LAB 1 – Comparing analytical models with measured "Parasitic" properties of passive components with a VNA

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Lab 1 of EE 133 focuses on building a practical understanding of how to use a VNA (Vector Network Analyzer). The goal is to use a vector network analyzer to confirm a "more realistic" model of a capacitor and inductor by measuring the components resonant frequencies and estimating the respective equivalent series inductance and shunt capacatance.

I. INTRODUCTION AND MOTIVATION

The goal of this lab was to begin to learn how to use a VNA (vector network analyzer). This included understanding at a high level the concept of S parameters and how they relate to impedance. In addition, the lab provided us practice in using a Smith Chart, and allowed us to measure properties of a DUT and compare it against models.

II. THEORETICAL BACKGROUND

For this lab, our device under test were a "real world" capacitor and inductor. Each component can be modeled by having "parasitics". A capacitor can be modeled by a equivalent series resistance and equivalent series inductance in addition to a resistor in parallel to the capacitor to account for leakage current.

Furthermore, an inductor can be modeled as a lumped package of series resistance and parallel capacitance and resistances.

Because our "real world" capacitor has a "parasitic" inductance, and vice versa, there will be a frequency of self resonance, (where the conductive and inductive reactantances cancel each other out). We can find that frequency f as such.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi C} \tag{1}$$

$$X_L = \omega L = 2\pi L \tag{2}$$

$$\omega_{res} = 2\pi f = \sqrt{\frac{1}{LC}} \tag{3}$$

From our calculations with equation (3) from the values assigned in the LT Spice circuit diagrams, our expected resonance for the capacitor is f = 18.37 MHz; the inductor has an expected resonant frequency of f = 50.33 MHz, both of which agree with the LT spice simulations in FIG. 1. and FIG. 2.

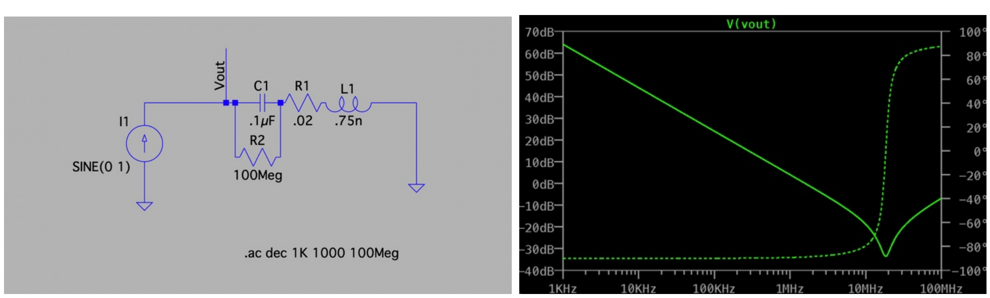

FIG. 1. **LT Spice circuit diagram of a realistic capacitor of 0.1 micro-farad and simulation of its requency response**

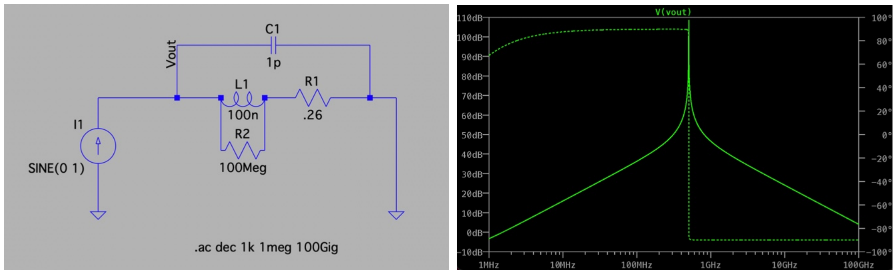

FIG. 2. **LT Spice circuit diagram of a realistic inductor of 100 nano-Henry and simulation of its frequency response characteristics**

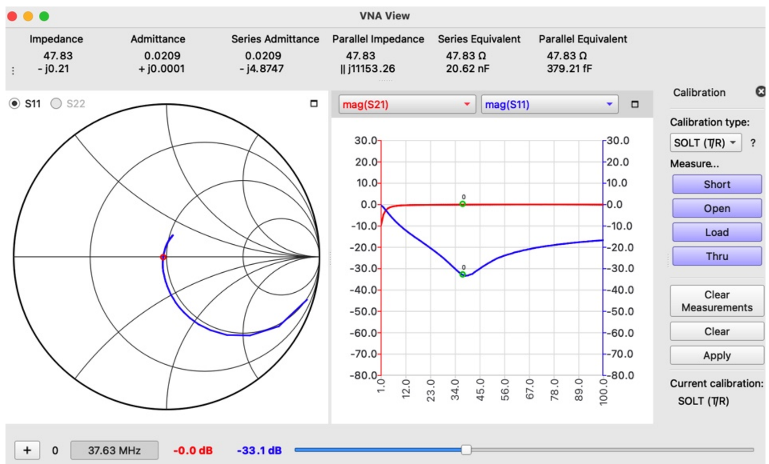

FIG. 3. **Reading from VNA of 470 pF DUT**

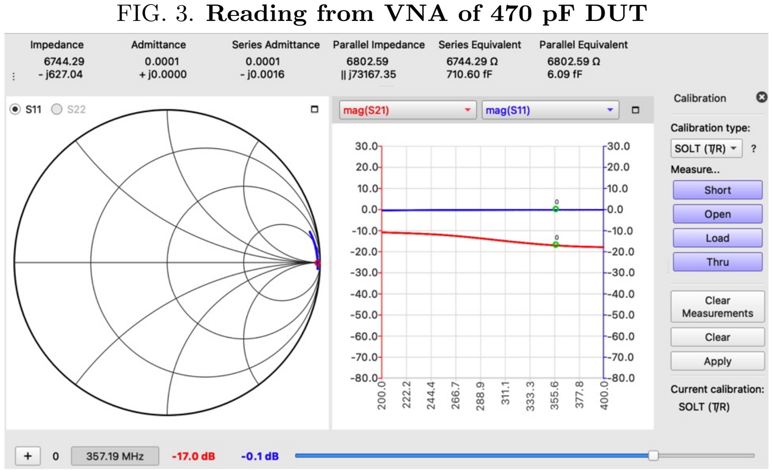

FIG. 4. **Reading from VNA of 206 nH DUT**

III. LAB PROCEDURE

We wanted to exercise our skills using the VNA to see if our model holds for physical components. First, we calibrate our VNA with SOLT (Short-Open-Load-Through) calibration, ensuring that our plane of calibration is at the end of our SMA cable. We are also careful to re-calibrate anytime we adjust the frequency through which we sweep.

We have two DUT: a 470 pF capacitor and a 206 nH inductor. With our VNA, we are searching for the frequency in which there is self resonance within the DUT. On the VNA's Smith chart this will occur when our curve leaves the capacative region and crosses the real axis (when the inductive and capacative reactance cancel eachother out). In FIG. 5., we see that for our 470 pF DUT, we cross the real axis at around $f = 37$ MHz.

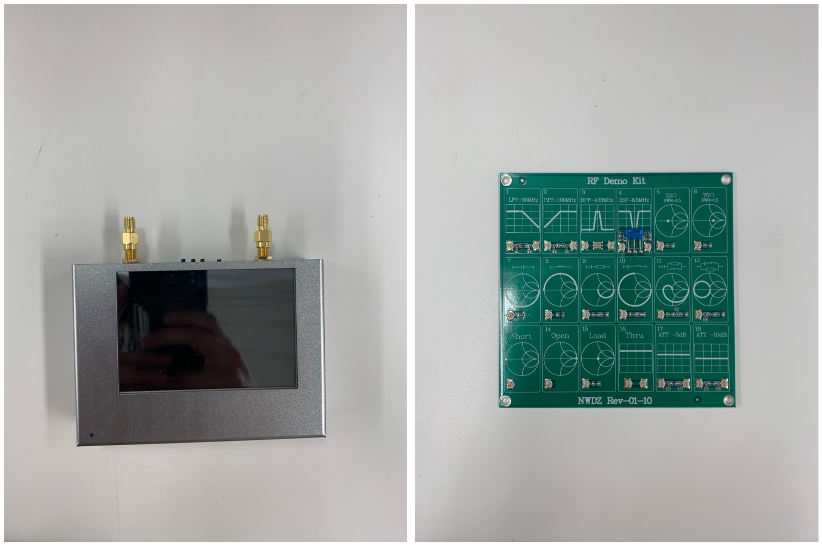

FIG. 5. **Compact Vector Network Analyzer used in this lab report and the demo board used to hone my VNA intuitions**

Additionally, we can see from FIG. 3. plotted the reflection S_{11} and S_{21}. We know that the reflection S_{11} is proportional to impedance (i.e. the power that is reflected back inverse of the power that is not transmitted through the DUT). This means that we can also see the analog capacative, resonant, and inductive frequency regions of our DUT using the VNA's reflection graph (as seen in the blue curve).

IV. FINDINGS

Looking at the Smith Charts in FIG. 3 and FIG. 4, we can identify the equivalent series inductances and resistances of our "real world" capacitor and inductor, agreeing with those that we defined in our analytic models.

Using equation (3), and the measured frequency resonance of $f = 37$ MHz, we can calculate our equivalent series inductance: $L_s = 39$ nH. Looking at the smith chart, we can see that, at resonance, the ESR is nominal (or at least outside the ability of the VNA's ability to measure).

Furthermore, FIG. 4. has a measured frequency resonance of $f = 357$ MHz. At resonance, we expect to see a large resistance, which we do see measured at around 7k ohms. This however is not as large as we would expect, according to our analytical model.

Next, consider the frequency characteristics of our reflection coefficients from port 1, defined by the blue curves in FIG. 3 and FIG. 4. We will begin to see more concretely discrepancies between our analytical model and measured components.

We would expect curves around the point of resonance that resembles the magnitude of the frequency response in FIG.1 and FIG.2. However, we see the effects higher degree "parasitic" not described in our analytical model. I believe that these effects are more pronounced than we would expect. This could be due to the inductance in the long leads of our components or to imperfections in our measuring equipment that lead to inaccurate measurements.

More investigation would be required to determine these higher degree effects, which would likely involve using a more precise VNA and creating a more standard apparatus by which we measure our components (likely using SMD).