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UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Frequency Behavior of a Shielded Loop Antenna with a Variable Gap Position

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Overview

- Motivation
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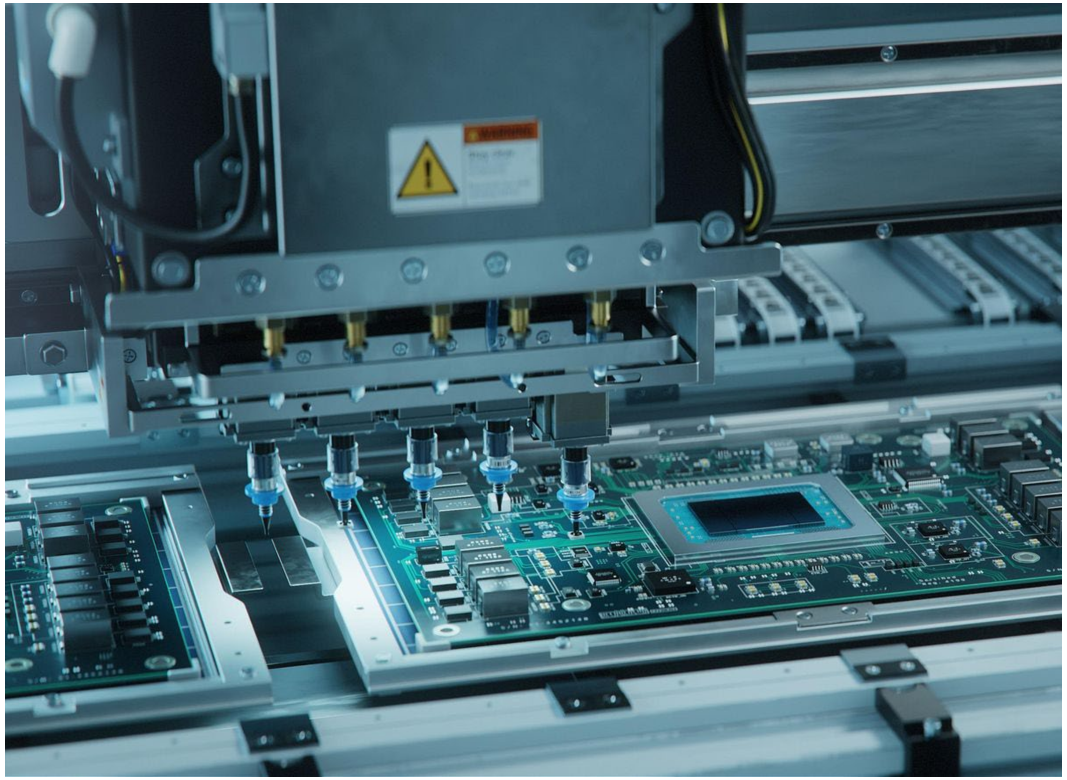
- Discussion of characteristics of interest
- Existing methodologies
  - Operational tradeoffs
- Preliminary investigation of shielded resonant loops
  - Initial design
- Frequency behavior investigation
  - Variable gap position
  - Scaling



High density PCB [1]

[1] Pepitone, J. (2022, April 21). *5 ways the chip shortage is rewiring tech*. IEEE Spectrum. Retrieved June 29, 2022, from https://spectrum.ieee.org/chip-shortage-rewiring-tech

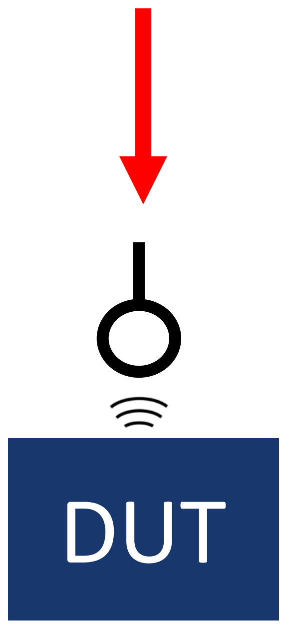
Motivation

Typical EMI testing is done in far-field

- Necessary for products to meet safety standards
- Not ideal for product development
- Would require pinpoint accuracy from an array to achieve desired resolution

Near-field can provide more information

- Increased accuracy and reliability
- Higher resolution capacity from higher proximity
- Better estimation of currents and EMI source locations
- Increasing module density requires higher resolution
- Low SNR, weak signal strength



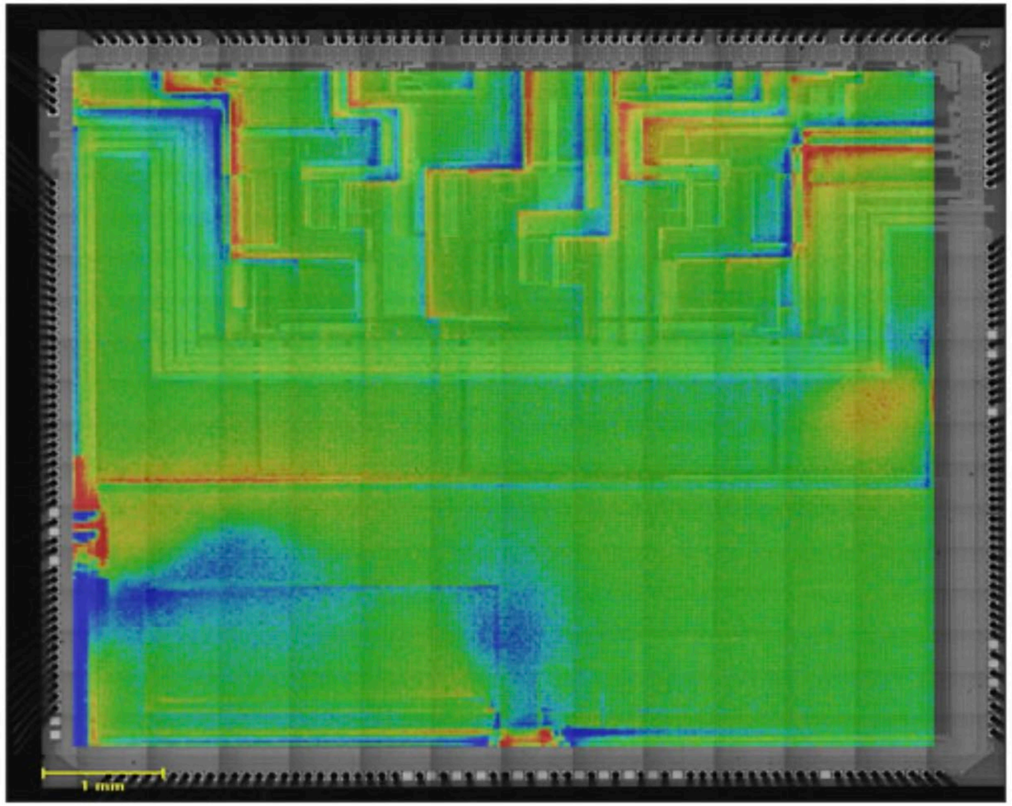
Motivation

Mapping probes lack combination of

- High resolution
- High sensitivity
- Small probe size
- Large bandwidth

Investigation of existing methodology revealed

- What sacrifices can be made
- What should be prioritized



Example near field magnetic field map from MicroMagnetics Circuit Scan [2]

[2] *CircuitScan 1000*. Micro Magnetics Sensible Solutions. (n.d.). Retrieved June 24, 2022, from https://www.micromagnetics.com/products_circuit_scan.html

Discussion of characteristics of interest

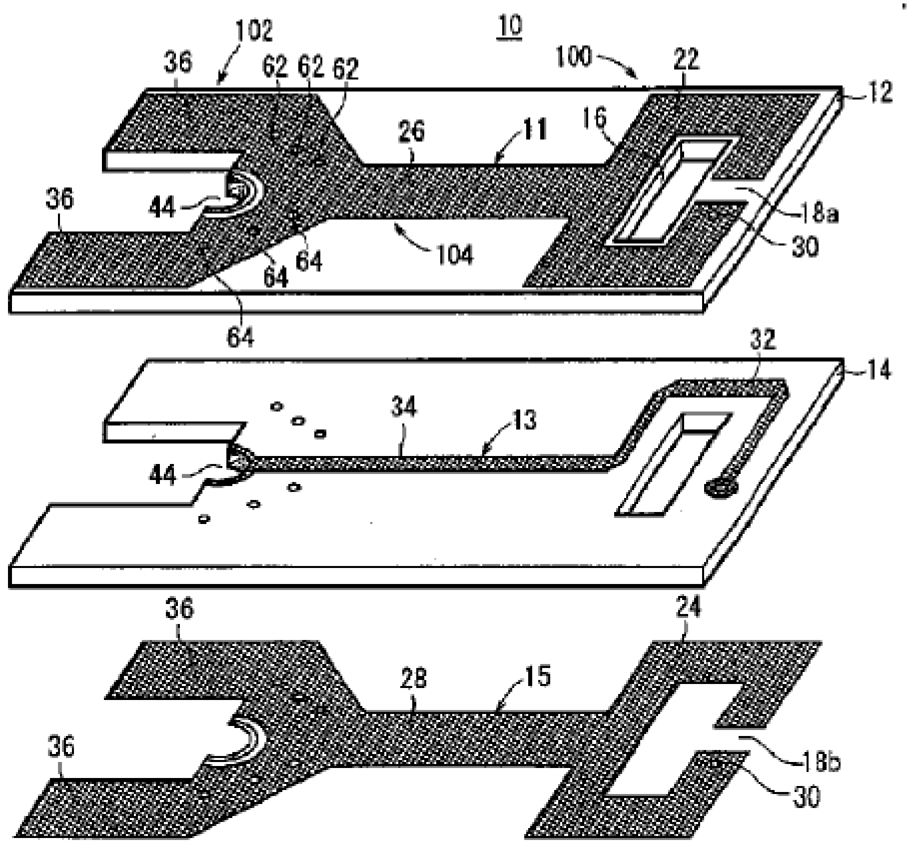
In order of priority:

1. High Resolution
   - 10 μm at minimum
   - Provides localization information even in dense modules
2. Large Bandwidth
   - 0.1 - 3.5 GHz
   - Lower and higher frequencies necessary for edge detection
3. High Sensitivity
   - Transient currents on the order of a tenth of mA
4. Small Probe Size
   - Less than 4 cm^3
   - Directly related to high resolution and desirable for the design

Existing methodologies

Tohoku University Shielded Loop

- Wide bandwidth
  - 1 – 5 GHz
- Highest resolution
  - 300 µm
- Small probe
  - 600 µm x 600 µm
- Shielded loop design has been replicated by others



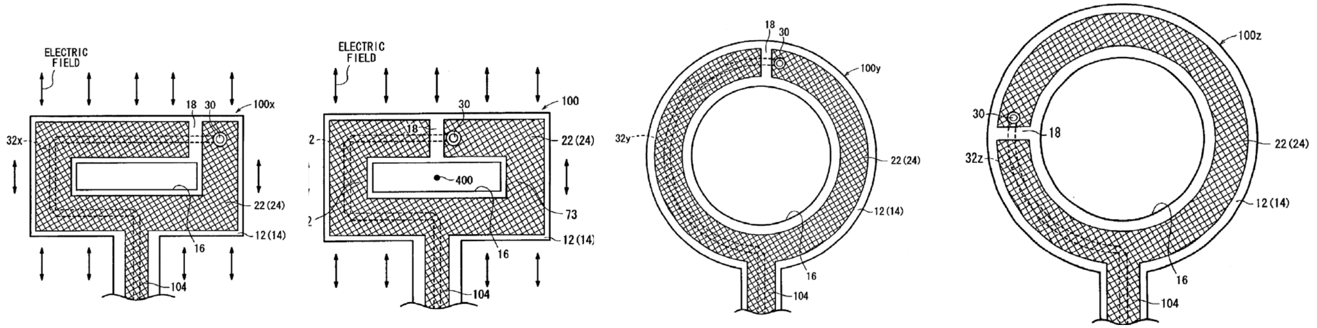
2005 Patented Loop [3]

[3] Miyazawa, Y., Kaminishi, K., Yamaguchi, M., & Arai, K. (2005, February 15). Magnetic Sensor, Side-Opened TEM Cell, and Apparatus Using Such Magnetic Sensor and Side-Opened TEM Cell. Patent No. 6,856,131

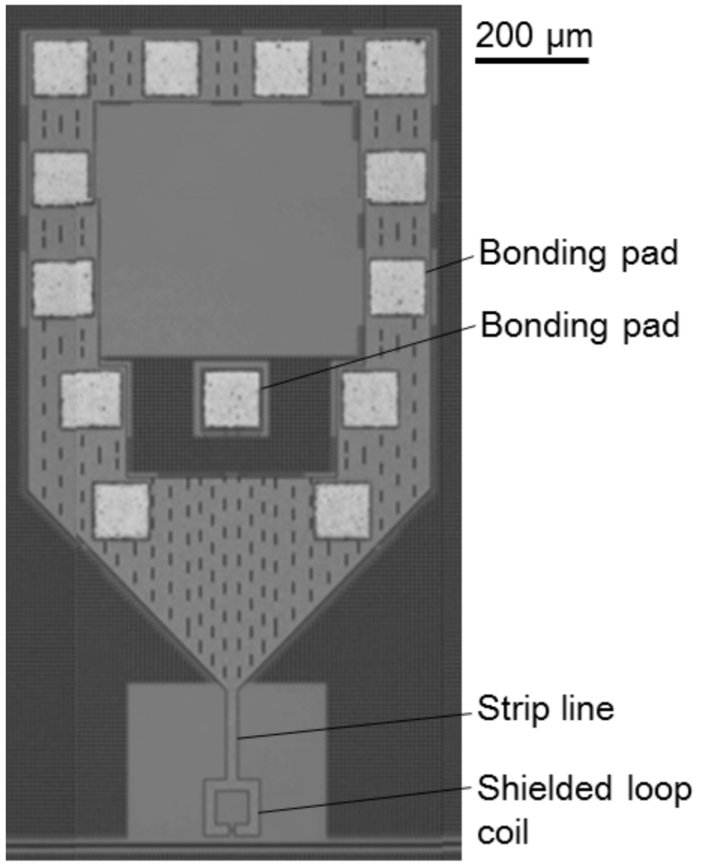
Existing methodologies

Tohoku University Shielded Loop

- Smaller size but higher resolution
  - Down to 60 µm x 60 µm
  - Resolution down to 10s of micrometers
- Low sensitivity
  - All designs require large amplification due to small size
  - LNA limited to 3 GHz



Tohoku Loop Variations [3]



Smallest Tohoku Probe Overview [4]

[4] M. Yamaguchi, S. Muroga, S. Nanba, K. Arai, K. Yanagi and Y. Endo, "A 60×60μm2 size planar shielded loop probe for low lift-off on-chip magnetic near field measurements," 2013 *International Symposium on Electromagnetic Compatibility*, 2013, pp. 977-980.

Existing Methodologies

Operational Tradeoffs

Resolution vs. Sensitivity

- High resolution typically needs a small probe
- Smaller probes have lower sensitivity and require the addition of an amplifier
- Amplifiers can limit the bandwidth of the probe

Bandwidth vs. Size

- The bandwidth of the probe is limited by the size
- Lower frequency detection is necessary, so we are looking for a broadband approach
- Larger size -> lower resolution

Preliminary investigation of shielded resonant loops

Primary desired characteristics are in direct conflict

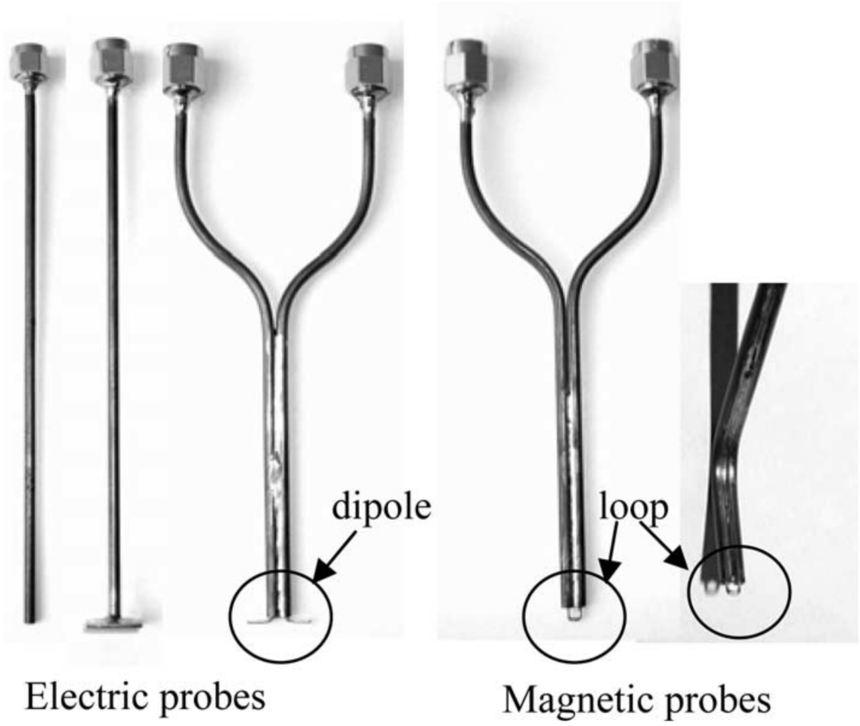
- Resolution and size vs. bandwidth and sensitivity
- What is the bar for sensitivity?
- What are methods to increase resolution without decreasing the size of the probe?
- What are methods to increase bandwidth while decreasing size?

Next Steps:

- Fully leverage prior work
- Focus on an array approach to achieve high resolution without sacrificing sensitivity
- Investigate shielded loop

Preliminary investigation of shielded resonant loops

- Shielded loop offered best sensitivity results
  - Suppresses common mode currents due to electric field [5]
  - This is important for sensitivity, as this would protect the signal from noise
- Goal to understand the shielded loop and its operation over all frequency regimes
  - Potential for broadband application
  - Can be miniaturized for high resolution
- Combined with Baudry coaxial experimentation
  - Good resolution when used with positioner



Coaxial probes used for EMI field map [6]

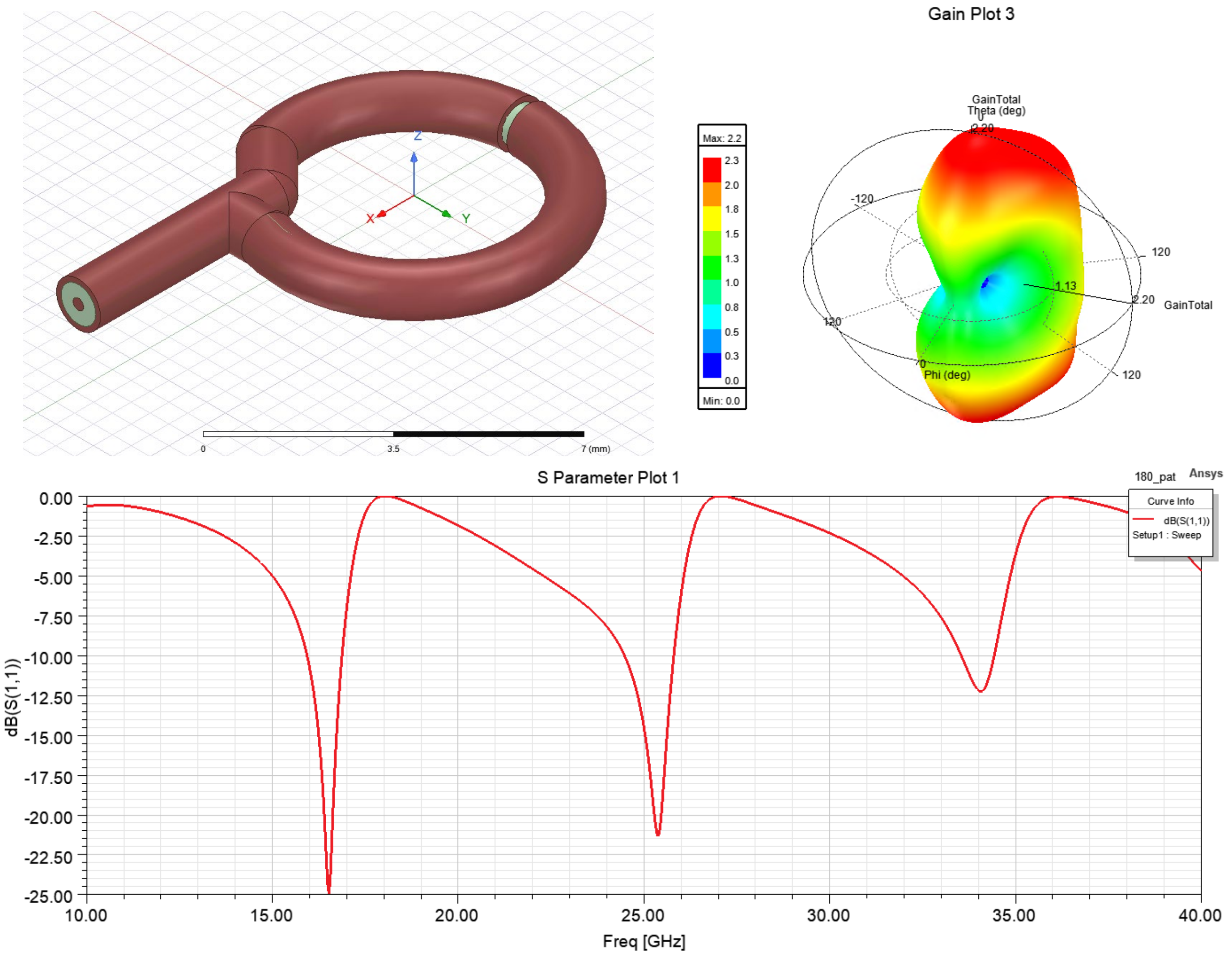
[5] Sivaraman, Nimisha. (2017). Design of magnetic probes for near field measurements and the development of algorithms for the prediction of EMC. *Compatibility*, 2013, pp. 977-980.

[6] D. Baudry, C. Arcambal, A. Louis, B. Mazari and P. Eudeline, "Applications of the near-field techniques in EMC investigations," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 49, no. 3, pp. 485-493, Aug. 2007, doi:10.1109/TEMC.2007.902194.

Preliminary investigation of shielded resonant loops

Initial Design

- Based on coaxial cable
  - Dielectric is fluorinated ethylene propylene (FEP)
  - Relative permittivity of 2.1
- Shield gap in typical position
  - Directly opposite the field line
- Multiple resonances seen in S_{11}
  - Gap location
- Potentially offers higher sensitivity and larger bandwidth
- High resolution from array of loops
- Seek to understand and define this frequency behavior



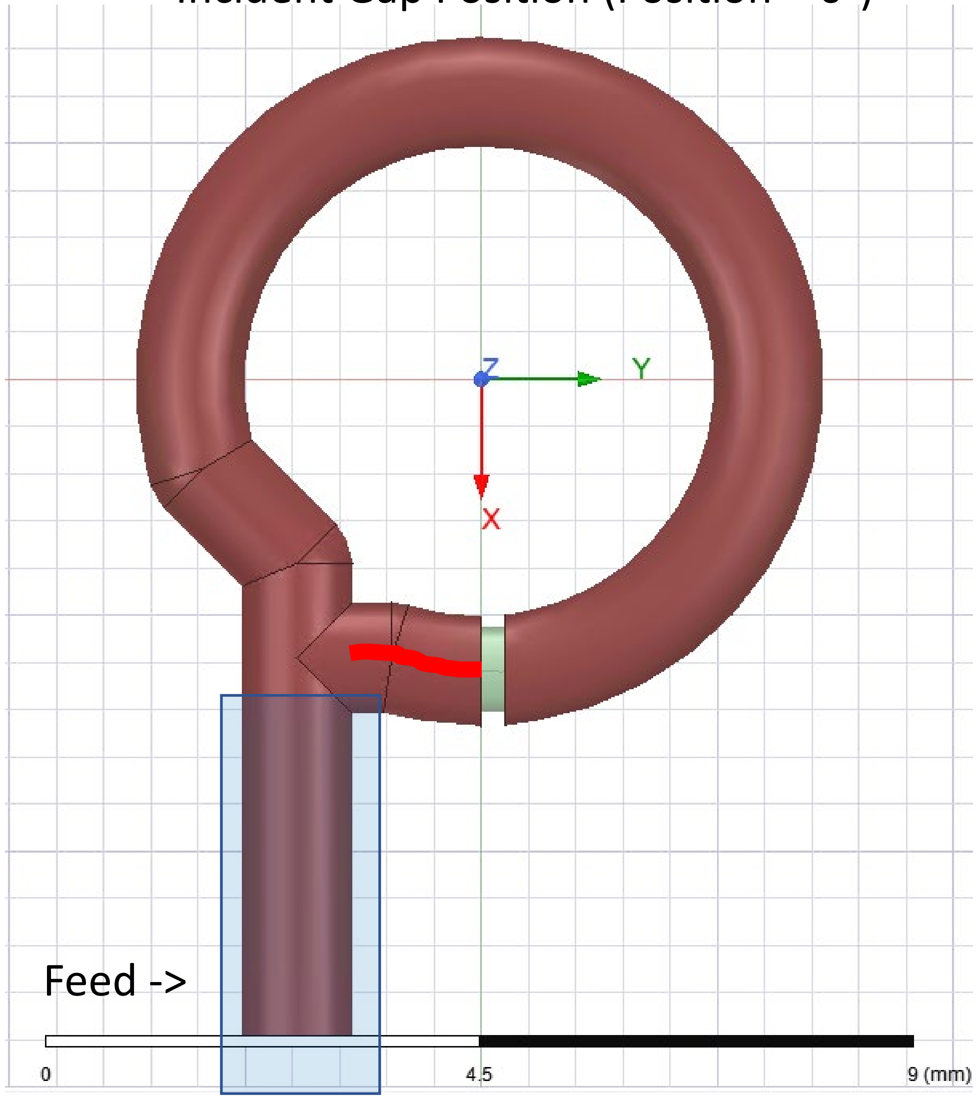
Sample coaxial loop and frequency response

Frequency behavior investigation

Definitions

- Loop Characteristics
  - Radius is 3.05 mm
    - Full loop length is approx. 19.16 mm
    - Gap width is 0.25 mm for all locations
  - Gap position is defined by the relative angle to the incident position
  - The electrical length from the gap to the short is used to classify the behavior of the loop

Incident Gap Position (Position = 0°)



Frequency behavior investigation

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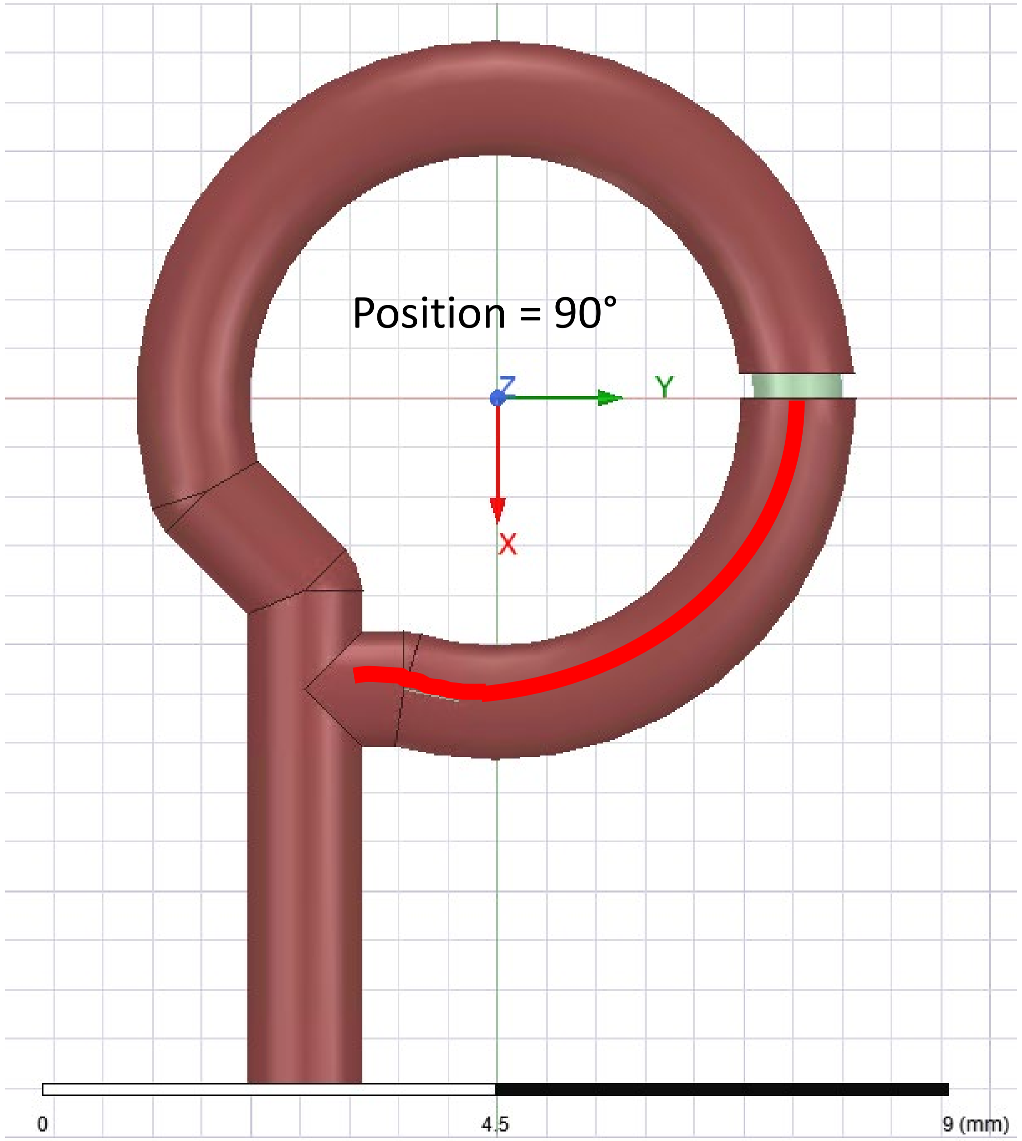
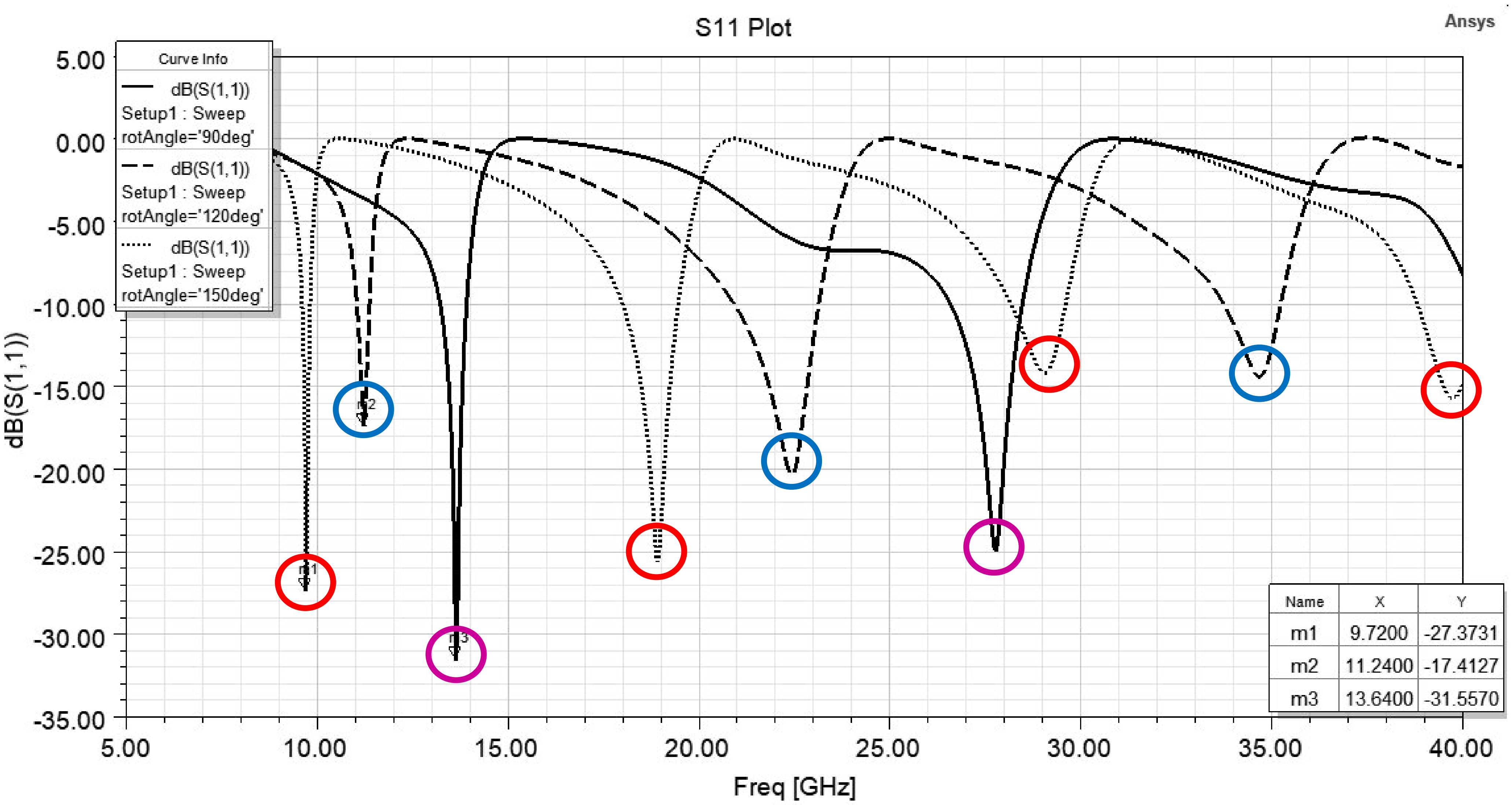
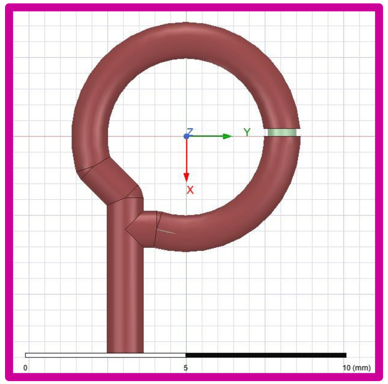
  - The electrical length from the gap to the short is used to classify the behavior of the loop
  - Characterization run up to 180° for now
    - Focus on 90°, 120°, 150° as reference points

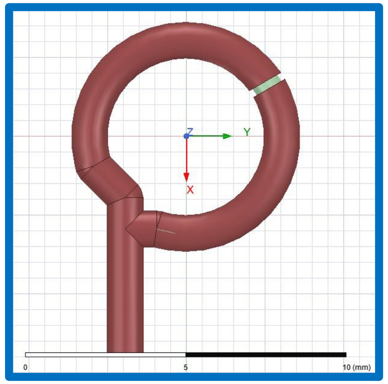


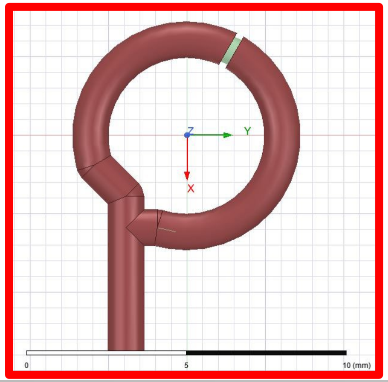
Frequency behavior investigation



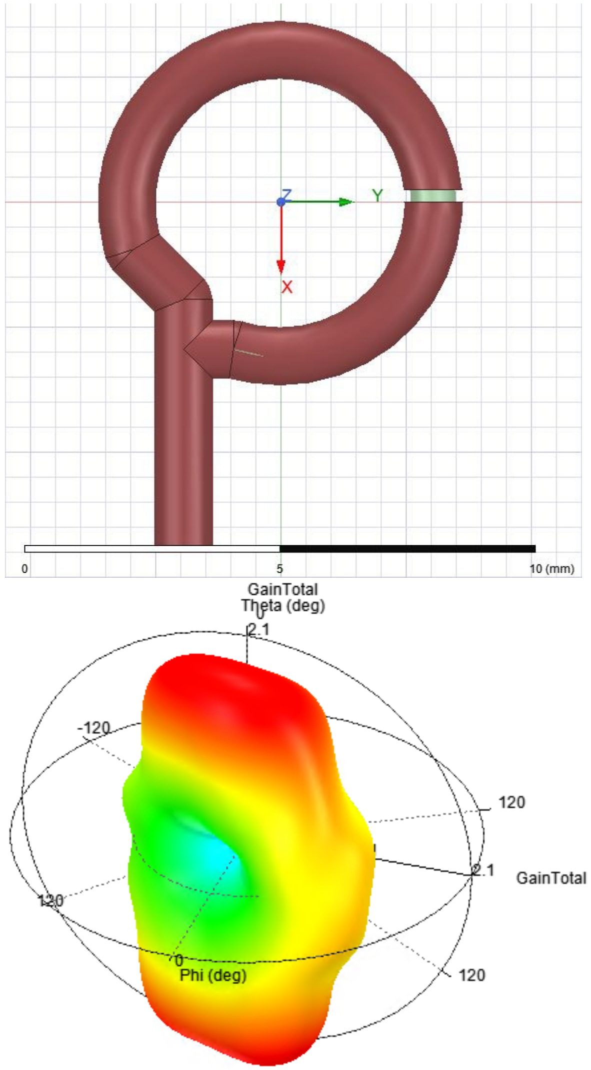
Name	X	Y
m1	9.7200	-27.3731
m2	11.2400	-17.4127
m3	13.6400	-31.5570

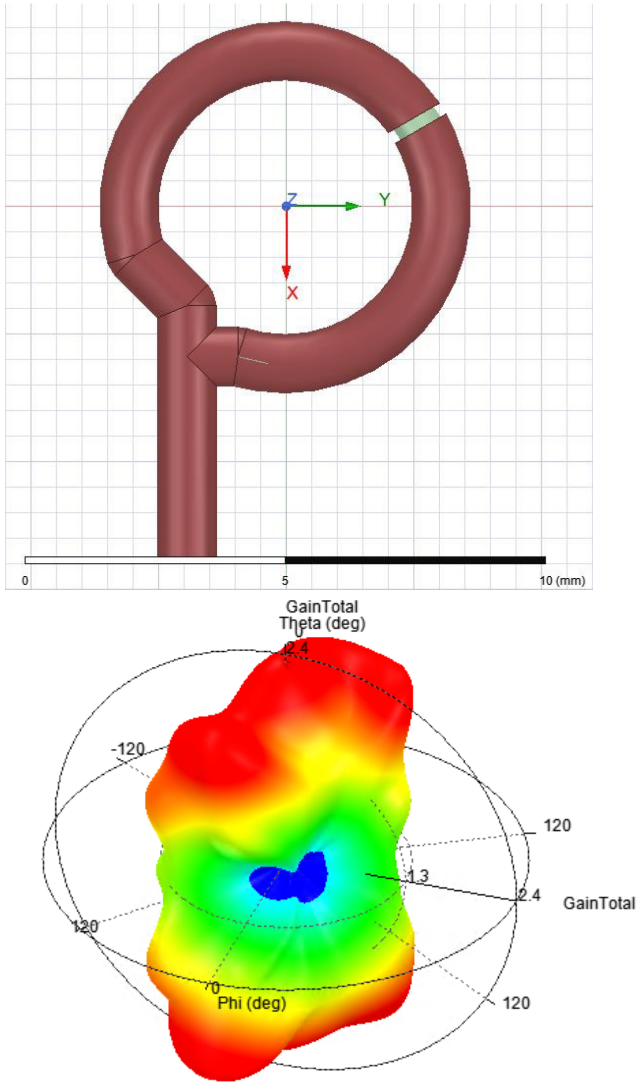


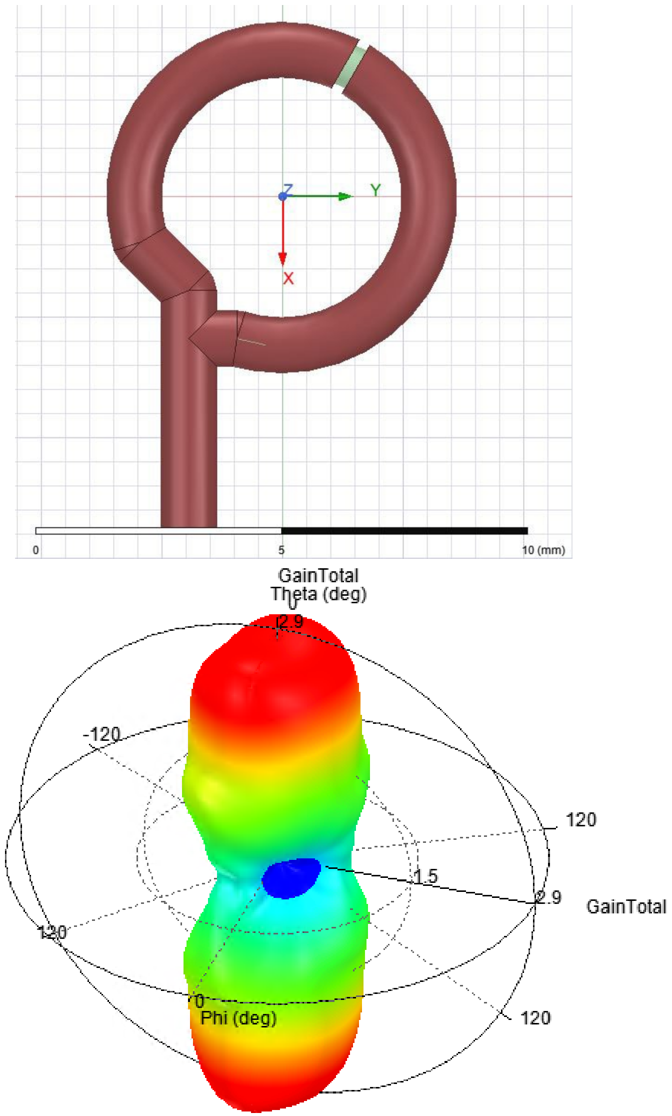




Frequency behavior investigation







Frequency behavior investigation

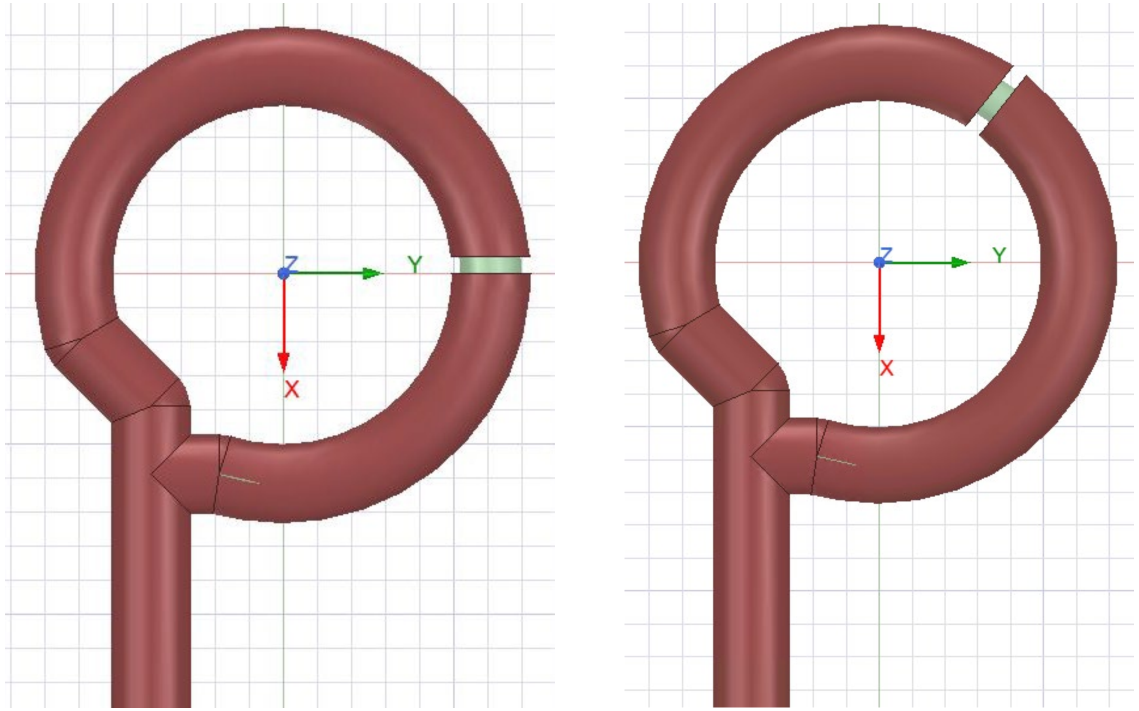
Observations:

- When the feedline is extended, the results remain the same, so the feed line does not alter the results of the simulations
- S_{11} dips occur first at approximately $\frac{2\lambda}{5}$
  - Reoccur approximately every additional $\frac{\lambda}{2}$
- Bandwidth appears to increase at each additional half wavelength, will require further exploration

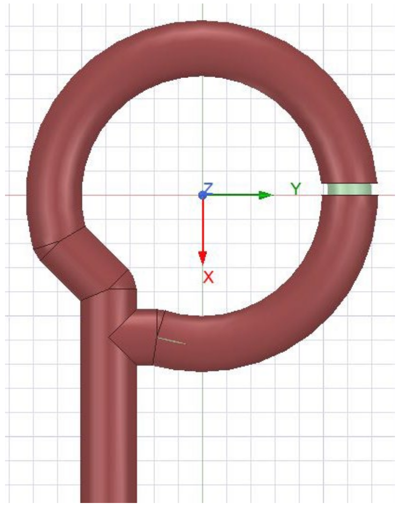
Gap Position	Resonance [GHz]	Length from Short [λ]
90°	13.64	0.404
120°	11.24	0.419
150°	9.72	0.436

Scaling

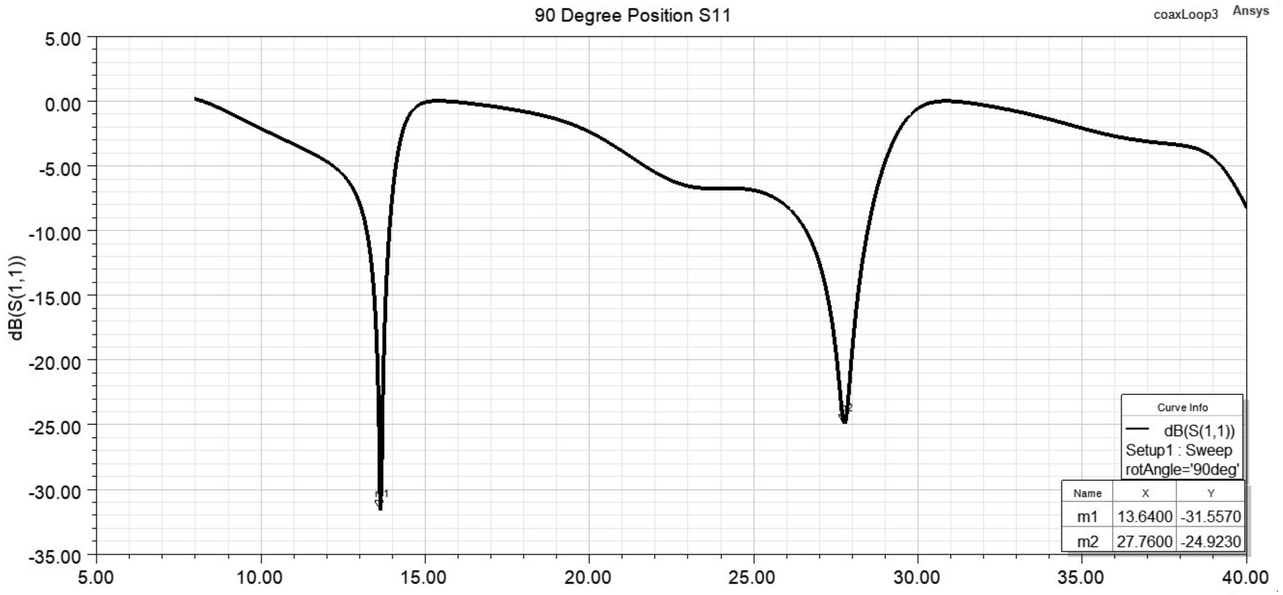
- To further investigate the pattern, we change the geometry of the coaxial cable
    - Dielectric changed to air
    - Conductors and dielectric dimension changes to be a 50 Ω line in air
- Relocate gap to be the same electrical length as the 90° position in FEP
- Compare S_{11} plots

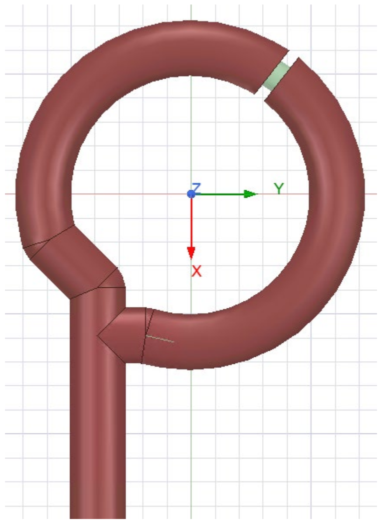


Frequency behavior investigation

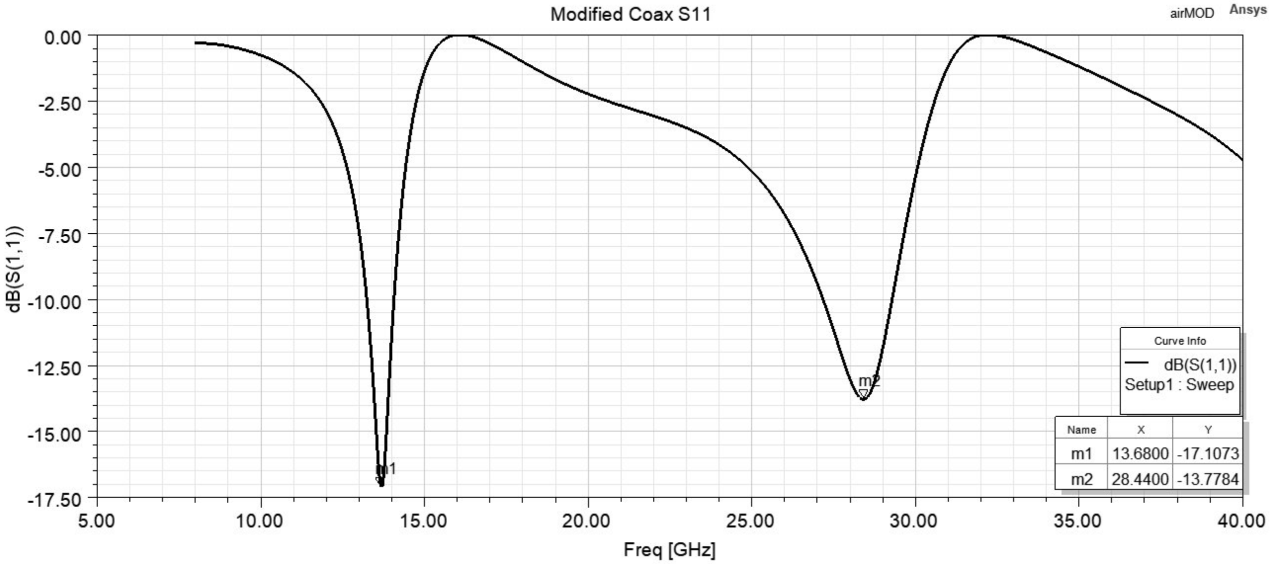


Length from short: 0.404λ
ε_r: 2.1
Resonance 1: 13.64 GHz
Resonance 2: 27.76 GHz





Length from short: 0.404λ
ε_r: 1
Resonance 1: 13.68 GHz
Resonance 2: 28.44 GHz



Conclusions

- Limitations on current designs require a different approach for our goals
- Array of coaxial loops
  - Possible solution to conflict between resolution and sensitivity, as arraying these loops could result in higher resolution without sacrificing sensitivity
  - Would avoid the need for a large amplifier
- Shielded loop frequency behavior can be defined by the electrical length between the shield gap and the short
- This behavior is consistent when scaled to a different coaxial size and relative permittivity

Future Work

- Explore the effect of the gap width
- Explore near field behavior of this shielded loop
- Investigate methods to array and tune these loops
- Construct and test a shielded loop prototype
    - Larger loop and lower frequency target for testing purposes

References

[1] Pepitone, J. (2022, April 21). *5 ways the chip shortage is rewiring tech*. IEEE Spectrum. Retrieved June 29, 2022, from https://spectrum.ieee.org/chip-shortage-rewiring-tech

[2] *CircuitScan 1000*. Micro Magnetics Sensible Solutions. (n.d.). Retrieved June 24, 2022, from https://www.micromagnetics.com/products_circuit_scan.html

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