabrication errors, the deviation can be corrected by stabilizing fabrication process and more analysis of the via effects. On the other hand, the process technology also has many factors causing inaccuracy. Firstly, during the co-firing, the organic solvent in the silver conductor can not discharge all air bubbles, which causes the inductance and capacitance smaller and the self-resonance frequency larger. Secondly, the effective values of the components can not be controlled accurately due to the difficulties of tiny manipulation problems.

4. Conclusions

In this paper, a compact $\pi$ section low pass filter has been implemented as multilayer integrated circuit using LTCC technology. The measured characteristics of the filters manufactured are in a good agreement with those HFSS simulations. This kind multilayer lumped-element topology allows a higher level of RF module integration and the elimination of the need for discrete filters.

References


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