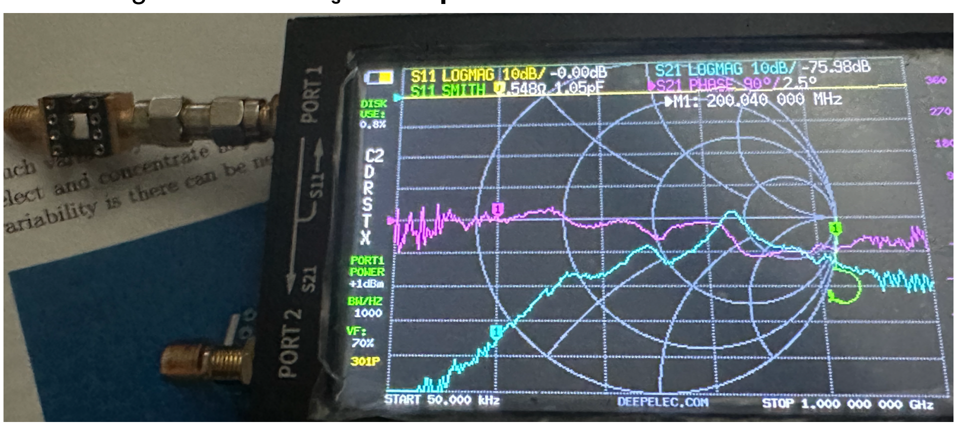
Sonia Zhang

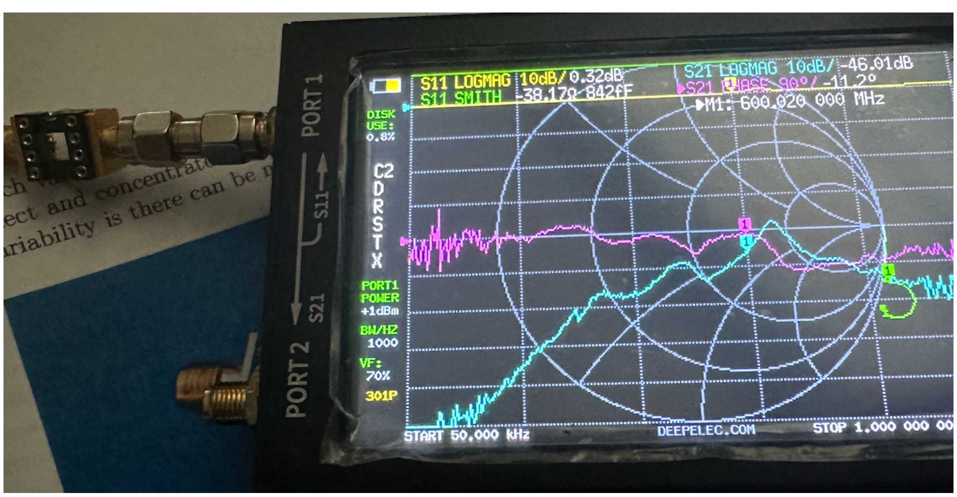
EE370 Lab 1

1. ~
2. ~
3. ~
4. ~
5. Test Fixture Measurements
   5.1. ~
   5.2. ~
   5.3. I took the S11 capacitance measurement at 200MHz, 400MHz, 600MHz, and 800MHz.

Frequency (MHz)	200	400	600	800	1000
Capacitance (pF)	1.04	.999	.862	1.02	.839

The average value was **C_s = .952 pF**

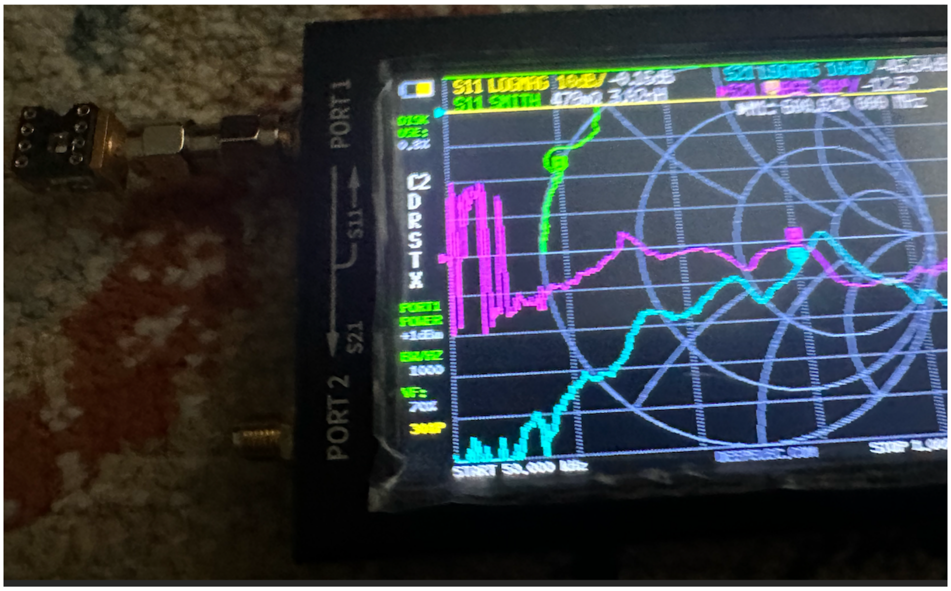




5.4. I inserted a small metal wire to the test fixture between the inner and outer conductors. I took the S11 inductance measurement at 200MHz, 400MHz, 600MHz, and 800MHz.

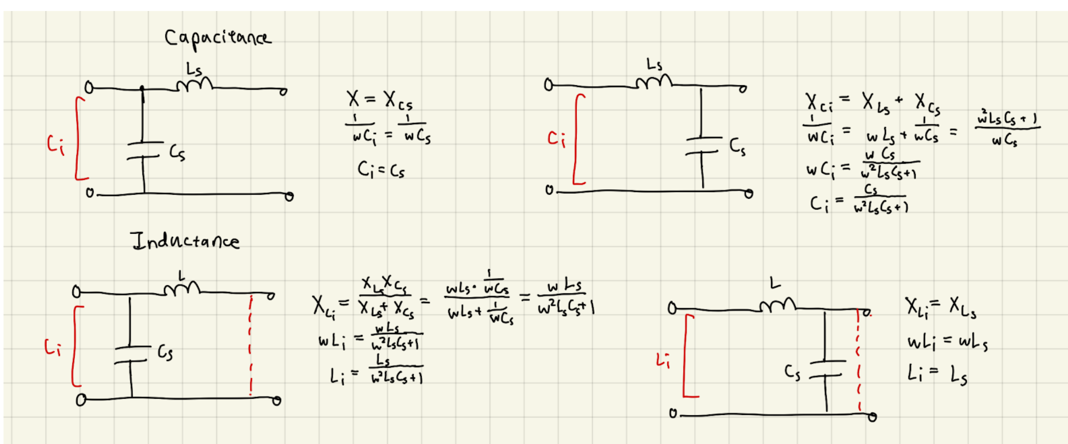
Frequency (MHz)	200	400	600	800	1000
Inductance (nH)	3.15	3.03	3.04	3.48	3.54

The average value was $\mathbf{L_s = 3.25}$ **nH**



(sorry for blurry picture)

5.5.



Capacitance:

	left circuit Calculation	difference from measurement	right circuit Calculation	difference from measurement

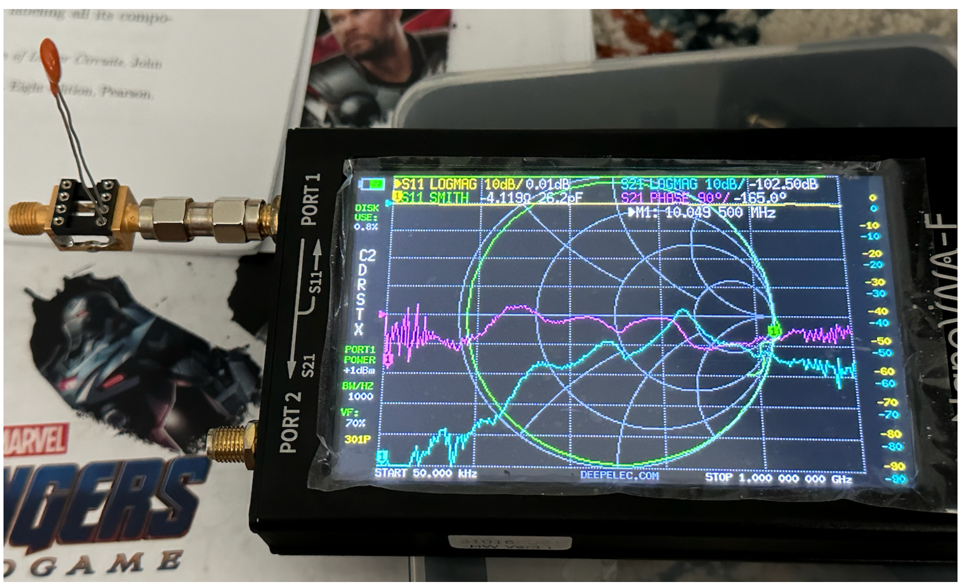
200 MHz	1.04 pF	0%	1.04 pF	0%
1000 MHz	.839 pF	0%	.836 pF	.36%

Inductance:

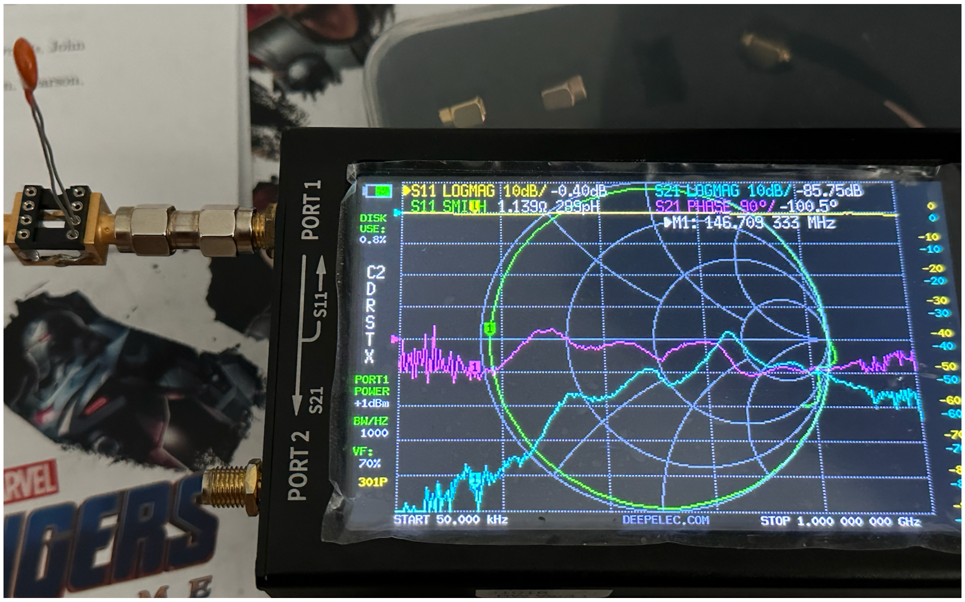
	left circuit	difference from measurement	right circuit	difference from measurement
200 MHz	3.15 nH	0%	3.15 nH	0%
1000 MHz	3.53 nH	.28%	3.54 nH	0%

The left circuit is marginally more accurate.

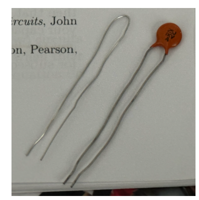
6. Capacitor Measurements
    6.1. ~
    6.2. I put the capacitor in the DIP8 test fixture with one lead on the inner conductor and one on the outer. The raw measurement was 26.2pF, so subtracting out the .925pF from the test fixture, **C_L = 25.3 pF**

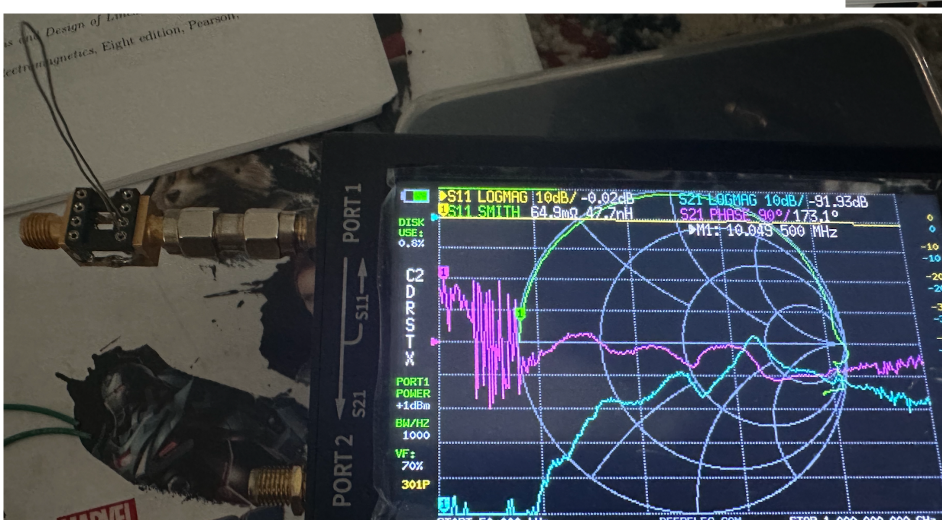


    6.3. I move the cursor until the S11 measurement changes from a capacitance measurement to inductance measurement. The resonance frequency happened at **f_o = 146.7 MHz**. This change happens because at the resonance frequency, the inductance and capacitance have equal but opposite reactance thereby canceling out. After this point, the inductance has a larger magnitude, so the VNA displays the inductance. Since the change was from a capacitance to inductance measurement, this circuit is a series circuit.



6.4. I made a hair pin structure that's the same size as the inductor. It's raw measurement at 10 MHz is 47.7 nH, so subtracting out the 3.25 nH from the test fixture, **L_p = 44.45 nH**



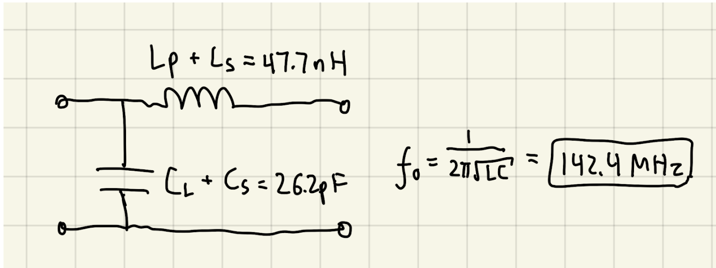


6.5. $L_w = \ell \mu_o / \pi \ln [D/2a + \sqrt{(D/2a)^2 - 1}]$

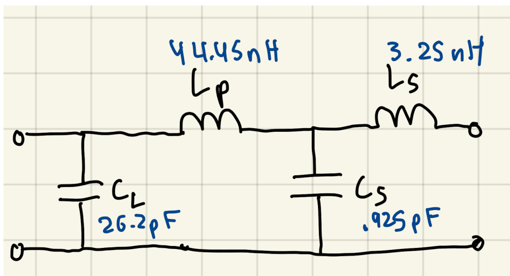
ℓ = 4.5 cm, D = .4 cm, a = .4 mm → **L_w = 41.3nH**

This value is a little smaller than the measured. It could be caused by the wires not running exactly parallel causing some sections to be further than 4 mm away from each other. This would increase the inductance of the hairpin. Also the hairpin structure is not located in free space. So the part where it loops back could possibly increase inductance as well.

6.6. Resonant Frequency Measurement



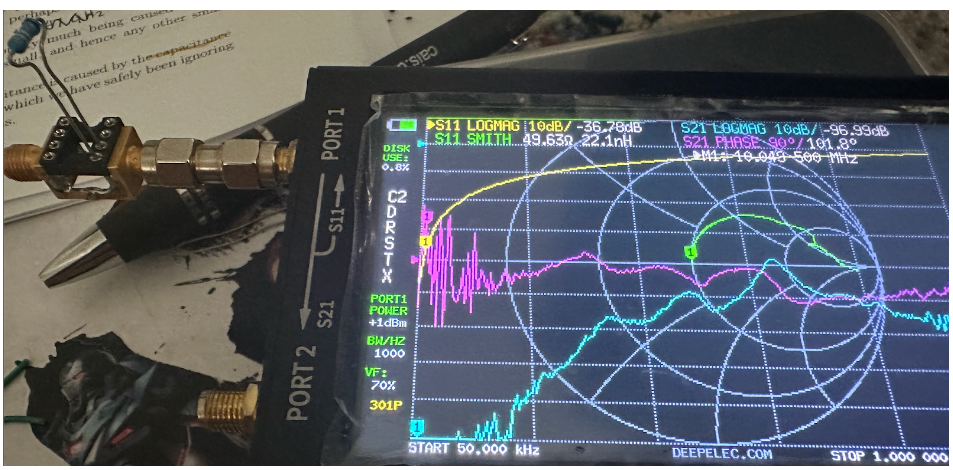
6.7. Equivalent Circuit



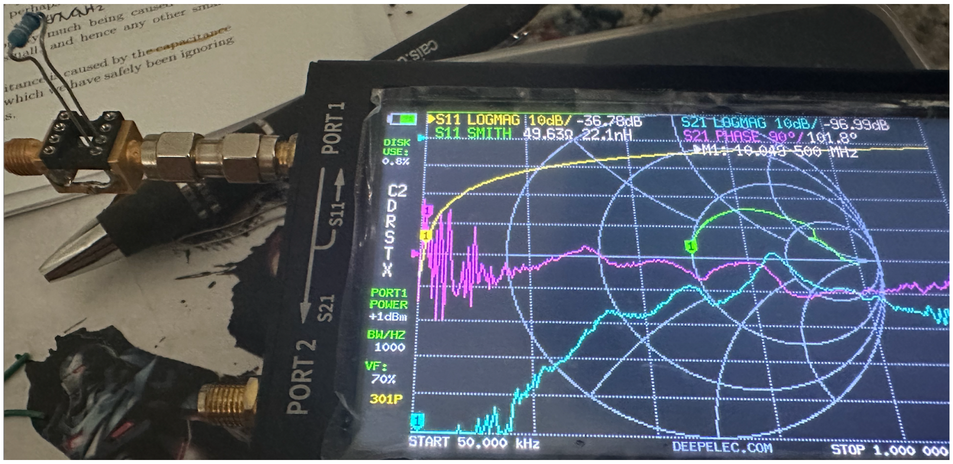
7. Resistor Measurements

7.1. ~

7.2. I put the resistor in the DIP8 test fixture with one lead on the inner conductor and one on the outer. The measurement at 10 MHz is **R_L = 49.61 Ohms**.

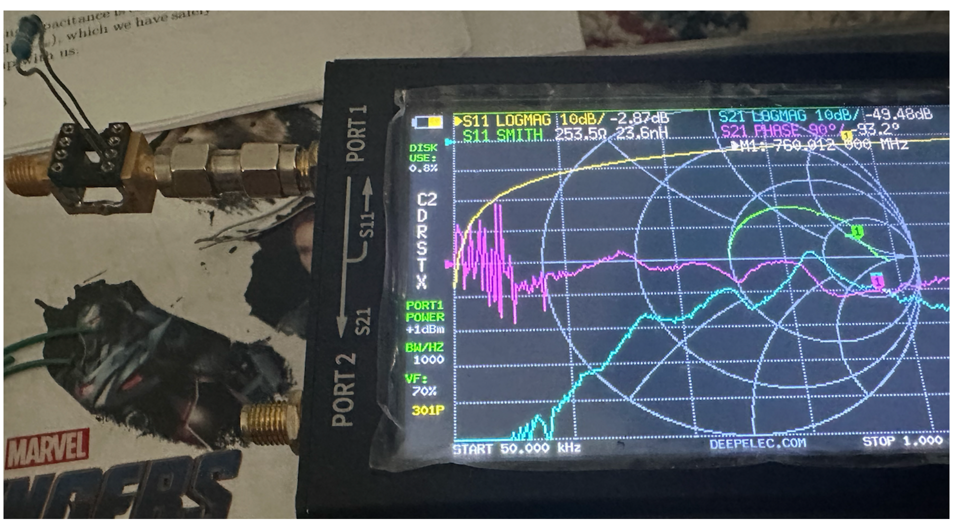


7.3. The inductance at 10 MHz is 22.1 nH - 3.25 nH, **L_L = 18.95 nH**.

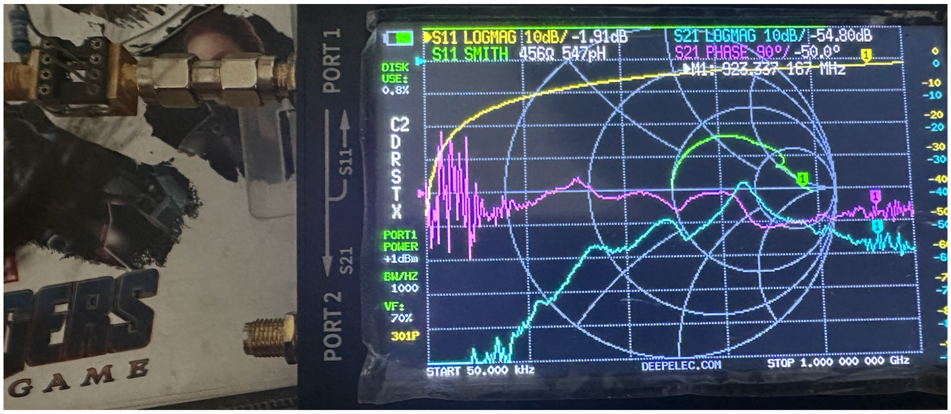


7.4. The hairpin structure has a measured inductance of 24.8 nH. Subtracting the test fixture, the inductance is **21.55 nH.**

7.5. At 760 MHz, the 49.9 Ohm resistor has a resistance of 253 Ohms.



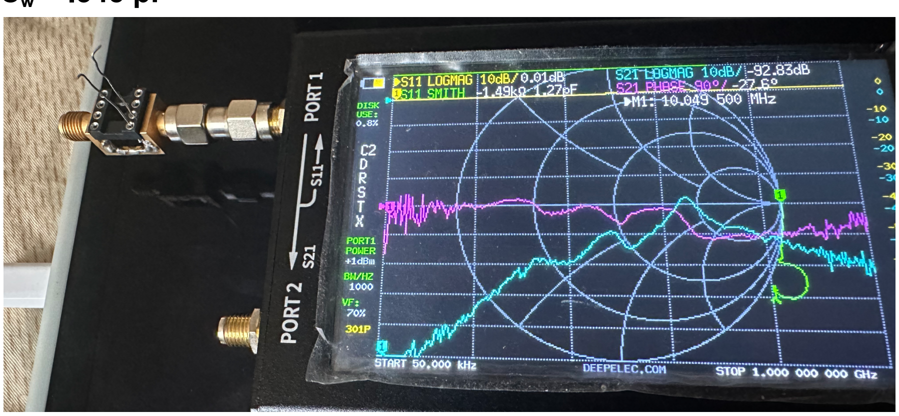
7.6. I move the cursor until the S11 measurement changes from an inductance measurement to capacitance measurement. The resonance frequency happened at $\mathbf{f_o}$ **= 923.3 MHz**. This was an inductance to capacitance transition, hence the circuit is a parallel circuit



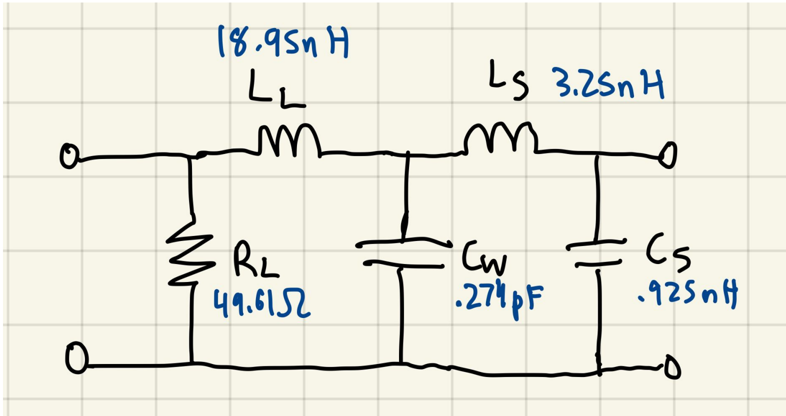
7.7. I replaced the resistor with a hairpin structure and did the same measurement. The resonance frequency happened at $\mathbf{f_{op}}$ **= 900 MHz**

7.8. Since resonance is caused by a combination of inductance and capacitance, the resonant frequency of the resistor is likely due to the parasitic from the test fixture and the wire leads. $1/\left(2\pi\sqrt{24.8\text{ nH} * .925\text{ pF}}\right) \rightarrow$ $\mathbf{f_{oe}}$ **= 1.05 GHz**

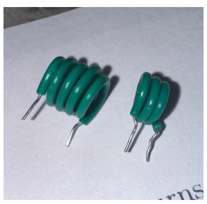
7.9. $923\text{ MHz} = 1/\left(2\pi\sqrt{24.8\text{ nH} * (.925\text{ pF}+C_w)}\right) \rightarrow$ $\mathbf{C_w}$ **= .274 pF**
I measured the capacitance to be 1.27 pF. Subtracting the test fixture, that is $\mathbf{C_w}$ **= .345 pF**



7.10. Equivalent Circuit

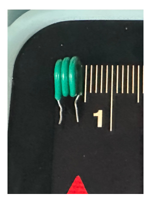


8. Inductor Measurements

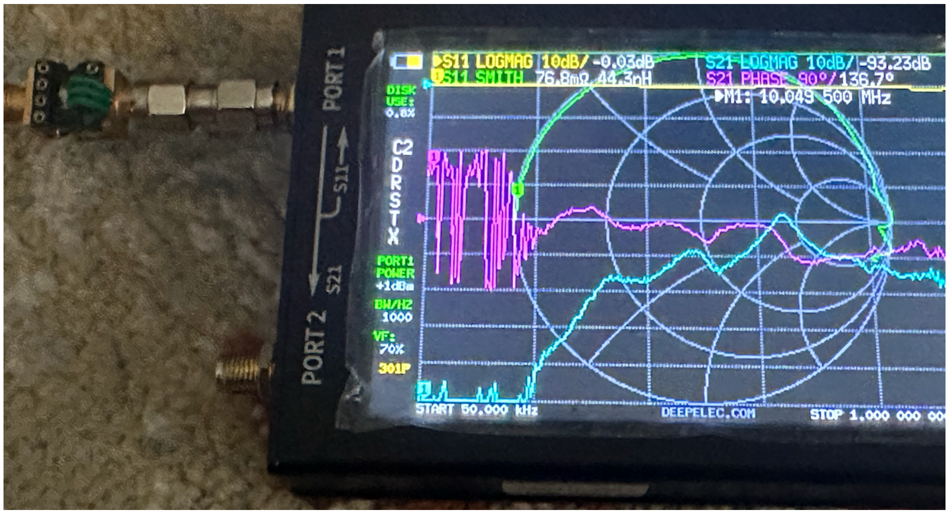


8.1. ~

8.2. With a diameter of 6.5mm, a length of 4.5 mm, and 3 coils, the calculated inductance is **L = 46.1 nH**



8.3. I put the inductor into the DIP8 test fixture. The measurement at 10 MHz is 44.3 nH, so subtracting out the 3.25 nH from the test fixture, **L_L = 40.75 nH.** One discrepancy could be that the diameter in the measurement does not take into account the insulation so it is larger than reality. Another discrepancy is that the coils may not be perfectly lined up, causing the effective coil area to be smaller than the calculated.



8.4. At 186 MHz, the inductance measurement of the 41 nH inductor was 47.2 nH

8.5. I moved the cursor until the S11 measurement changed from an inductance measurement to capacitance measurement. The resonance frequency happened at $\mathbf{f_o}$ **= 653.4 MHz**. Since it went from an inductance to capacitance measurement, this series is parallel.

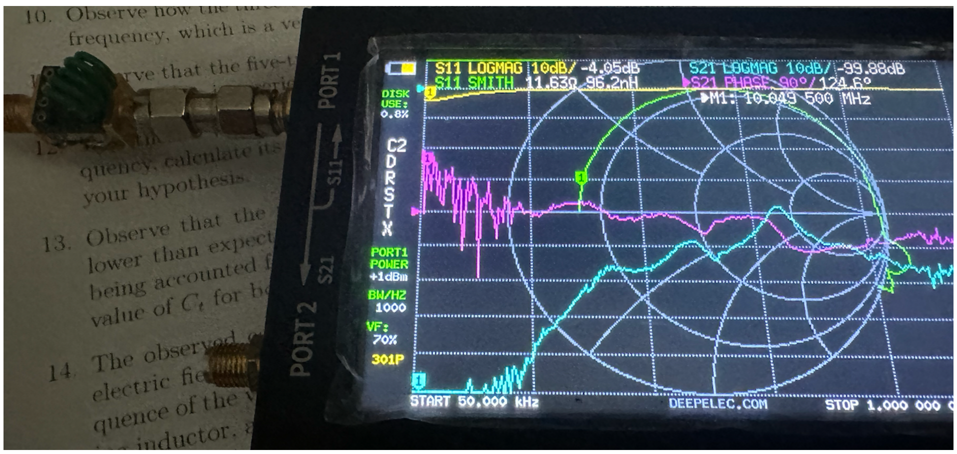
8.6. There is likely some capacitance on the leads of the inductor and also there is the stray capacitance of the test fixture.

$$f_{0e} = \frac{1}{2\pi\sqrt{44.3nH \cdot .925pF}} = 786\ MHz$$

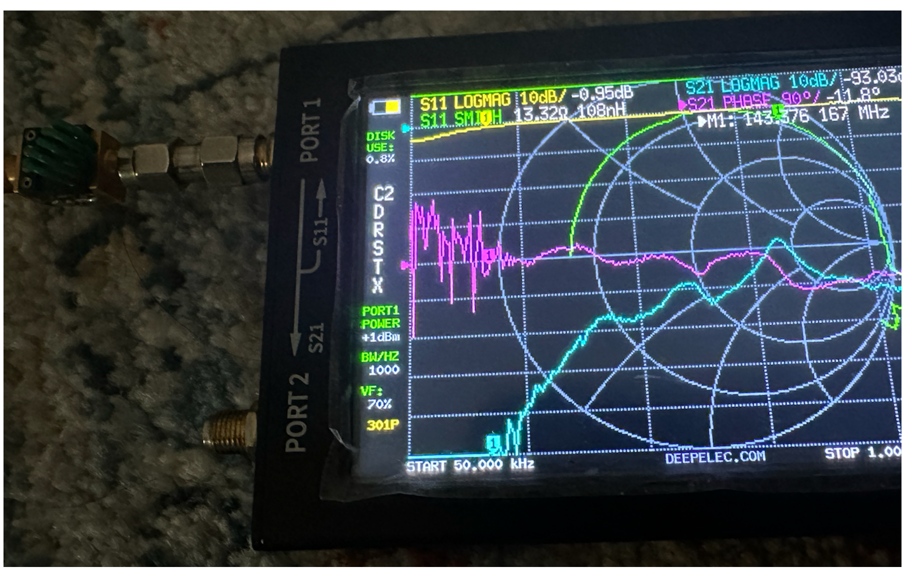
8.7. ~

8.8. With a diameter of 7mm, a length of 7 mm, and 5 coils, the calculated inductance is **L = 90.5 nH**

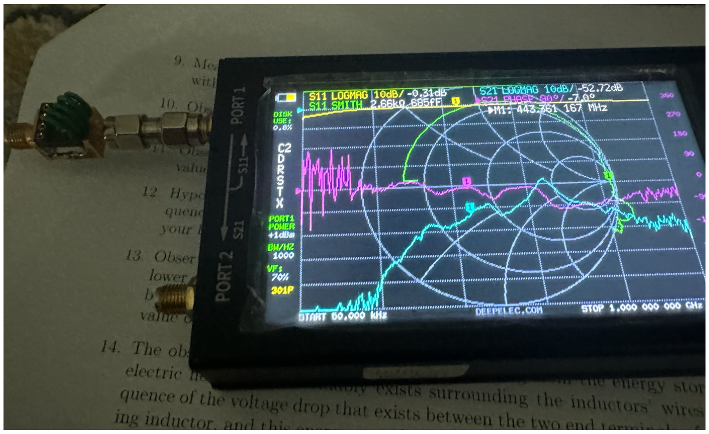
8.9. I put the inductor into the DIP8 test fixture. The measurement at 10 MHz is 96.2 nH, so subtracting out the 3.25 nH from the test fixture, $\mathbf{L_L}$ **= 92.95 nH.** It is slightly larger than the calculated measurement, with the same discrepancies as before (the insulation width not being properly accounted for and the coils not being perfectly lined up).



8.10. At 143 MHz, the ~90nH inductor had an inductance measurement of 108 nH.



8.11. I moved the cursor until the S11 measurement changed from an inductance to a capacitance. This happened at $\mathbf{f_o}$ **= 443 MHz**. Because the transition was from inductance to capacitance, this is a parallel circuit.



8.12. Like with the 3 turn inductor, there is likely some capacitance on the leads of the inductor and also there is the stray capacitance of the test fixture.

$$f_{0e} = \frac{1}{2\pi\sqrt{96.2\,nH \cdot .925\,pF}} = 533\ MHz$$

8.13. C_t for both inductors

$$\text{3 turns:}\quad 653.4\ MHz = \frac{1}{2\pi\sqrt{44.3\,nH \cdot (.925\,pF + C_t)}}$$

$$C_t = .414\ pF$$

$$\text{5 turns:}\quad 443\ MHz = \frac{1}{2\pi\sqrt{96.2\,nH \cdot (.925\,pF + C_t)}}$$

$$C_t = .417\ pF$$

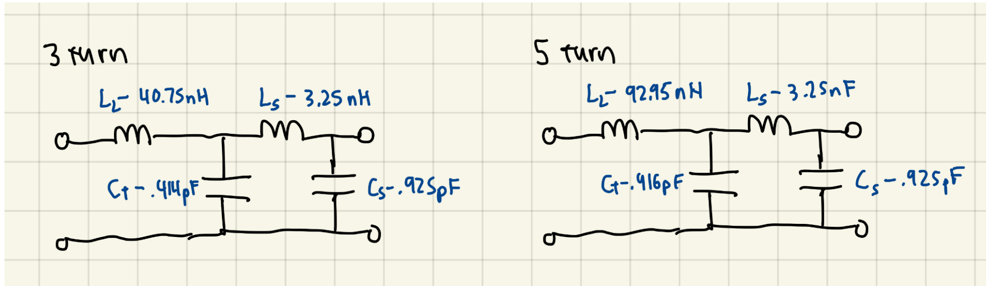
8.14. Calculated C_t using Miranda-Pirochim's theorem
For the 3 turn inductor, I used a diameter of 6.5 mm and a length of 4.5 mm.
For the 5 turn inductor, I used a diameter of 7 mm and a length of 7 mm.

$$\text{3 turns:}\quad C_t = \frac{\mu_0 \epsilon_0}{.4L}(.0065 \cdot 3)^2 \left(\frac{.0065}{.0045}\right)^{.4} = .301\,pF$$

$$\text{5 turns:}\quad C_t = \frac{\mu_0 \epsilon_0}{.4L}(.007 \cdot 5)^2 \left(\frac{.007}{.007}\right)^{.4} = .366\,pF$$

The calculated C_t is a little smaller than the one calculated from measurements. There may still be a little bit of capacitance unaccounted for, perhaps in the leads, or maybe due to physical gaps between windings caused by the insulator.

8.15. In these equivalent circuits, L_s and C_s are part of the measurement setup.



8.16. Calculating self resonant frequency

$$f_{0a} = \frac{1}{2\pi\sqrt{L_L \cdot C_t}} = \frac{1}{2\pi\sqrt{40.75nH \cdot .414pF}} = 1.22\ GHz$$

8.17. ½ * f_{Oa} = **610 MHz** as the maximum practical operation frequency