APPLICATION NOTE 026

CAPACITOR PI NETWORK FOR IMPEDANCE MATCHING

PI Matching Networks

Designing matching networks is one of the key aspects of RF/Microwave design. A lossless network that matches an arbitrary load to real impedance has to have at least two reactive elements. However, two elements do not give control over the bandwidth and the degree of match simultaneously. Three-element matching networks, i.e. Pi- and Tee-networks, provide additional control of the frequency response.

In this application note we explore the idea of designing an all-capacitor Pi matching network by using one of the elements beyond its self-resonant frequency, when it has become inductive rather than capacitive. Essentially, the effective series inductance (ESL) of the series element in the Pi network is utilized. The design process is enabled via the broad-band accuracy of the Modelithics Global capacitor models, in particular those for ATC 600L 0402 capacitors. The use of method of moments co-simulation, wherein numerical electromagnetic simulation is used to represent the distributed interconnects and discrete models are used for the lumped components, is also demonstrated.

Capacitors Used as Inductors after SRF

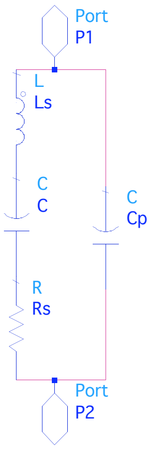

Figure 1 Simple circuit model.

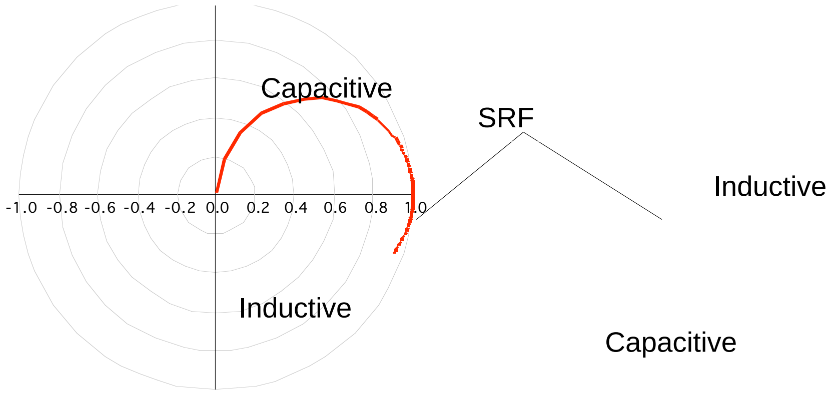

Figure 2 Frequency response of simple model (S21 on left, S11 on right).

Figure 1 shows a simplified two port equivalent circuit of a capacitor; C – Capacitance, Ls – Series Inductance, Cp – Parallel capacitance, Rs – Series resistance. As there are three reactive components in the circuit model, there are at least two resonant frequencies – the series resonant frequency (SRF) and the parallel resonant frequency (PRF). At the SRF the capacitor's impedance is a minimum, while at the PRF it is a maximum. Usually, the parallel capacitance (Cp) is much smaller than the nominal component value (C) and the PRF occurs at a higher frequency than the SRF.

Figure 2 shows a 2-port S-Parameter simulation of the circuit shown in Figure 1. It can be seen that at above the resonant frequency the capacitor acts like an inductor. In general, the SRF sets the frequency limit on the useful operating range of a capacitor. But in this application, we exploit this phenomenon and use a capacitor as an inductor after SRF to match a complex load to a real load.

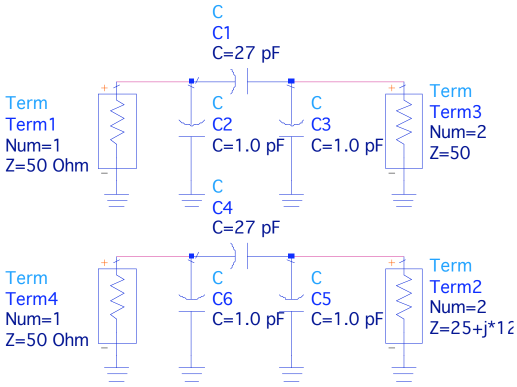

Figure 3 Simplified equivalent circuit.

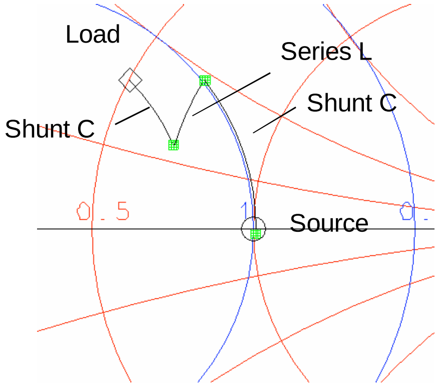

Figure 4 Typical path traced on the Smith Chart at the center frequency.

The simplified schematic of the matching network is shown in Figure 3. The design specification is to match an impedance of 25+j12Ω to a 50Ω load at 1.6GHz. As mentioned earlier, the basic idea is to use the capacitor C1 (27pF) in the series arm of the PI network, as an inductor after SRF. The new pad-scalable model for ATC 600L capacitors (CAP-ATC-0402-101) and Rogers 60 mil-thick R04003 (εr = 3.6) substrate were used in the design. The impedance transformation at the center frequency is illustrated in Figure 4. Figure 5 shows the layout of the PCB. It is important to note that the inductance of interconnects does play a role in determining the SRF and hence the effective equivalent series inductance.

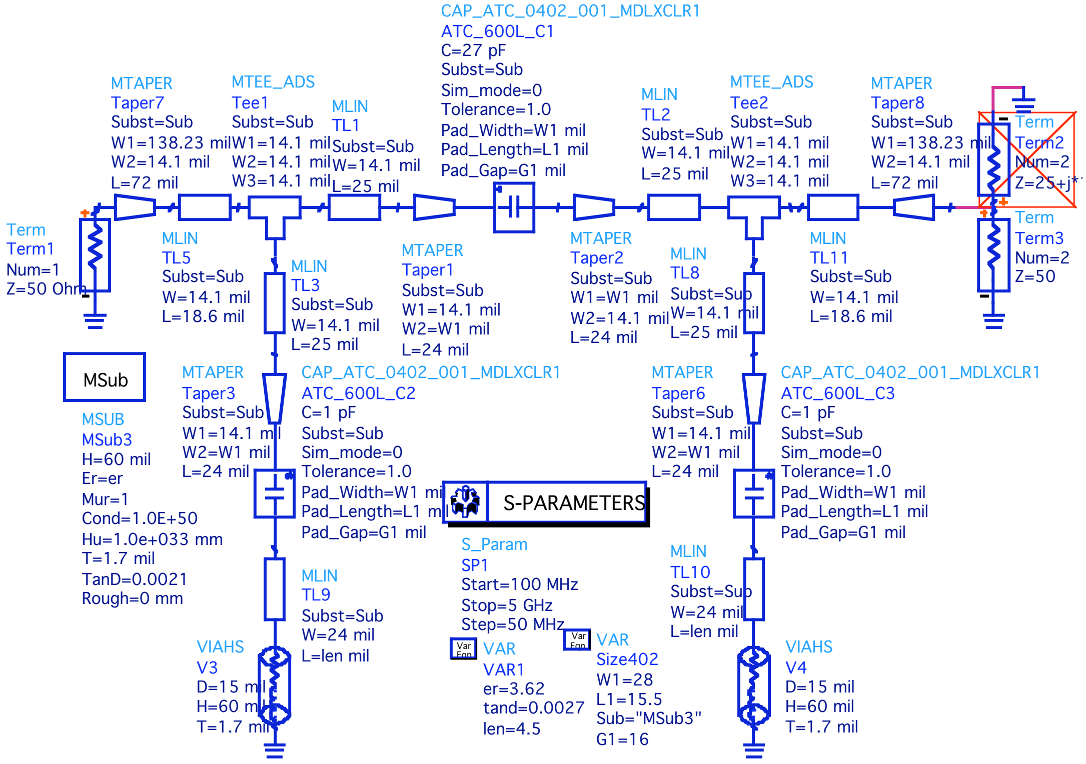

Figure 5.ADS schematic of the layout used.

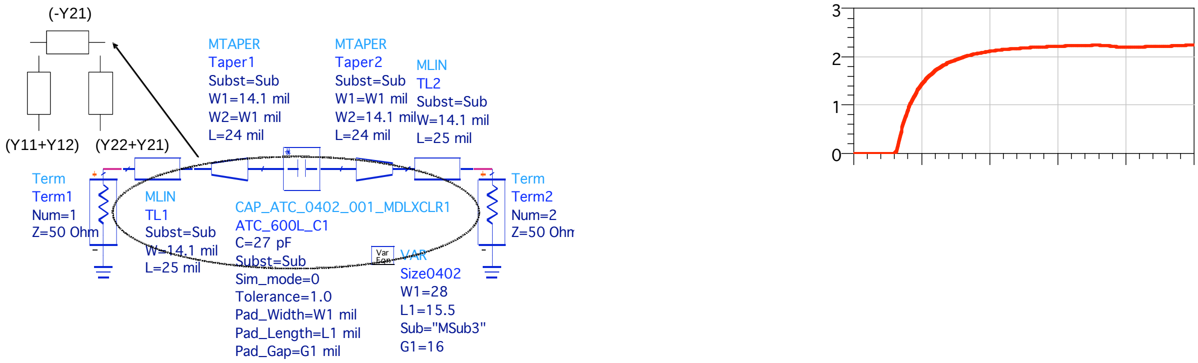

Figure 6.ADS schematic used to extract Ls (right). Extracted values for nominal Capacitance (C) and series Inductance (Ls) (left)

Figure 6 shows the schematic of the circuit used to extract the equivalent capacitance (C) and inductance (Ls) of the series element in the matching network; these values are found by using Y21. When -Imag(Y21) > 0, C=-Imag(Y21)/(2πf), and when -Imag(Y21) < 0, Ls=1/(Imag(Y21)2πf). The microstrip and taper sections are included with the capacitor effects in this calculation. It is interesting to note that the Ls value is fairly constant at ~2.2 nH after the SRF.

Results

Figures 7 and 8 compare the measured result with circuit simulation and method-of-moments (MoM) co-simulation results. The layout of the PCB used in the MoM simulation is shown in Figure 9. The taper at the input and the output side is used to match the 50Ω line (not shown in the layout) with the mounting pads for the capacitor. The MoM co-simulation results provide improved comparisons to the measured data, as the interconnect and ground-via effects are more accurately represented.

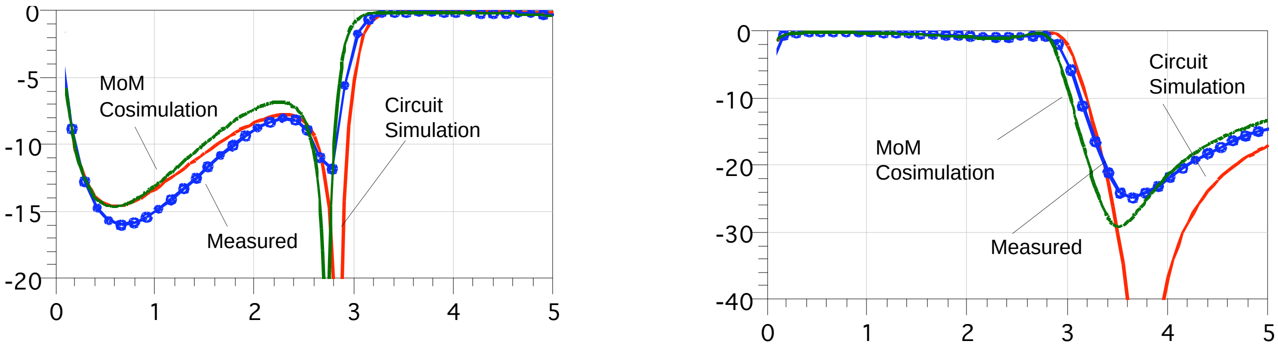

Figure 7 Comparison between simulated and measured response when port 2 is terminated with 50Ω.

The properties of the substrate (thickness and ε_r) used are critical in obtaining a good correlation between measured and simulated data. The substrate-scaling features of the Modelithics Global models enable all substrate-related parasitics to be taken into account. To illustrate this feature, a simulation comparing two substrates is shown in Figure 11.

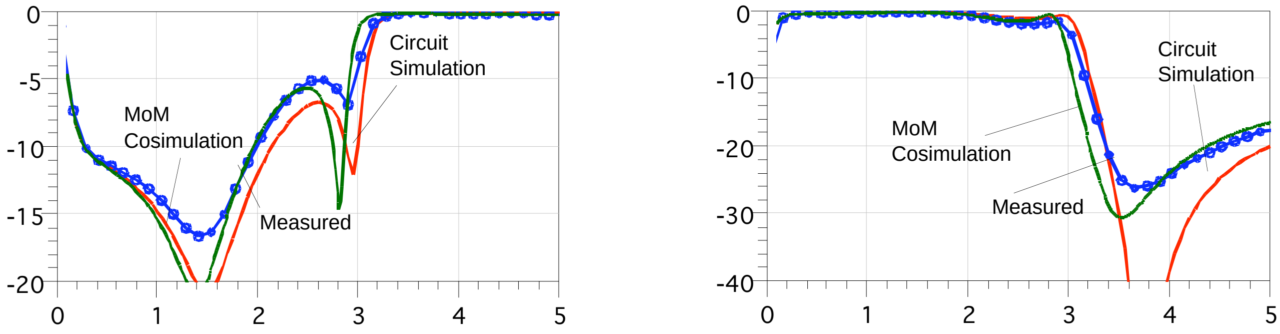

Figure 8 Comparison between simulated and measured response when port 2 is terminated with 25+j12Ω.

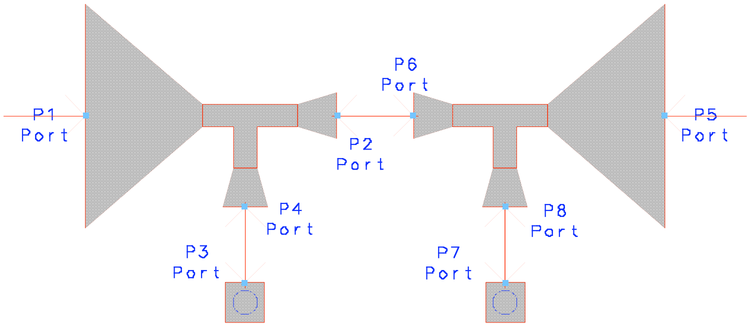

Figure 9 Layout of the PCB used in the MoM Simulation.

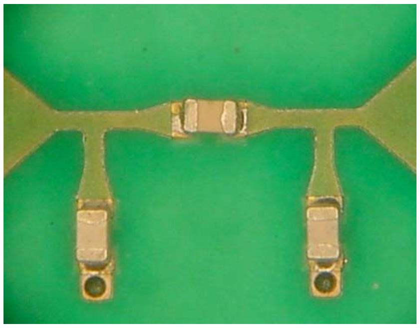

Figure 10 Photograph of the matching circuit.

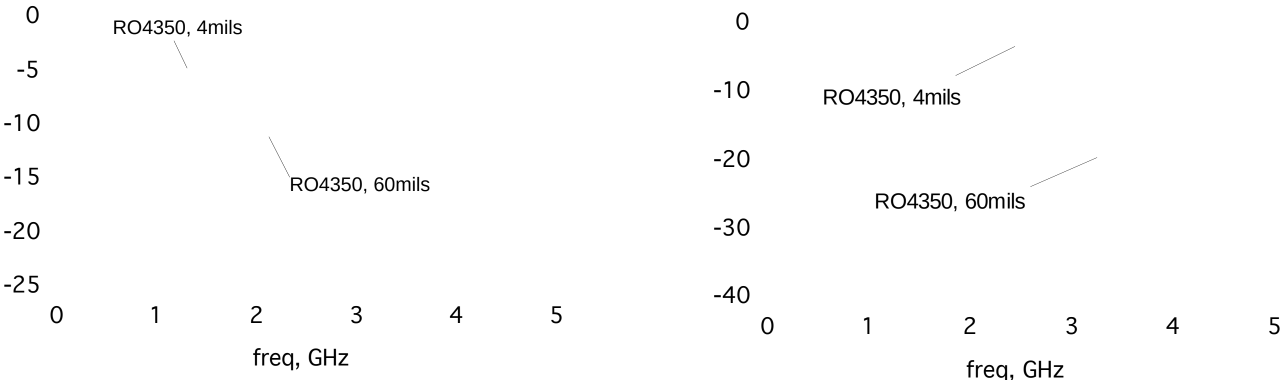

Figure 11.Comparison of simulated results Case1: RO4350 60 mils substrate, Case2: RO4350 4 mils substrate and Case3: RO4350 60 mils substrate using ideal components. Port 2 is terminated with 25+j12Ω

About this work

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