DESIGN AND PERFORMANCE OF UHF BAND INDUCTORS, CAPACITORS AND RESONATORS USING LTCC TECHNOLOGY FOR MOBILE COMMUNICATION SYSTEMS

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ABSTRACT

We report on basic passive components integrated into ceramic substrate and on the performance of a finite element software package. The inductors of different types in a range of 1 nH to 10 nH show moderate dependence on frequency. Spurious resonances indicate coupling of neighbored structures. Shunt capacitors between 6 pF and 128 pF have resonances in contrast to the series capacitors depending on the ground plane. Stripline and lumped element resonators at 1 GHz showed Q factors around 100 and 50 respectively. Fair agreement of measurement and simulation was observed.

INTRODUCTION

On PCB boards usually up to 75% of the total area is covered by passive components. One possibility to decrease that space is integration into a multilayer substrate. This can be done by means of the LTCC (Low Temperature Cofired Ceramics) technology [1,2] by which metallization is screenprinted onto green ceramic sheets. Printed sheets are stacked, laminated and fired. Since co-firing is done at relative low temperatures (< 950 °C) highly conductive metalization layers of silver or copper can be used in this step. The thickness of these conductors is around 10 µm, which is about three times the skin depth at 1 GHz. As a result of that and since losses due to the ceramic can be ignored compared to conductor losses, the LTCC method is very useful for integrating inductors and resonators with high quality factors at high frequencies. Though the relative permittivity of LTCC ceramic is usually in a range of 6 to 10, capacitors with high values can be achieved by creating a multilayer structure. Materials with higher permittivity are at the development stage at the moment. Onto the surface of a LTCC module active elements like IC´s can be bonded or soldered. It was calculated that the required area for a LTCC module is about 25% of a traditional PCB board. Very important applications for this technology are mobile communication devices, where miniaturisation is urgently needed. With reduction in size parasitics and crosstalk become more and more important. Therefore lumped circuit simulation is not sufficient and full 3D-simulation is necessary. To demonstrate the electrical behavior at UHF band frequencies, different fundamental types of inductors, capacitors and resonators were fabricated and as well simulated using a finite element software package. The results are presented here.

SIMULATION TECHNIQUES

Simulation can be carried out by different commercial software packages based on, e.g. TLM or spectral domain methods [3]. Further on the market are boundary element and finite element programs. The choice for finite elements was made since that combines the advantage of full three dimensionality with the possibility to use materials with complex permittivity and permeability. In addition a benchmark showed that the calculation time of the commercial FEM soft-

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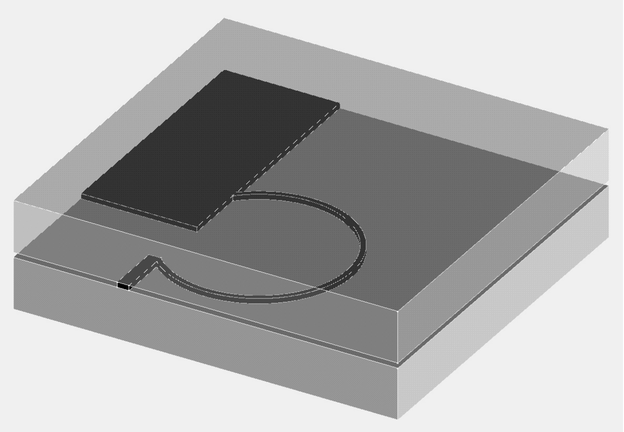

Figure 1: Three quarter circle inductor

ware package used here is superior even to programs that only offer 2½-D modeling.

INDUCTORS

As inductors straight lines, meander structures and a couple of three quarter circles in stripline technique were chosen (Fig. 1) and placed side by side on one board. In Figs. 2 to 4 some examples for measured and simulated inductances are shown. Neighbored structures were too close to each other so that interference occured. This was minimized during measurement by adhesive copper strips pasted over the neighbored structures. Nevertheless the graphs show some spurious resonances. Apart from this resonances measured and simulated curves agree fairly. In particular the general frequency dependence is similar. Quantitative deviations, e.g. Fig. 3 shows an error of about 4% at 500 MHz, may be caused by a non-ideal test fixture. This is also true for all other results presented here.

CAPACITORS

The second group of passive components under consideration is given by series and shunt capacitors made in microstrip technology. For each specific value two or three elements were arranged side by side onto one board (Fig. 5). The neighbored structures caused similar interference as was the case with the inductors. Since calculation was easy, they were simulated with and without neighbors. During measurement, again copper strips were used. The graphs suggest that the shielding was sometimes successful (Fig. 6), but sometimes not (Fig. 7). The curves of the shunt capacitors show a shift in the resonance frequency. This can be explained by the fact, that the resonance itself is related with standing waves occuring on the narrow ground planes of the shunt capacitors. Thus the reso-

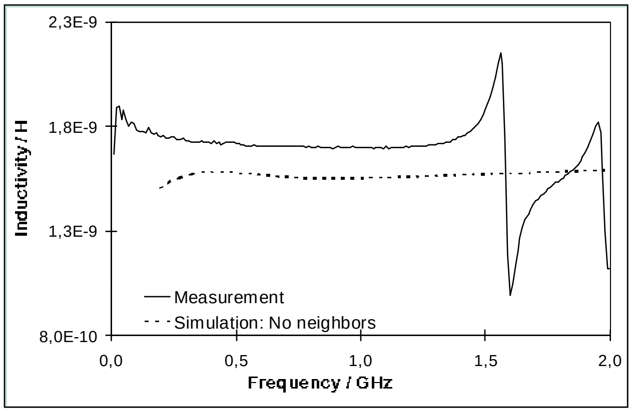

Figure 2: Straight line

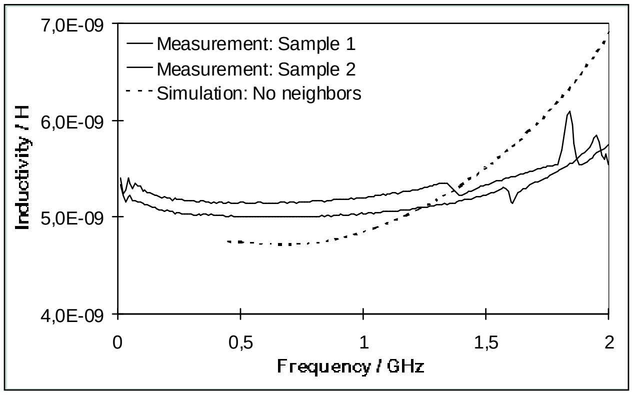

Figure 3: Three quarter circle inductivity

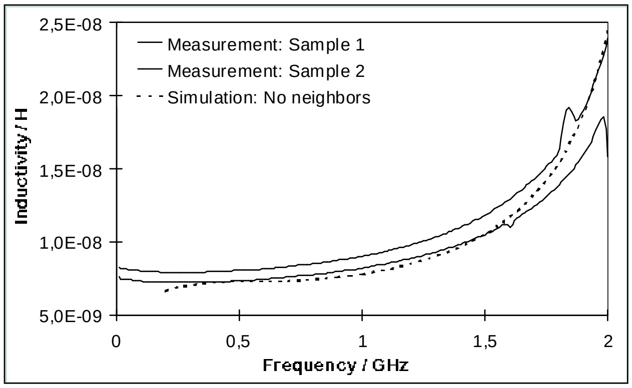

Figure 4: Meander inductivity

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nance frequency is dependent on the position of the connected capacitor. During simulation always the middle capacitor was connected, but during measurement another element was taken. This explaines the frequency shift. Broad ground planes and shorter connections of the ground planes itself to ground should be used to prevent from the spurious resonances. In Fig. 8 a result for a series capacitor is presented. Since there are no ground planes resonances cannot be observed. In summary simulation was able to predict the influence of crosstalk.

RESONATORS

Finally two resonators fabricated in stripline technique are presented. One is a meander and shunt capacitor combination and the other is a stripline resonator. All measurements regarding the resonators were done with two samples of the same style of construction. Therefore always two results in the figures and tables are given. In Tab. 1 measured and simulated resonance frequencies are shown. The simulation was done using the eigenmode solver of the finite element software package. The values agree very well to the measured data. For the determination of the Q factor by simulation a frequency sweep is required. Furthermore, the software package offers two possibilities for modeling the conductors. First there are 2D-elements which can be loaded with a resistance (Method 1). Although this resistance depends on frequency due to the skin effect, the program only accepts one value for all frequencies. Therefore the surface resistance must be chosen according to a specific frequency, e.g. the resonance frequency. The second alternative for modeling is to use 3D-elements (Method 2), which is able to deal with frequency dependent resistivity. However this method results in models with a large number of elements and long computation times. The resonators have been simulated using both ways of modeling (Tab. 2). First it must be stated, that in the diagrams (Fig. 9 and 10) the graphs obtained by Method 2 always show higher values

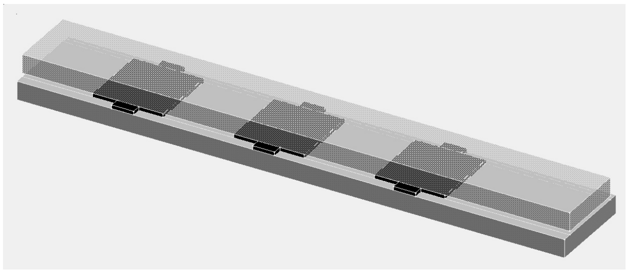

Figure 5: Shunt capacitor arrangement

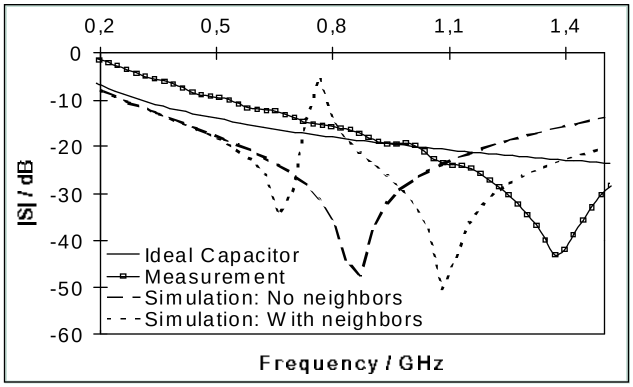

Figure 6: $|S_{12}|$ of shunt capacitor, 63 pF

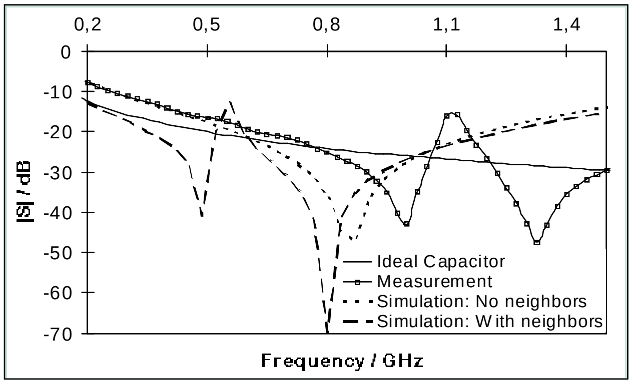

Figure 7: $|S_{12}|$ of shunt capacitor, 127 pF

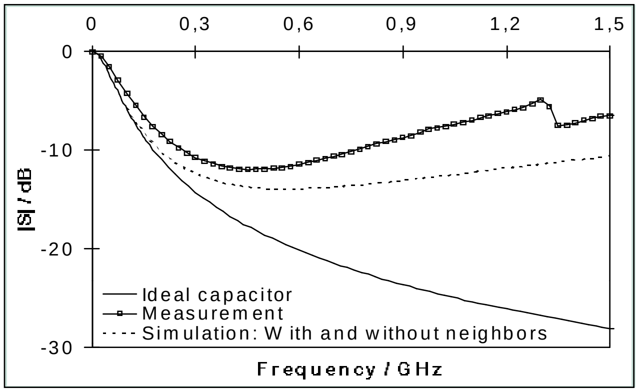

Figure 8: $|S_{11}|$ of series capacitor, 27 pF

then those obtained with Method 1. This is not fully understood up to now. Looking at the results for the LC resonator (Fig. 9) the measured curve agrees well with the simulated one obtained by Method 2. The Q factor in the case of Method 1 is much lower. A contrary behavior can be observed with the stripline resonator (Fig. 10). Method 2 delivers higher Q factors. This behavior may be explained by the fact that the LC resonators in contrast to the stripline resonators have very fine structures compared with the whole device so that numerical effects lead to the deviations.

CONCLUSION

It can be stated that simulation is able to predict the electrodynamic behavior of LTCC components. Care should be taken when determining the Q factors of resonators. The potential of miniaturization and reliability inherent in the LTCC technology leads to the wish to integrate whole networks into substrates. Therefore the necessity to find design rules for integrated components arises. Much freedom is provided for choosing the design parameters for getting the best possible electrical performance. Thus the LTCC technology has a great potential for future generation mobile communication units.

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	Resonance frequency / GHz	
	Measured	**Simulated**
LC Combination	1.285; 1.335	1.266
Stripline shortend	0.980; 0.980	0.976

Table 1: Measured and simulated resonance frequencies using the eigenmode solver

Resonator	**Type of data**	**Peak-frq./ GHz**	**Peak-height / Ω**	**Q**
LC Combination	Measured	1.280	1707	52.5
		1.335	1800	46.5
	Surf.Res.	1.319	526	15
	3D-Elem.	1.301	1972	53
Stripline shortend	Measured	1.165	1813	109
		1.180	1779	112
	Surf.Res.	1.184	1663	109
	3D-Elem.	1.168	3825	236

Table 2: Measured and simulated resonance peaks

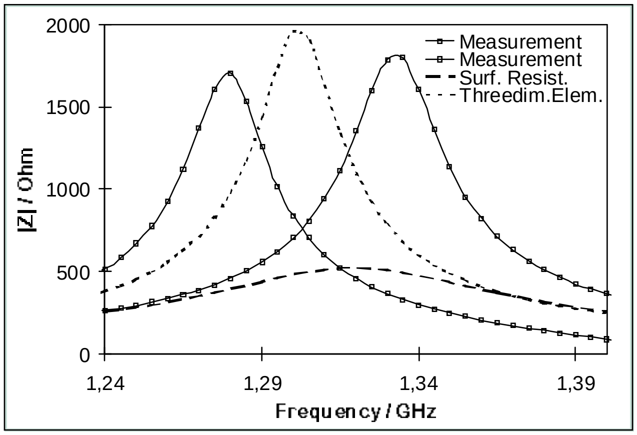

Figure 9: Meander / shunt capacitor combination

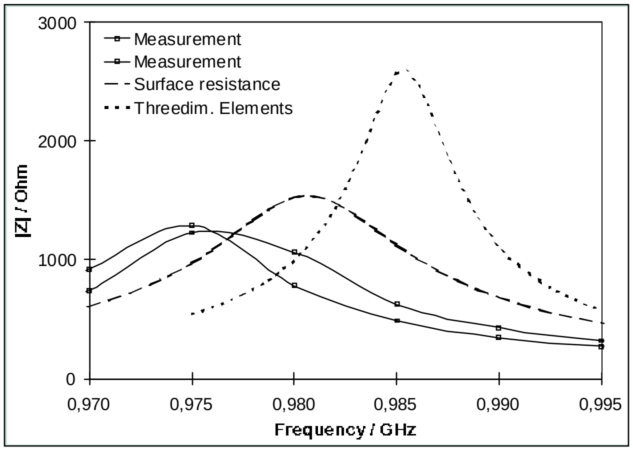

Figure 10: Stripline resonator; shortend