An Embedded RF Lumped Element Hybrid Coupler Using LTCC Technology

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Abstract – A novel embedded RF lumped element 3-dB hybrid coupler is proposed by a 3D vertical architecture using LTCC technology. The innovative architecture deliberately inherits the parasitic capacitance that is inevitable to embedded inductors for size reduction. A prototype is build and tested to prove the concept. This work demonstrates the advantages of LTCC technology for reducing the size and manufacturing cost of RF circuits.

I. Introduction

The latest wireless products demand ever-greater functionality, higher performance and lower cost in smaller and lighter formats. Due to the overlong wavelength of current popular wireless frequency bands, a distributed RF circuit has its inherent limitation in size reduction. Lumped element circuits, on the other hand, provide an effective means to alleviate the predicament, provided that an appropriate low loss multilayer substrate is employed. Low Temperature Cofired Ceramic (LTCC) technology, with its low dielectric loss, high flexibility for a 3D circuit configuration, and low manufacturing cost for high volume production, is certainly an excellent candidate for the purpose [1,2].

3-dB hybrid coupler is one of the most popular components used in RF/microwave engineering [3,4]. However, for RF applications, a distributed element hybrid coupler occupies a large real estate due to the nature of quarter wavelength branch lines. A significant size reduction can be realized by using a high Q lumped element circuit without noticeable degradation in electrical performance.

In this paper, a novel 3D vertical architecture for embedded lumped element 3-dB hybrid coupler is proposed. The layout is deliberately designed in the way that the parasitic capacitance is beneficially used to reduce the circuit size. A prototype of the proposed coupler is built in a 7-layer LTCC substrate to prove the concept. A good agreement between the measured and the designed can be observed.

II. The Lumped Element 3-dB Coupler

In order to replace a quarter wavelength transmission line of impedance Z_o by a lumped element 'π' network as shown in Fig. 1(a) and to determine the values of the L and C elements, the ABCD matrix of the quarter wavelength transmission line is equated to that of the lumped element 'π' network at the center frequency [5], i.e.

$$X_L = Z_o \quad or \quad L = Z_o/\omega \tag{1a}$$

$$B_C = 1/Z_o \quad or \quad C = 1/\omega Z_o \tag{1b}$$

The required component values for the lumped element 3dB branch line coupler at the center frequency of 1.88GHz can be determined by equation (1) and they are listed in Table 1.

Table 1 Component values for a lumped element 3dB branch line coupler at center frequency of 1.88GHz

Z_o (Ω)	L (nH)	C (pF)
50	4.23	1.69
35.355	2.99	2.39

Two considerations are taken into account for choosing the 'π' network: (1) it is preferable to construct serial inductors and shunt capacitors in a multilayer circuit because of less influence of parasite; and (2) the parasitic capacitances of the serial inductor can be absorbed by the two shunt capacitors at the ends of the inductor. This concept is illustrated in Fig. 1(b). Having understood the basic 'pi' network, a schematic lumped element circuit of the 3-dB branch line coupler with center frequency of 1.88 GHz can be easily constructed as shown in Fig. 2.

The lumped element 3-dB coupler is implemented in a 7-layer LTCC substrate. The thickness for each layer is 90 μm and dielectric constant is 7.8. As shown in Fig.3, the inductors are built on the upper layers of the 'π' network to reduce the loss induced on ground plane. Due to the parasitic capacitance to ground of the inductors, the required value of the shunt capacitors is reduced from 4.09pF to 3.2pF. Consequently, this reduction helps to reduce the real estate of the circuit. The x-y size of the coupler is 5.3mm × 4.7mm. The overall structure can be designed using an Electromagnetic (EM) simulation tool (for example, IE3D of Zeland in this case).

The designed LTCC lumped element 3-dB coupler has been prototyped and measured. As shown in Fig. 4, although the measured center frequency is moved up about 150 MHz, the measured electrical performance matches to the predicted response very well. It is worthy to mention that the insertion loss of the lumped element coupler is better than 0.3 dB at resonant frequency.

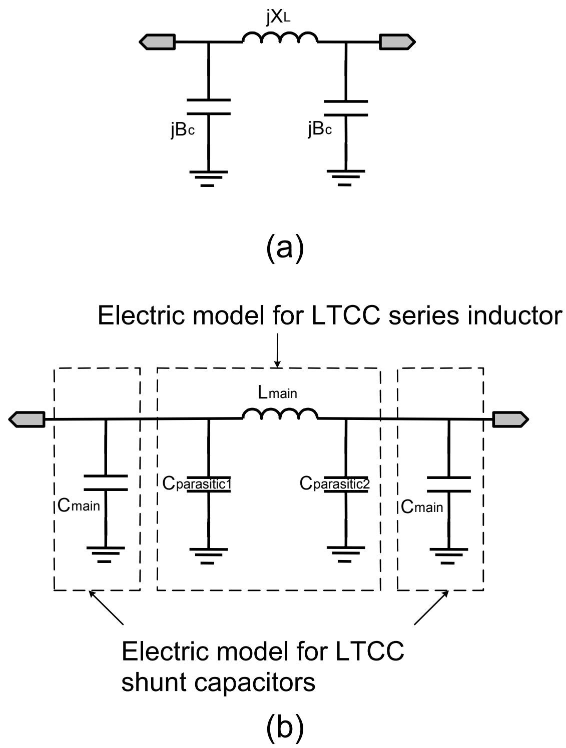

Fig.1. (a) A low-pass 'π' network for replacing quarter wavelength transmission line. (b) The 'π' network with possible parasitic capacitance.

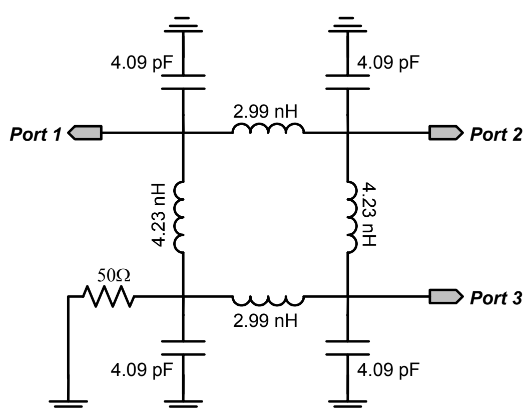

Fig. 2. The schematic of the lumped element 3-dB hybrid coupler with center frequency of 1.88GHz.

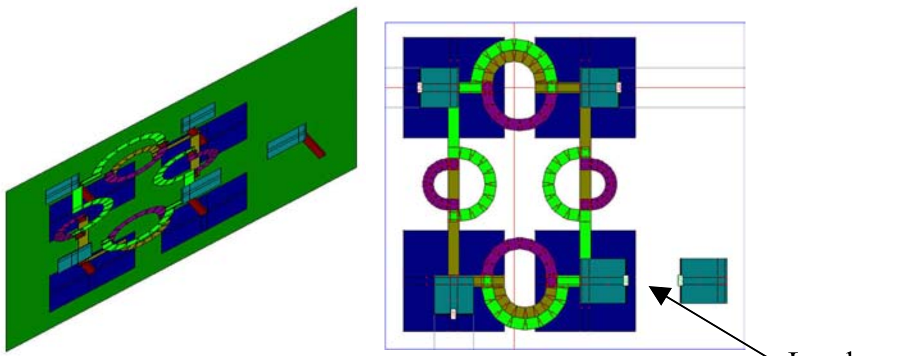

Fig.3. The top and perspective views of the layout of the lumped element coupler in a 7-laver LTCC substrate.

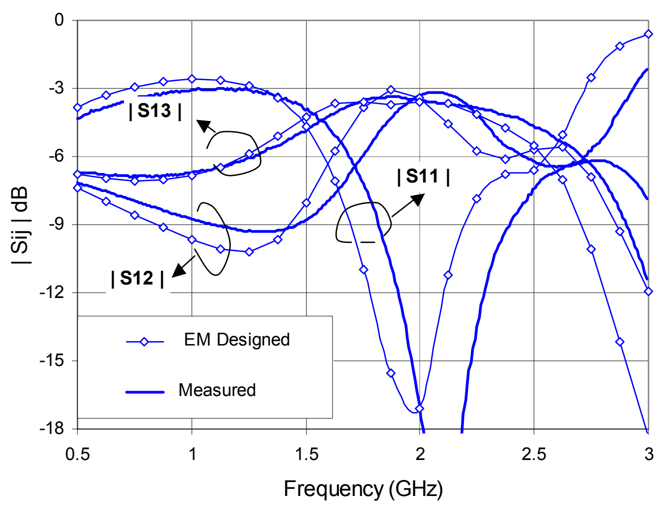

Fig.4. The measured and the EM designed performance of the LTCC lumped element 3-dB hybrid coupler.

III. Conclusions

An innovative RF embedded lumped element 3-dB hybrid coupler is proposed and implemented, for the first time, in a 3D vertical configuration using LTCC technology.

The schematic circuit and the LTCC layout are ingeniously designed in the way that the parasitic effects are fully used for reducing the circuit size. Since an accurate EM simulation is used, all the parasitic couplings are accounted in designing the overall layout. As the result, the measured performance agrees well with that of the designed. This new configuration of embedded passives can be used in many other applications such as lumped element Wilkinson's power dividers and low pass filters with reduced size and manufacturing cost.

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