Modified Equivalent Circuit Model of Microwave Filter with LTCC Technique

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Abstract—Because microwave products in the consumer electronics market are continuous developing, device and component manufacturers have to seek new advanced integration, packaging and interconnection technologies, as size, cost and performance are critical factors for the success of a microwave product.

One of the most promising integration technologies is the multilayer low temperature co-fired ceramic technology (LTCC). In this technology, passive components, such as inductors, capacitors and filters, are integrated into multilayer LTCC substrate. The purpose of this paper is to address the special method that should be considered for designing LTCC microwave filter. It is given how to get equivalent circuit about multilayer ceramic microwave filter that is striplines configuration or LC configuration, especially, modified equivalent circuit model is proposed, where the relation between the lumped parameters and physical dimension of LTCC microwave filter is discussed. The capacitance and inductance matrix of LTCC microwave filter is obtained using the fast multipole method. Finally, two microwave filters are designed by the novel design method of field-circuit and HFSS. The novel design method of field-circuit is more efficient, therefore, the designing time can be shortened.

1. Introduction

Low-temperature-cofired ceramics (LTCC) for microwave applications represent a key position in the development of future electronic products in a high frequency application for IC packaging radar, antennas and wireless technologies. The integration of passive components in LTCC is, therefore, particularly interesting in multilayers technology. Integration of passive devices in wireless application corresponds to the trend of mobilization and miniaturization with high electrical performance using conductive electrode materials such as gold, silver and copper. Several kinds of multilayer microwave devices have been developed, and some design methods and fabrication procedures reported [1-4]. Hence, they can be easily incorporated in the design of a variety of RF components such as passive components, voltage controlled oscillators (VCO_s), power amplifiers (PA_s), and mixers.

Among various passive components, people usually pay the most attention to the filter. Now a lumpedelement RF filter can be implemented in a stacked structure. Engineers usually use HFSS, which is a software employed by Ansoft used for high frequency E/M simulation, to design these passive components. One side, HFSS is an advanced simulation software, which can accurately calculate the E/M fields with every engaged point in the component. So its result is convictive. On the other side, HFSS is not very effectively because of long time waste depending on the capability of your computer and the simulation precision you want. This paper introduces the designing of fast multipole method for the passive filter. It is shown more effective than the HFSS by experiment proof-testing.

2. Getting Capacitance and Inductance Matrix Using the Fast Multipole Method (FMM)

Figure 1 shows there are M conductors between two grounds. $\therefore Q_n = \sum_{m=1}^M C_{n,m}V_m$, where Q_n is the quantity of charge of conductor n and V_m is the electric potential of conductor m. $C_{n,m}$ represents the capacitance between conductor n and conductor m when the electric potential of conductor m is V_m and the electric potential of conductor n is 0.

Provided that S_n , $\rho_n(r')$ are, respectively, the superficial area and surface charge density of conductor n, quantities of electric charge Q_n of conductor n can be given as:

$$Q_n = \int_{S_n} \rho_n(r') dS \tag{1}$$

For every point on the conductor surface, the electric potential of the point can be drived by considering the

image charges, we have

$$\Psi(r) = \frac{1}{4\pi\varepsilon_r\varepsilon_0} \left[\sum_{n=1}^M \int_{S_n} \frac{\rho_n(r')}{|r-r'|} dS + \sum_{i=1}^\infty \sum_{n=1}^M \int_{S_n^i} \frac{\rho'_{n,i}(r')}{|r-r'_{n,i}|} dS \right]; r \in S_m, m = 1, 2, \dots, M$$
(2)

where $\rho'_{n,i}(r')$ represents the *i*-th mirror of $\rho'_n(r')$, S^i_n represents the superficies of $\rho'_n(r')$.



Figure 1: Multi-condutor system in medium between two grounds.

Using moments method we can devide the superficies of the conductor to N pieces, provided that the charge on every piece is uniform:

$$\Psi_{l}(r_{l}) = \frac{1}{4\pi\varepsilon_{r}\varepsilon_{0}} \left[\sum_{k=1}^{N} \int_{T_{k}} \frac{\rho_{l}(r')}{|r_{l} - r'|} dS + \sum_{i=1}^{\infty} \sum_{k=1}^{N} \int_{T_{k}^{i}} \frac{\rho_{l,i}'(r')}{|r_{l} - r_{l,i}'|} dS \right]; r \in T_{k}, k = 1, 2, \dots, N$$
(3)

The capacitance matrix can be formed by the above sets of equations:



Figure 2: The structure of stripline configuration filter with LTCC.

The inductance matrix can be expressed as:

$$[L]_{n,m} = \varepsilon_0 \mu_0 \left[C_0 \right]_{n,m}^{-1} \tag{5}$$

With the equations based on the multipolar method we can get the capacitance matrix and the inductance matrix. we have proved that the method is convincing.

3. Modified Equivalent Circuit of BPF (Bandpass Filter)

3.1. Analysis of the Striplines Configuration Filter [5–7]

The schematic configuration for the striplines filter to be implemented is shown in Figure 2. It is consisted by three layers: T layer, M layer, and B layer. It is shown that this is a two LC resonance filter, and the configuration of two LC resonance is uniform. In the experimental filter, inductance L of resonance is presented by self-in-inductance LM of conductor M. resonate capacitance M is presented by self-in-capacitance CM of conductor M and coupling capacitance CT between conductor M and conductor T and coupling capacitance CB between conductor M and conductor B. Coupling C12 between resonance cells are consisted by the total of each coupling capacitance.

We give the modified equivalent circuit about the striplines configuration filter, as shown in Figure 2. The schematic illustration of the modified equivalent circuit is shown as Figure 4:



Figure 3: Traditional equivalent circuit.

Figure 4: Modified equivalent circuit.

In traditional equivalent circuit, there is no one-to-one relationship between the striplines configuration and equivalent circuit numerical value in detail. But in modifided equivalent circuit, there is one-to-one relationship between the striplines configuration and equivalent circuit numerical value in detail.

3.2. Simulation Results

The scatterring parameter S_{11} , S_{21} can be expressed as follows:

$$IL = 10\log\frac{P_{in}}{P_L} = 10\log\frac{1}{|S_{21}|^2} = -10\log|S_{21}|^2 \text{ (dB)}$$
(6)

where $S_{11} = \Gamma_{in}$, $\rho = \frac{1+|S_{11}|}{1-|S_{11}|}$, $\Gamma_{in} = \frac{Z_{in}-Z_0}{Z_{in}+Z_0}$

Every no-loss component can be expressed as:

$$|S_{21}|^2 = 1 - |S_{11}|^2 \tag{7}$$

Through the above parameters we can get Insert Loss (IL), Bandpass (B) and VSWR. The input impedance can be obtained in following equations:

$$Z_{in} = \left((Z_L / / Z_{CT2} / / Z_{LM2} / / Z_{CM2} / / Z_{CB2}) + Z_{C12} \right) / / Z_{CT1} / / Z_{LM1} / / Z_{CM1} / / Z_{CB1}$$
(8)

The characteristic parameter of the component can be expressed in curves through following equations:

$$S_{11} = 20 \log \left| \frac{Z_{in} - Z_G}{Z_{in} - Z_G} \right| (dB)$$

$$\tag{9}$$

$$S_{21} = 10\log(1 - |S_{11}|^2) = 10\log(1 - \left|\frac{Z_{in} - Z_G}{Z_{in} - Z_G}\right|^2)(\text{dB})$$
(10)

Now we provide a multiplayer ceramic microwave filter with the size of $2.0 \text{ mm} \times 1.25 \text{ mm} \times 0.95 \text{ mm}^3$ to certify the correctness of the method comparing HFSS simulation with the dielectric constant 27:

The following graphs demonstrate the results respectively:



Figure 5: The structure of models.

model	d1	d2	d3	d4	T_L	T_W	M_L	M_W	B_L	B_W
0	0.045	0.26	0.28	0.5	1	0.15	1	0.35	1	0.25
1	0.05	0.26	0.28	0.5	1	0.15	1	0.35	1	0.25
2	0.04	0.26	0.28	0.5	1	0.15	1	0.35	1	0.25
3	0.045	0.26	0.28	0.6	1	0.15	1	0.35	1	0.25
4	0.045	0.26	0.28	0.7	1	0.15	1	0.35	1	0.25
5	0.045	0.26	0.28	0.6	1	0.15	0.8	0.3	1	0.25
6	0.045	0.26	0.28	0.6	1	0.15	0.8	0.5	1	0.25
7	0.048	0.49	0.55	0.8	2.3	0.4	2.3	0.6	2.3	0.2
8	0.048	0.49	0.55	0.65	2	0.2	2	0.4	2	0.3
9	0.048	0.49	0.55	0.65	1	0.15	3	0.3	1	0.25
Note: d1=d,d2=d_t,d3=d_b,d4=d_centers										



Figure 6: Result using the modified equivalent circuit(left) and with HFSS(right).

Analyzing the two graphs above, several differences can be found including inset loss, stop band attenuation, band width, reflection in the input port.

4. Conclusion

The simulation results prove that modified equivalent circuit model where the relationship between the concentrate parameters and physical dimension of LTCC microwave filter is corrected. The novel design method

of field-circuit has high efficiency, therefore, the designing time can be shortened.

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