Accurate Co-Simulation of Surface-mount Capacitors in Shunt Configurations

One of the challenges in developing high-accuracy compact models is enabling sufficient versatility for designers to select layout configurations that are different from the test fixtures used in the characterization and model extraction process. For modeling passive surface-mount components, series two-port fixtures are typically used to obtain the S-parameter data that are subsequently utilized in model fitting. These test fixtures have well-defined reference planes to establish the boundaries of the model. An example of such a fixture is shown in ***Figure 1***; here linear tapers are used to transition from the 50 Ω feed-lines to the dimensions of the mounting pad stacks. In practice, designers are likely to use mounting layouts that vary in one or more ways from this configuration.

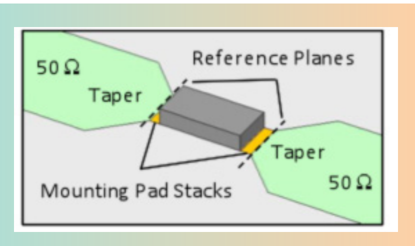

Figure 1 A typical series 2-port test fixture used for surface-mount component S-parameter measurements for model development purposes.

This application note focuses on co-simulation – which combines circuit and numerical electromagnetic (EM) simulation – of surface-mount capacitors in shunt configurations. This is an important topic especially for microwave power amplifier designers, who commonly use shunt-mounted capacitors in impedance matching networks that require very precise impedance transformations. The accuracy of the simulations is important at the fundamental design frequency as well as at several harmonics. One situation addressed herein is that when a portion of the mounting pad stack is embedded in the interconnect transmission line that runs orthogonally to the major axis of the component (***Figure 2***). A second configuration, sometimes used by designers for load sharing purposes, consists of two closely-spaced capacitors mounted side-by-side (Figure 2, with the second pair of pad stacks occupied). The distribution of current on the pad stacks, and how it enters the capacitor(s), varies between the series and shunt two-port fixtures and must be properly emulated in the simulator in order to accurately predict the circuit performance.

Another common difference between model development test fixtures and actual layouts used in practice is the shape and/or size of the mounting pad stacks. As described in the following, the capability of the model to

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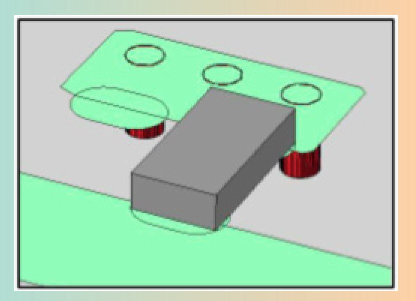

Figure 2 Shunt connection with the mounting pads embedded in the transmission line and the ground pad.

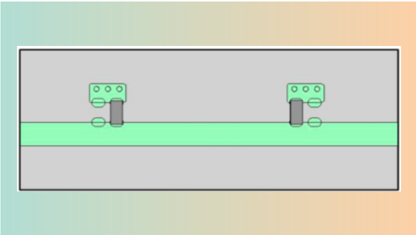

Figure 3 Test fixture used for 0603 ATC 600S capacitors to validate the recommended co-simulation approach with Modelithics models and Sonnet.

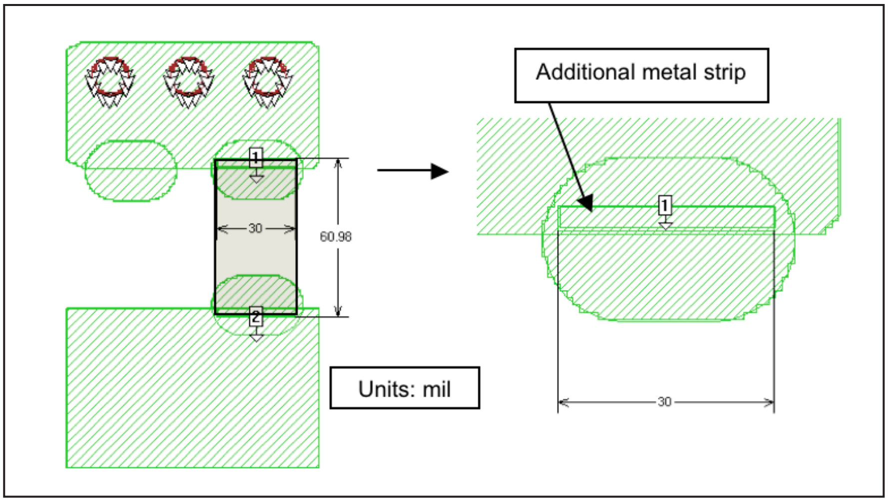

Figure 4 Location of the auto-grounded port matching the dimensions of a 0603 surface mount capacitor.

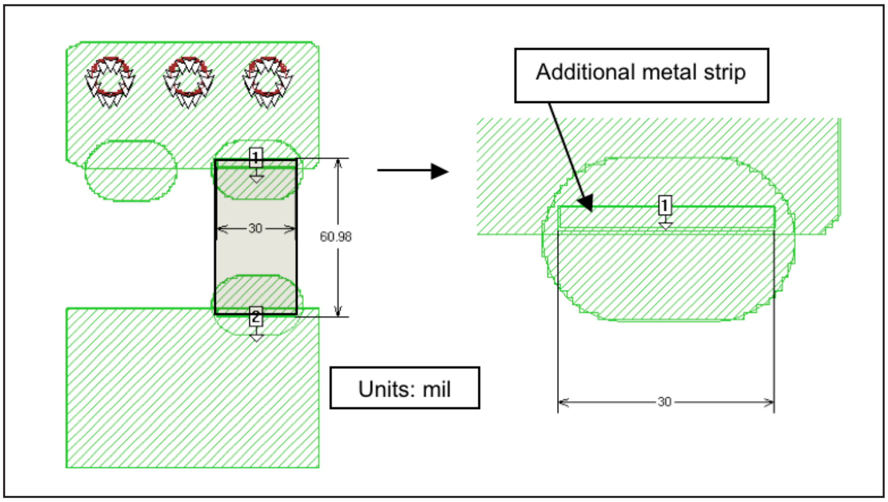

Figure 5 Measured (blue markers) and simulated (red lines) data using the test fixture of Figure 3 and port configuration of Figure 4, for 12 pF ATC 600S capacitors.

accommodate different pad stack dimensions and geometries is related to the approaches for simulating shunt-mounted components that are discussed. That is, in the Modelithics models utilized in this work features are provided to allow designers to define custom pad stack geometries. One way this is done is through pad stack parameters (length, width and spacing) that are accessible to designers in those models that are 'pad-stack scalable'.[1] Another approach, which is available in all Modelithics models, is to completely de-activate pad stacks (by setting the Sim_Mode parameter to 2).[2] When this option is selected the designer must emulate pad stack effects through some other mechanism, either by adding elements to a circuit schematic or by including the pad effects in the EM simulation. The latter approach is used in this application note.

The following sections illustrate suggested practices for defining pad stacks and selecting the port type and location used in the numerical EM simulation software. The models used are those for the ATC 600S (0603) and 600F (0805) capacitors from the Modelithics CLR™ Library, and Sonnet® is the simulation tool that is used. All test fixtures were built using 30 mil-thick Rogers 4350 substrates.

SINGLE PAIR OF SHUNT-MOUNTED CAPACITORS

0603 Capacitors – The first example is based on the configuration shown in Figure 3 in which two 0603 capacitors are mounted in shunt and separated by a distance of 315 mils. As in Figure 2, a portion of the mounting pads for the capacitors are embedded in the 50 Ω interconnect transmission line and the grounded pads. The reference planes for the S-parameter measurements and simulations were at the outer edges of the structure in ***Figure 3***. In order to perform the simulations, Sonnet® was used for the transmission line sections and this data was used along with the Modelithics models in the ADS circuit simulator.

Important considerations in setting up the EM simulation include the representation of the mounting pad stack, the type of port that is used and the location of the port. It was found that excellent correlation between measured and simulation data was achieved by including the complete pad geometry in the EM simulation, and accordingly using the Sim_Mode = 2 option (which de-activates all pad effects) in the Modelithics models. The "auto-grounded" port type was used in Sonnet and the ports were positioned at the locations corresponding to the outer edges of the parts. ***Figure 4*** shows the suggested location of the ports along with a shaded area equal to the size of a 0603 capacitor. Note that an additional metal strip has been used in order to insert the port, and Sonnet will use the edge of the strip

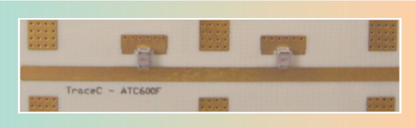

Figure 6 – Test fixture of Figure 3 for ATC 600F (0805) capacitors.

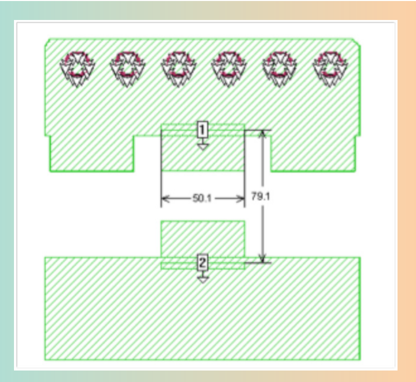

Figure 7 Location of the auto-grounded port matching the dimensions of a 0805 capacitor. Approximately 50 percent of each pad stack is embedded in the adjacent conductor (transmission line or ground pad).

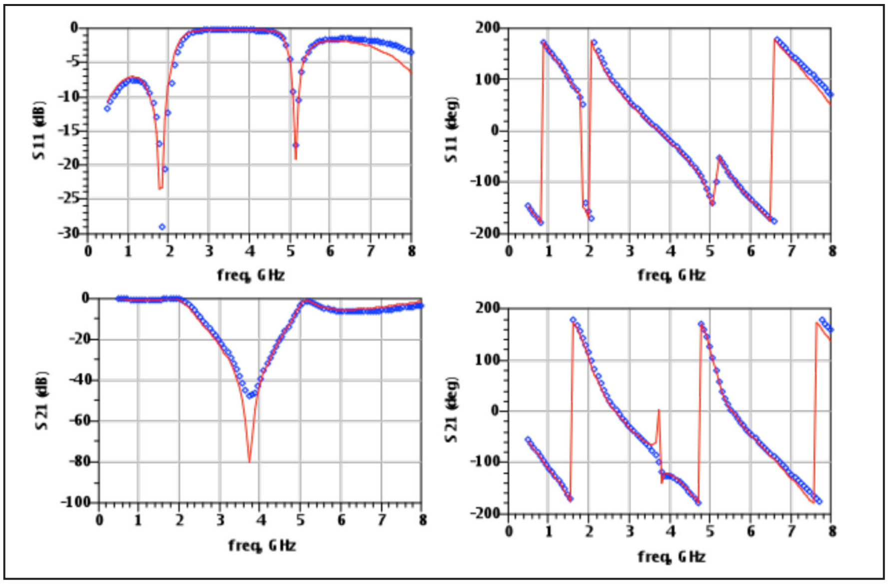

Figure 8 Measured (blue markers) and simulated (red lines) data using the test fixture of Figure 6 and port configuration of Figure 7, for 1.8 pF ATC 600F capacitors.

(where the port is attached) to determine the width of the port. Using the orientation in the illustration, the x-dimension was set to 30 mils in this case for the 0603 components. The y-dimension of the inserted metal strip is arbitrary, although as noted the edge defining the port should correspond to the location of the outer edge of the component when it is mounted on the board.

The results of the co-simulation are compared against measured data in ***Figure 5***. In this case, 12 pF capacitors were used. Equivalent agreement with measurement data was observed using fixtures built with 1, 2.7 and 47 pF values. These results validate the accuracy of using properly-sized auto-grounded ports internal to the geometry, as well as the Sim_Mode=2 option in the Modelithics models.

0805 Capacitors – To further validate the methodology, the tests using a single pair of components were repeated using 0805 capacitors. The fixture (***Figure 6***) is identical to that used for the 0603 parts except for the separation between components (515 mils) and the dimensions of the mounting pad stacks and the ground pad. As before, the EM simulation was performed using auto-grounded ports that match the width of the capacitors and are positioned at the locations corresponding to the outer of edges the capacitors (***Figure 7***). The measured and simulated results using 1.8 pF capacitors are shown in ***Figure 8***. Similar comparisons were found using 0.2, 12 and 36 pF parts.

Pair of Side-by-Side Shunt-Mounted Capacitors

The test fixture illustrated in Figure 3 was also used to investigate arrangements where two closely-spaced capacitors were mounted side-by-side at both ends of the circuit (***Figure 9***). One situation in which this type of configuration is used is for bench-tuning of matching networks. It was found that the EM simulation approach using auto-grounded ports did not provide satisfactory results, due to coupling between neighboring ports.

An alternative approach which was found to provide excellent results is based on the use of the co-calibrated ports introduced by Sonnet.[3] These ports account for the interaction between other ports that belong to the same calibration group. One requirement in using these ports is that they must be placed at the edge of a polygon (whereas auto-grounded ports can be inside polygons) and there must be an empty space in the area defined by the co-calibration group. The implication for this example configuration is that the entire mounting pad geometry cannot be included in the EM simulation as was done above. Instead, a layout that excludes the portion of the pads that extends beyond the transmission line or ground pad is

Figure 9 Test fixture of Figure 3 populated with closely spaced 0603 (600S) capacitors.

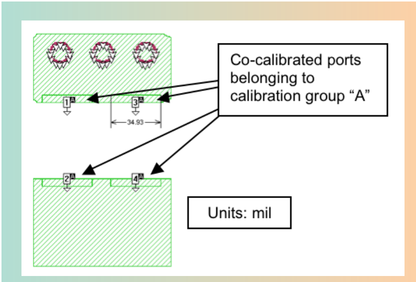

Figure 10 Use of co-calibrated ports when closely spaced ports are needed.

recommended (***Figure 10***). Ideally, the portion of the pads that is excluded from the EM simulation would be accounted for in the capacitor model during the co-simulation process. However, the options available in the standard Modelithics CLR™ models include either complete pad representation or no pad representation; there is currently no option to include an intermediate amount of pad.

Figure 10 – Use of co-calibrated ports when closely spaced ports are needed.

While not an exact representation of the actual test configuration, it was nevertheless found that very close agreement to measurement data was obtained using the port configuration

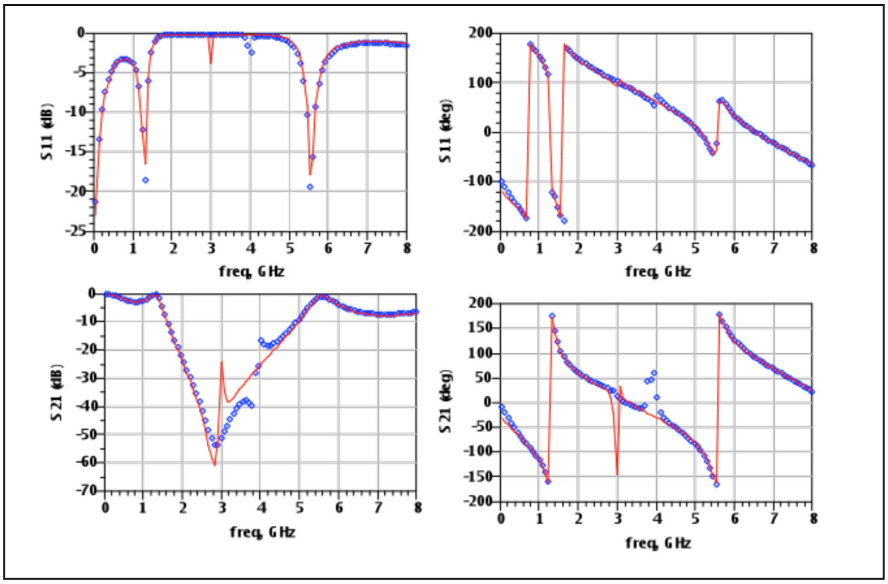

Figure 11 Measured (blue markers) and simulated (red lines) data using the test fixture of Figure 9 and port configuration of Figure 10 with Sim_Mode=0 in the 2.7 pF 600S capacitor models.

of Figure 10 while also including the full pad effects in the capacitor models (Sim_Mode=0). A comparison between measurements and simulation data using 2.7 pF 600S capacitors is shown in ***Figure 11***; similar results were found with other 600S part values and with 600F capacitors. With this simulation setup, the portions of the pads that are embedded in the transmission line and ground pads are effectively double-counted. Customized versions of the capacitor models were created to de-activate the portions of the pads included in the EM simulations, and the results exhibited only minor improvement in the correlation with measurement data.

SUMMARY

This application note has presented approaches to achieve accurate simulation results for shunt-mounted capacitors using Sonnet® EM simulation software with Modelithics™ CLR models in a co-simulation approach. In particular, configurations in which a portion of the component mounting pad stacks are embedded within the interconnect lines and ground pad. For a simple shunt mounting configuration, the use of auto-grounded internal ports in the EM simulator combined with the Sim_Mode=2 option (de-activated pads) in the component models provides very accurate results. In the case where two capacitors are closely-spaced and mounted side-by-side in the shunt configuration, co-calibrated ports should be used to properly account for interaction between the ports.

ACKNOWLEDGMENTS

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References

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