# FDTD Modeling of 3D Metal-LTCC Structures for RF(MM)ICs

*X. T. Dong, B. Guo, W.Y. Yin, and Y. B. Gan*

Temasek Laboratories, National University of Singapore (NUS), 10 Kent Ridge Crescent, Singapore 119260, E-mail:tsldx@nus.edu.sg or tslyinwy@nus.edu.sg

***Abstract:*** Three-dimensional (3D) metal-low temperature co-fired ceramics (LTCCs) structures are studied using the finite-difference time-domain (FDTD) method. These types of materials have excellent high frequency performances for the design of multi-layer superstrate-substrate for various passive microwave devices. Numerical results are presented to show the effects of LTCC permittivity and loss on the reflection and transmission coefficients of microstrip discontinuities, including air-bridges and spiral inductors.

## I. INTRODUCTION

3D metal-dielectric structures are widely used in radio frequency and monolithic microwave integrated circuits (RF(MM)ICs), including bond-wires, via-holes and air-bridges *et al*. To deal with these geometries, various analysis methods have been proposed, including the method of moments, the volume integral equation method, the finite-element method, the finite-difference time-domain method, and so on. Relatively speaking, the FDTD method is the most popular three-dimensional full-wave numerical algorithm which can be used to model electromagnetic phenomena and interactions in various fields [1,2].

LTCCs (low temperature co-fired ceramics) are commonly used to design high-density interconnects and packaging for high-frequency applications [3], due to their excellent high frequency performances. In the fabrication technology, LTCCs usually consist of a mixture of glass, ceramic and organic materials which are cast into green sheets, while microstrip patterns are made by different thick-film techniques on these sheets. Depending on the composition and processing, the relative permittivity $\varepsilon_r$ and loss tangent $tg\delta$ of LTCCs can be significantly changed to meet certain requirement. In this paper, the effects of the LTCC permittivity and loss on the reflection and transmission coefficients of the 3D metal-LTCC structures for RF(MM)IC applications are studied using the FDTD method.

## II. GEOMETRIES

Two typical structures are selected for consideration, including an air-bridge and a spiral inductor which play significant roles in recent RF(MM)IC circuits. Fig. 1 shows the schematic map of the air-bridge and the spiral inductor on a single-layer LTCC substrate backed by a metal plane. The dimensions in

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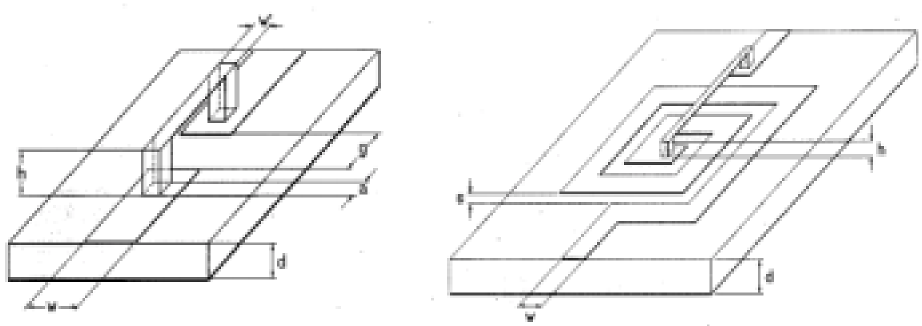
micrometers are chosen to be the same as given in [4], where in Fig.1 (a), $d = w = g = 635\mu m$, $a = w' = 211.6\mu m$, $h = 200\mu m$, and in Fig.1 (b), we have $d = 635\mu m$, $w = 625\mu m$, $s = 312.5\mu m$, $h = 317.5\mu m$.



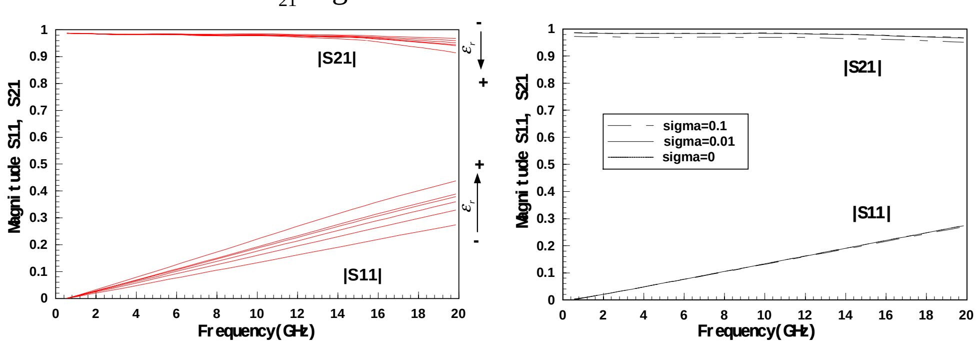
(a) (b)

Figure 1. Geometries of the air-bridge (a) and the “spiral” inductor (b).

## III NUMERICAL RESULTS

### (a) air-bridge

Fig. 2(a) shows the computed *S*-parameters for the air-bridge as a function of frequency, where the low-loss effect of LTCC will not be considered. In our FD-TD computation, the cell size is given by $\Delta x = \Delta y = 52.917\mu m$, $\Delta z = 79.375\mu m$, and $\Delta t = \min\{\Delta x,\ \Delta y,\ \Delta z\}/2$. The permittivities of the LTCC substrates are chosen to be $\varepsilon_r$ = 4.2, 5.9, 7.0, 7.8, 8.2, and 10.6, respectively. Comparing our results with that shown in [4], where $\varepsilon_r = 9.8$, similar phenomena are observed, *i.e.*, with frequency increases, the magnitude of $S_{11}$ increases linearly while $S_{21}$ decreases. In addition, it is observed that as the permittivity of substrate increases, the magnitude of $S_{11}$ increases while $S_{21}$ decreases. In Fig. 2(b), $\varepsilon_r$ is chosen to be 4.2, and the LTCC conductivities are supposed to be 0, 0.01, and 0.1, respectively. It is obvious that the LTCC loss has little effect on $S_{11}$ and $S_{21}$ when $\sigma$ =0.01, and only in the high-loss case is its effect on $S_{21}$ significant.




(a) (b)

Figure 2. Scattering parameters for an air-bridge on different LTCC substrates.

**(b) “spiral” inductor**

Fig.3 shows the *S*-parameters of the spiral inductor shown in Fig.1(b), corresponding to different permittivities of the LTCC substrates. Here, the cell size of FDTD calculation is given by $\Delta x = \Delta y = 78.125\mu m$, $\Delta z = 79.375\mu m$, and $\Delta t = \min\{\Delta x,\ \Delta y,\ \Delta z\}/2$, the loss effect of LTCC will not be considered.

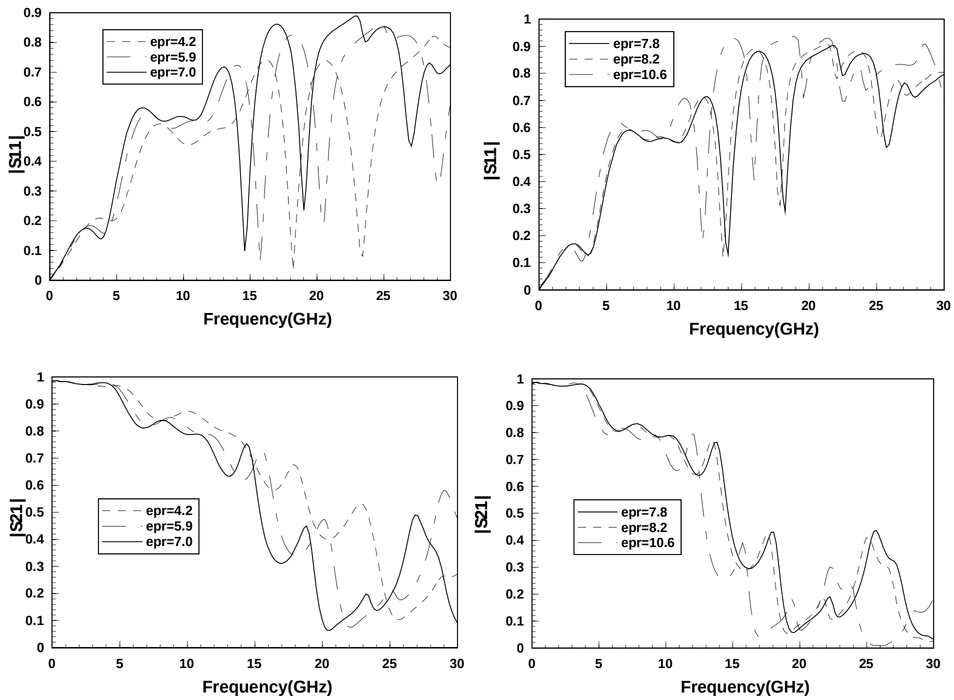
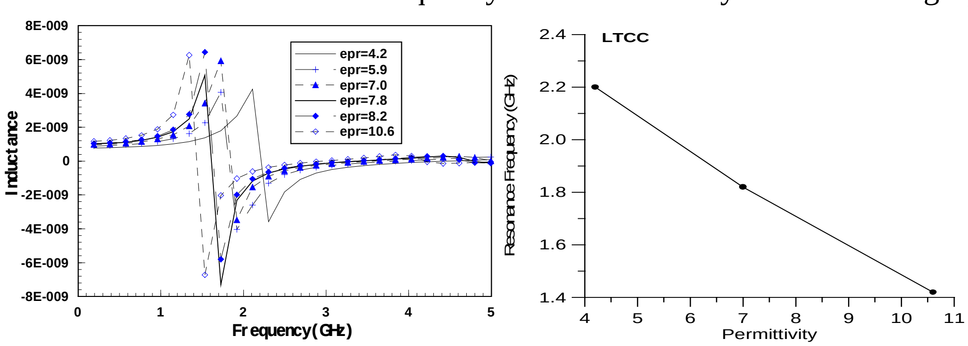



Figure 3. Scattering parameters for a spiral inductor on different LTCC substrates where $\varepsilon_r$ = 4.2, 5.9, 7.0, 7.8, 8.2, and 10.6, respectively.

Based on the S-parameters, the 2-port Y-parameters as well as the equivalent inductance of the inductor can be easily derived [5]. The inductance of the geometry on the six sets of LTCC substrate is shown in Fig. 4 (a). Fig. 4(b) shows the self-resonances of these inductors on different LTCC substrates. It is noted that the resonance frequency decreases linearly with increasing $\varepsilon_r$.




(a) (b)

Figure 4. (a) Inductance and (b) resonance frequency of the inductor.

Fig. 5 shows the effects of lossy coefficients of LTCCs on the scattering parameters of the inductor, where the conductivity of LTCC substrates are supposed to be 0 (lossless), 0.01*S/m* (low-lossy), and 0.1*S/m*(high lossy), respectively. It is seen that there is little difference between the cases of $\sigma = 0$ and $\sigma = 0.01$*S/m*. As $\sigma$ increases to 0.1*S/m*, the lossy effects of LTCC become dominant, in which $|S_{11}|$ is enhanced and $|S_{21}|$ is reduced.

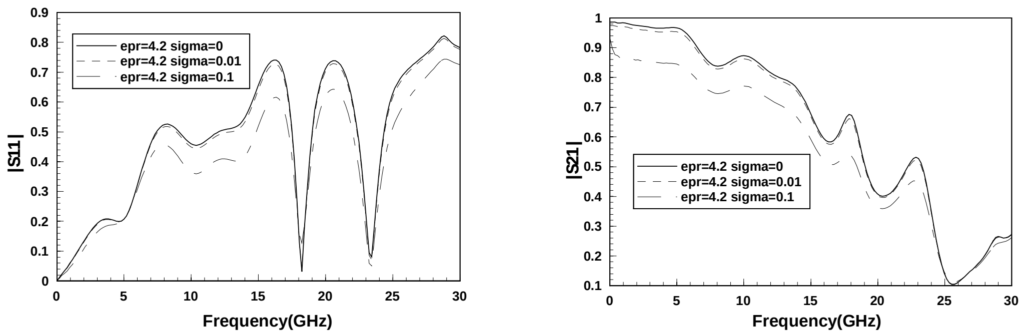


Figure 5. Scattering parameters of the inductor on lossy LTCC substrates.

## IV CONCLUSION

In this paper, the FD-TD method is employed to study the reflection and transmission characteristics of typical three-dimensional air-bridges and spiral inductors on a single-layer low temperature co-fired ceramic (LTCC) substrate, corresponding to different geometrical and permittivity parameters, respectively. Numerical results are presented to show the LTCC permittivity and loss on the reflection and transmission coefficients of air-bridges and spiral inductors.

## REFERENCE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