

Electromagnetic analysis of LTCC high frequency devices

In response to the constant pressure to reduce both size and part count in mobile telephone handsets and other RF and microwave circuits, compact low temperature co-fired ceramic (LTCC) modules integrating many active and passive components into one multi-layer module with up to 20 or more layers. This paper focuses on the RF simulation and layout aspects of these multilayer LTCC circuits.

The LTCC module may contain integrated passives such as inductors, capacitors and impedance controlled transmission lines, as well as additional active or passive devices mounted on top of the module. With a typical dielectric sheet thickness of 0.05 - 0.10mm and a dielectric constant of $\epsilon = 7.8$, capacitors with up to 20pF can be implemented with tolerances of ~10%. Inductors are typically realised as multi-layer stacked loops with values up to 20nH, with much higher Q factors than their silicon integrated counterparts.

The design challenge

RF design for LTCC circuits starts with a lumped element ideal schematic as usual, but then many components such as capacitors and inductors are implemented as layout features, rather than dropping in the suitable SMD component values. A virtually unlimited number of layout implementations exists for a given circuit, and it is up to the design engineer to pick the layout implementation that fits into the given circuit size and can be designed efficiently with the available simulation tools.

The use of model-based libraries is limited in case of multilayer circuits because only very few multilayer models and libraries exist. A new field solver based library called IMST MULTILIB has been introduced recently, which allows the inclusion of typical multilayer layout components in an ADS circuit simulation. This simplifies the design of the individual layout components, but does not provide information about coupling between them, which is also critical due to the high package density.

The following list shows the design steps:

- 1 Design ideal (functional) schematic, determine component values

- 2 Create each component shape, use EM analysis to tune layout for desired values
- 3 Floor planning with all shapes, with coupling and size in mind
- 4 Modify shapes for package optimisation, if necessary
- 5 Assemble all components, run complete EM analysis to include all coupling
- 6 Back to step 3 until specifications are met.

Electromagnetic analysis

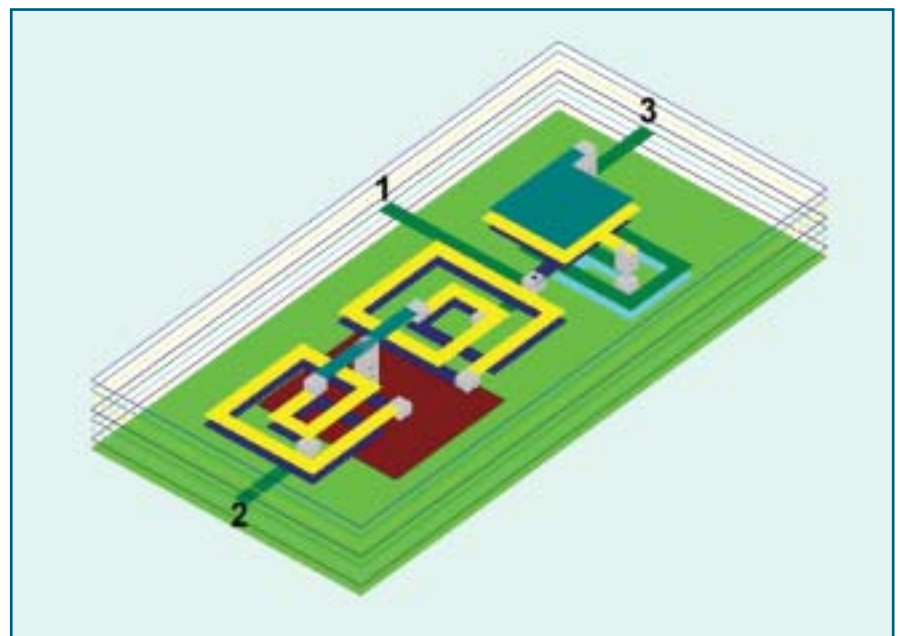
When no models exist and coupling or radiation is relevant, electromagnetic (EM) analysis is the right approach. In this paper, we use the same EM analysis tool both for the design of the components and to account for their coupling.

Due to the planar nature of the LTCC technology, we chose a specialised planar EM analysis tool, which is considered to be more accurate and efficient than general purpose 3D EM tools.

With these planar tools, only the current density of layer metallisations and vias have to be solved for. The dielectric materials do not need to be discretised as their thicknesses and dielectric properties are accounted for differently.

A very efficient planar electromagnetic tool is the Sonnet Professional Suite. This package utilises the so-called closed-box solution in conjunction with a uniform grid. The advantage of this method is that it is very straightforward without any numerical integration, so it is not only fast but also very reliable with virtually no limit to the number,

Figure 1: Example of a LTCC circuit with six metallisation layers. The size of the circuit is $5.1 \times 1.9 \times 0.35\text{mm}^3$ (without feed lines)



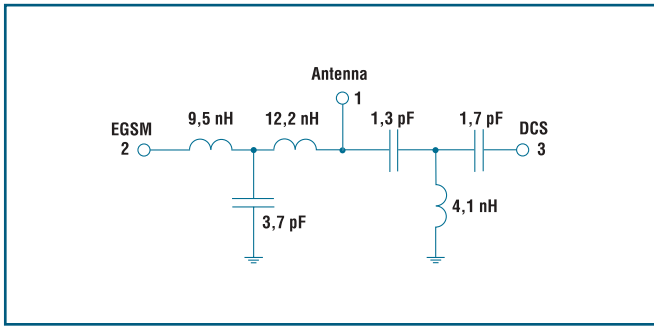
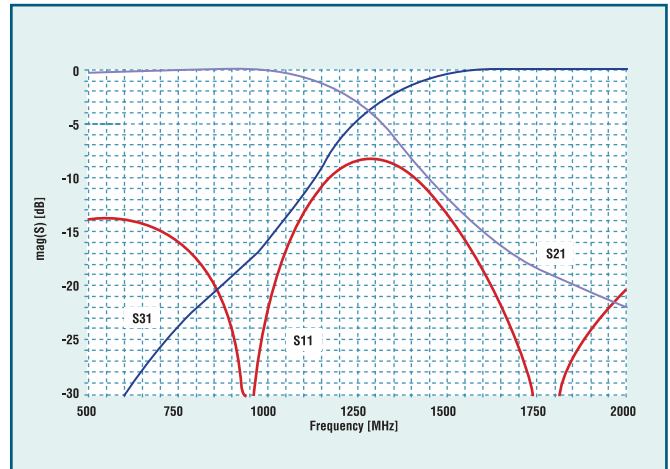


Figure 2: (a) above, L/C equivalent circuit of the EGSM/DCS diplexer, and (b) right, S-parameters of the antenna EGSM transmission (S_{21}), the antenna DCS transmission (S_{31}), and the matching (S_{11}) of the antenna port



thickness or properties of the dielectric materials.

Example: EGSM/DCS diplexer in LTCC technology

As an example, we will design a LTCC high frequency diplexer. One application for such diplexers is in the RF front-end of dual-band mobile phones, where they separate the two frequency bands for EGSM (880 – 960MHz) and DCS (1710 – 1880 MHz). Many different implementations are possible to achieve the desired frequency response. In our case, a lumped element low pass filter is used for the EGSM frequency range, and a lumped el-

ement high pass filter for DCS.

To get started, we first synthesise the low pass and high pass sections independently with a filter synthesis tool. When both filters are connected to the common antenna port as shown in Figure 2, the filter matching is degraded. The six L/C values of the two single filters must be optimised to achieve good diplexer performance. This can be done easily with a circuit simulator such as Agilent ADS, with input matching and insertion loss for both frequency ranges used as optimisation goals. The element values given in Figure 2 are already the optimised values. Without losses, an insertion loss of less than

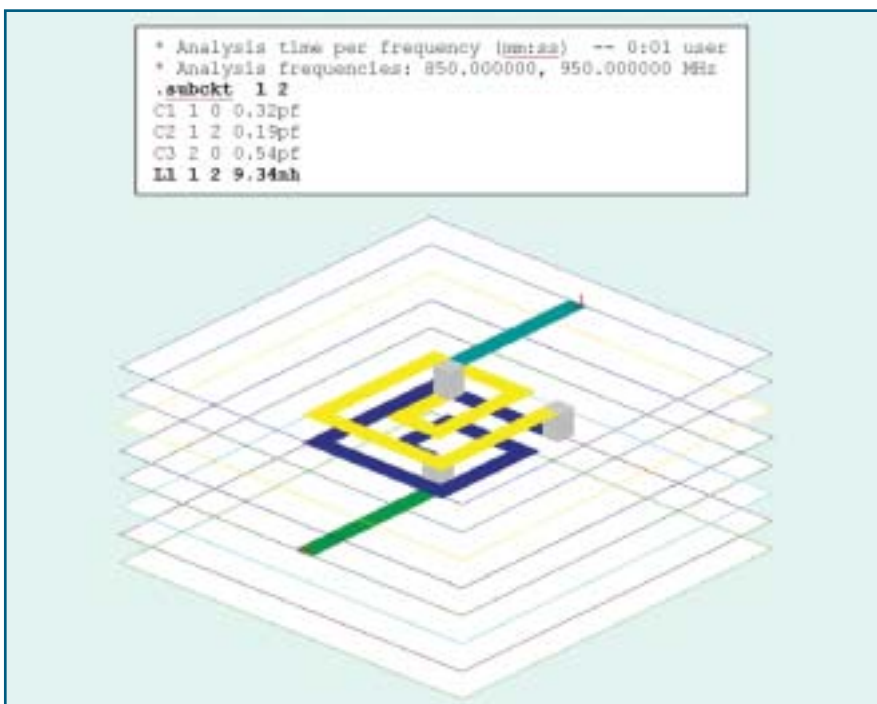
0.1dB has been achieved.

When the lumped element L/C schematic is finished and the best element values are determined, the next step is to create the equivalent layout for each of the inductors and capacitors. We will design for a LTCC process with seven dielectric layers, with a dielectric thickness of 0.05mm and a dielectric constant (ϵ) of 7.8. Inductors are implemented as two layer loops, capacitors as parallel-plate capacitors. Each single element is drawn and analysed individually in Sonnet. Because we are designing simple inductors and capacitors, all we are interested in are equivalent L and C values rather than the full frequency response. The Sonnet analysis data display supports this by displaying equivalent circuit values in SPICE format directly. This way, we can check the analysis result directly against the desired L or C value.

This advantage of using the SPICE data can be demonstrated with the example shown in Figure 3. A 3D view of a LTCC inductor is shown together with the SPICE data output of Sonnet for 850MHz and 950MHz. We can identify an inductance of $L1 = 9.34\text{nH}$ and a parasitic capacitance of $C2 = 0.19\text{pF}$ between the ports 1 and 2. Additionally we can identify parasitic capacitors to ground of $C1 = 0.32\text{pF}$ at port 1 and $C3 = 0.54\text{pF}$ at port 2. Due to the electromagnetic analysis we have not only found the inductance value for $L1$, but also (unavoidable) parasitic capacitors. Thus, parasitic elements can be identified already in an early stage of the design and, if necessary, they can be minimised by modifying the layout.

When all six L/C elements have been designed, the complete diplexer can be composed. This sounds like a trivial task, but due to unavoidable cross coupling, the

Figure 3: 3D View of an inductor in LTCC multilayer technology together with the SPICE data output of the Sonnet EM analysis



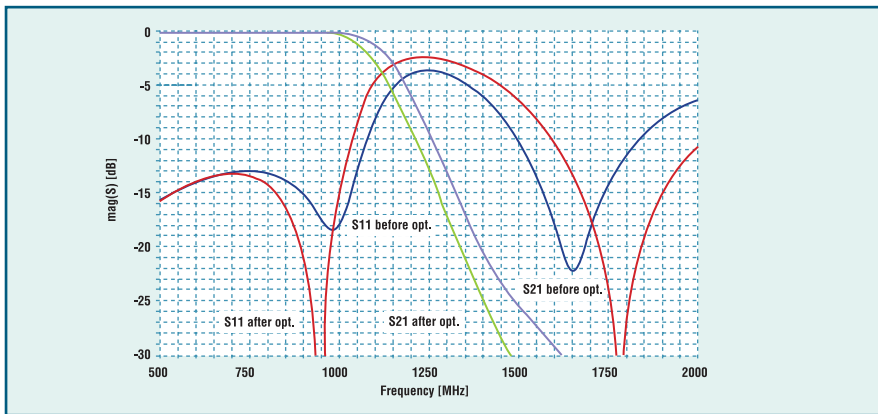


Figure 4(a): Results of the EM analysis for the LTCC diplexer before and after optimisation for antenna EGSM transmission

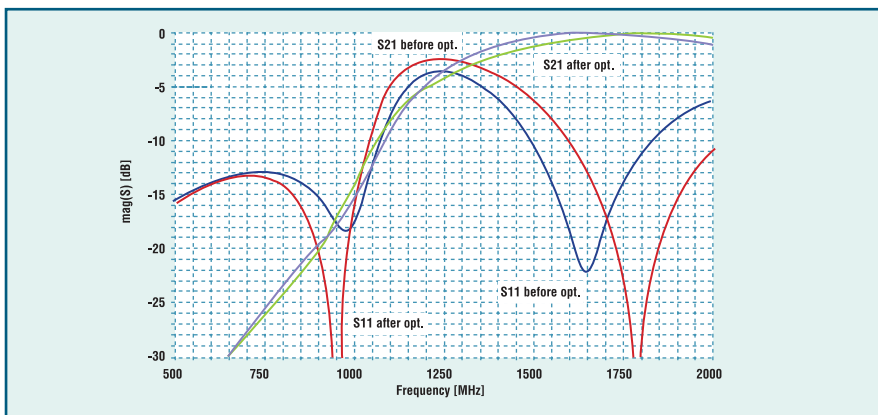


Figure 4(b): Results of the EM analysis for the LTCC diplexer before and after optimisation for antenna DCS transmission

circuit performance will also depend on the placement of elements. For example, there can be strong parasitic coupling between the low pass and the high pass filter elements, or possible crosstalk between the antenna and the EGSM/DCS ports. Proper placement of the circuit elements and functional blocks is important to achieve a good overall performance. Fortunately, the electromagnetic analysis of the full layout takes all coupling into account, so that possible problems can be detected easily.

The layout of the diplexer is shown in

Figure 1. The size is only $5.1 \times 1.9 \times 0.35 \text{ mm}^3$ (feed lines not included).

When the cross-coupling between the elements has been minimised with a good layout strategy, the initial electromagnetic analysis of the complete circuit should already give good agreement with respect to the ideal lumped element case. Differences between the simulated and the ideal circuit can be explained by the parasitics of each element, and by parasitic coupling between the L/C elements among each other. Both effects can be minimised, but not completely avoided. However, all

parasitic effects are accounted for in the analysis, and the performance of the diplexer can be optimised by small changes (fine tuning) of the six L/C elements. Such a fine tuning can be performed efficiently by using the ungrounded internal ports of Sonnet. If such a port is used e.g. within an inductor, a tuning inductance DL can be added externally after the analysis. A potential correction of L for an improved performance of the diplexer can be obtained by changing the value of DL without the need of repeated electromagnetic analyses.

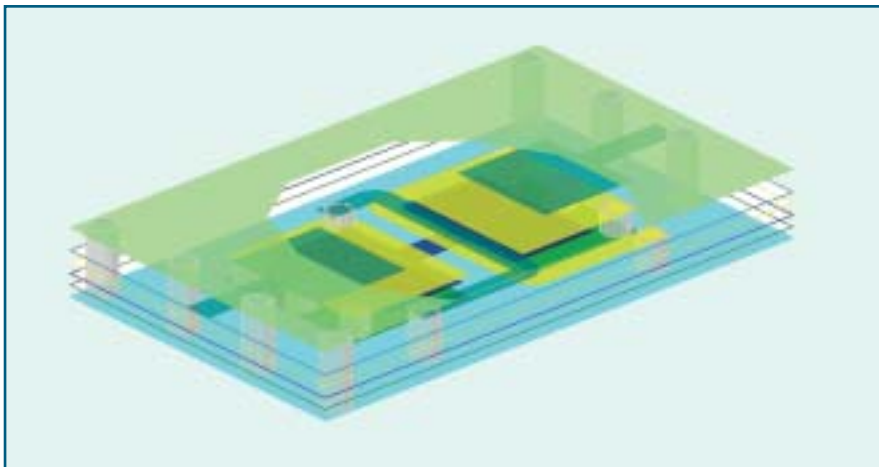


Figure 5: 3D view of a compact LTCC Bluetooth bandpass filter

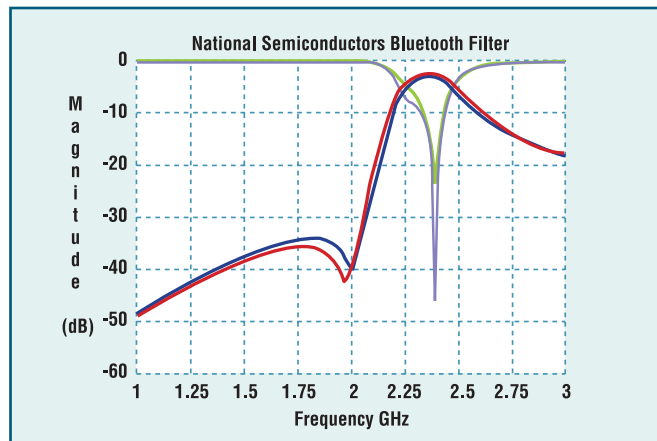


Figure 6: Simulation results versus measured for the LTCC Bluetooth bandpass filter

The results of the electromagnetic analysis before and after the fine-tuning are shown in Figure 4. Within the specified frequency ranges, the optimised circuit has an insertion loss of less than 0.1dB. This is the same low value as for the ideal L/C circuit.

LTCC Bluetooth filter

In the previous example, we used simple layout elements and a relatively small package density, to better illustrate the design steps. More complex layout is found in real world circuits, and the package density will also be higher. Figure 5 shows the layout of a Bluetooth LTCC band pass filter. Figure 6 shows the corresponding simulation and measurement results (design and measurements courtesy of National Semiconductor [8]).

Conclusion

The development of LTCC circuits can be significantly accelerated with the help of electromagnetic analyses. Additionally, in some cases EM analyses are the only way to identify parasitic couplings between different circuit groups already in an early stage of a design. An efficient design flow even for complex circuits can be obtained when an appropriate electromagnetic analysis method is used. An example of an EGSM/DCS diplexer in LTCC technology has been presented to show how electromagnetic analysis with the Sonnet Professional Suite was used to transfer an ideal L/C circuit into a multilayer design with similar performance.

References

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