Lab 1 – Measuring "Parasitics" of Passive Components with a VNA

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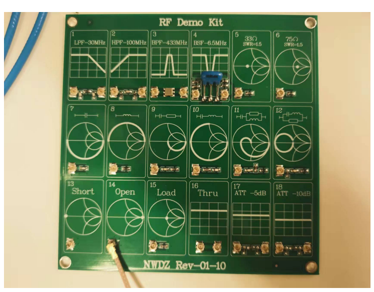
Abstract

S-Parameters of passive components are measured using a Vector Network Analyzer (VNA), and more realistic circuit models containing parasitics are proposed. The proposed circuit models are simulated in LTSPice, and compared against the experimentally obtained results.

1 Introduction

Real life passive components are far from ideal. All capacitors, inductors, and resistors have some parasitic capacitance, inductance, and resistance. But how can we measure these parasitics? How can we build good electric models of these real-world componenets? To this end, we use Vector Network Analyzers (VNA) to measure the frequency response of these passive components, use our understanding of circuit elements to conjecture about good circuit models, and use LTSpice to verify that the circuit models match what we observe.

2 Experimental Setup



(a) Picture of RF Demo Kit NWDZ

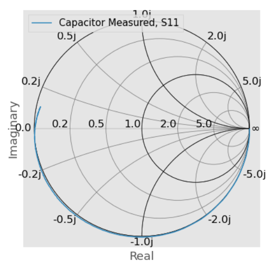
(b) Picture of NanoVNA

Figure 1: Picture of Tools used in Experiment

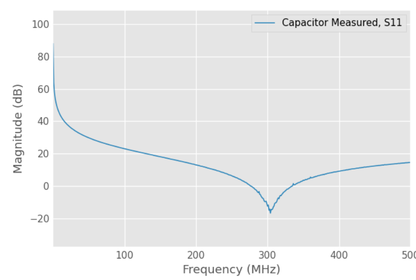
The passive componenets of interest are all surface mount components on the *RF Demo Kit NWDZ Rev-01-10* (Figure 1a), and we use the NanoVNA (Figure 1b) to perform the measurements. Care is taken to calibrate the NanoVNA each time before use.

3 Measurements and Results

3.1 Capacitor



(a) S11 on Smith Chart



(b) Magnitude of Impedance

Frequency (MHz)	S11	Impedance (Ohm)
0.05	1.00-0.00j	1114.88-24861.18j
10.049	0.82-0.58j	-0.17-157.00j
100.04	-0.86-0.53j	-0.41-14.14j
304.020	-0.99-0.00j	0.14-0.03j
500	-0.94+0.20j	0.98+5.25j

(c) S11 and Impedance at certain frequencies

Figure 2: S Parameter of Measured Capacitor

We measured the S-Parameters of the capacitor in the kit (item 7 in Figure 1a), and the results are depicted in Figure 2.

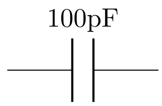
3.1.1 Ideal Capacitor Model

Using the impendance at 10MHz, we see that the capacitance is roughly

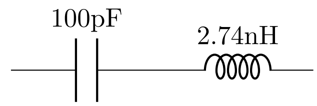
$$\frac{1}{2\pi \cdot 10MHz \cdot 157\Omega} \approx 100pF.$$

So our first model of the element would just be an ideal capacitor of $100pF$ (Figure 3a).

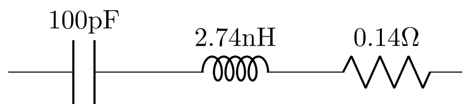
However, immediately we see that the ideal capacitor does not fully characterize the real capacitor. In the Smith chart (Figure 4a), S11 crosses the real axis and goes into the upper half of the unit circle, and in the impedance magnitude plot (Figure 4b), the impedance has a minimum at around 300MHz.



(a) Ideal Capacitor Model



(b) Capacitor with Series Inductance



(c) Capacitor with Series Inductance and Resistance

Figure 3: Electric Models of Real Life Capacitor

3.1.2 Series Inductance

Since the measured impedance of the capacitor goes up beyond 300MHz, this indicates the existance of some parasitic inductance. Since parasitic inductance is often introduced by the magnetic field caused by conductors, we choose to model it as **series parasitic inductance** (Figure 3b).

The minimum impedance occurs at roughly 304MHz (which corresponds to S11 crossing the real axis). This indicates that the 304MHz is the resonance frequency of the LC circuit. So the series inductance can be calculated as

$$L = \frac{1}{(2\pi f)^2 C} = \frac{1}{(2\pi 304MHz)^2 \cdot 100pF} \approx 2.74nH.$$

As seen in Figure 4, the LC model correctly predicts a minimum in the magnitude of the impedance around 300MHz, and the crossing of the real axis by the s parameter.

3.1.3 Series Resistance

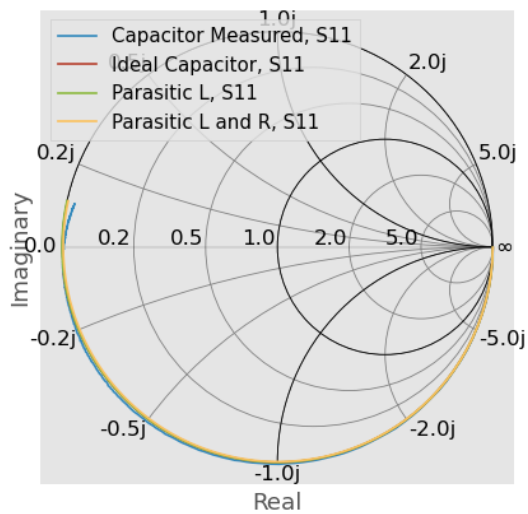
Examining Figure 4 further, we see that our LC model still does not fully capture the electric properties of the real world capacitor. In Figure 4b, our LC model predicts far lower impedance at 304MHz than our measurements.

Indeed, at resonance frequency, an ideal LC circuit would have 0 impedance, which is impossible in the real world because there is always some resistance. We model this parasitic resistance as series resistance in Figure 3c, where its value is calculated by looking at the impedance at resonance frequency.

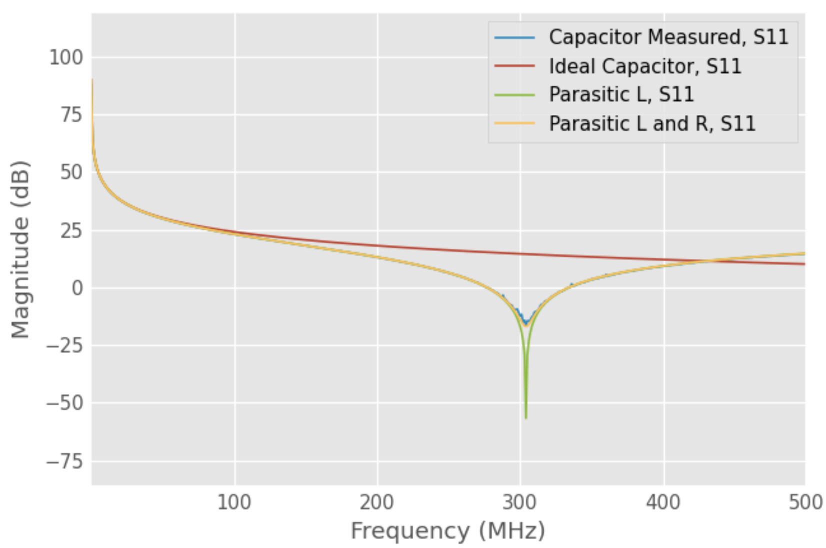
At resonance frequency, the impedances of the inductor and the capacitor will cancel, so the only thing left would be the series resistance. Examining Figure 2c, we set the series resistance to 0.14Ω. Again, the results of LTSpice simulation are plotted in Figure 4. With the introduction of the series resistance, we see that the magnitude of the impedance predicted by the model almost exactly matches that of the real componenet.

3.1.4 Other Parasitics

We are done a pretty good job of modelling the real life capacitor by introducing series inductance and series resistance. However, there are still some aspects of



(a) S11 of electric models of capacitor on Smith Chart



(b) Magnitude of Impedance of electric models of capacitor

Figure 4: Electric Characteristics of real capacitor compared with various models

measured data that our model cannot explain. For example, in Figure 4a, our RLC model predicts that S11 will always stay on the unit circle, but in our measurements S11 goes inside the unit circle. This may be explained by adding other parasitics to our electric model (maybe parallel resistance), but that will be left for future work.

3.2 Inductor