Constant Impedance Tunable IOT Power Extraction Circuit

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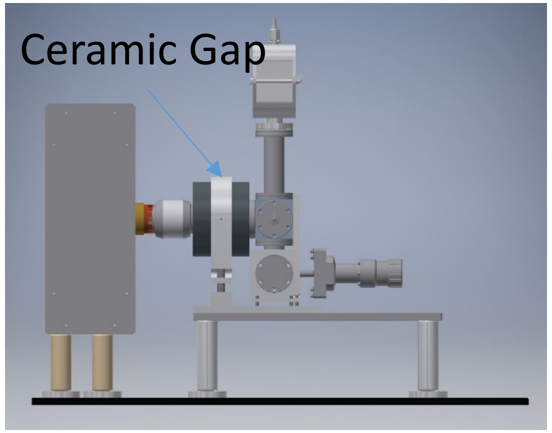
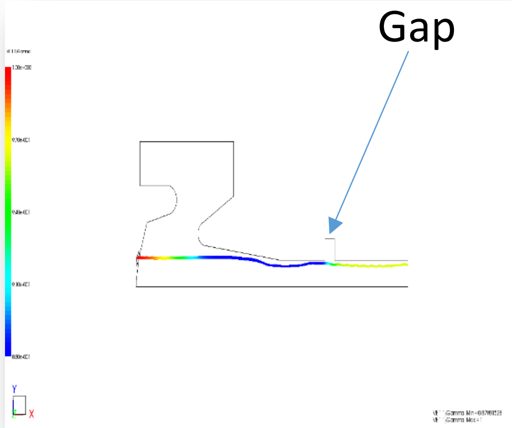
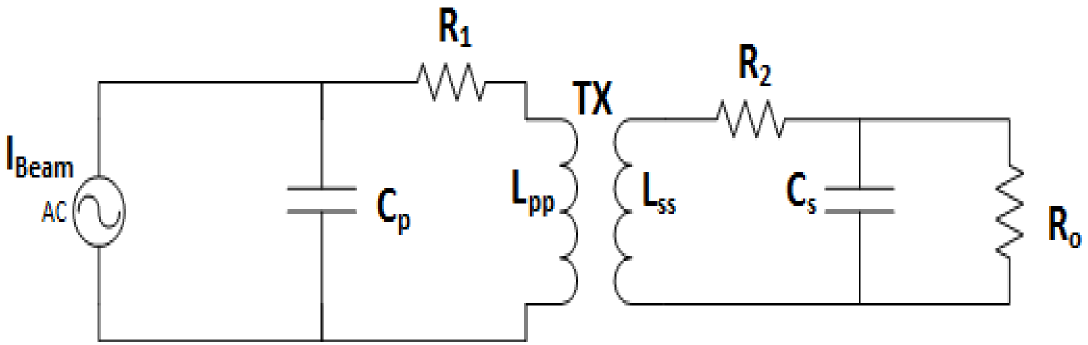
Presentation Outline

- Need for Power Extraction Circuit: Why and Where?
- Constant Impedance Tunable Circuit
- Experiments with Transformers of different Coupling Coefficients
- Measurements & Comparison for one of the transformers
- Improvements: Tunable Circuit, Shielded Box, Better Transformer
- Transformer Designs for Improving the Coupling Coefficient
- Conclusion

Why and Where do we need the Power Extraction Circuit ?

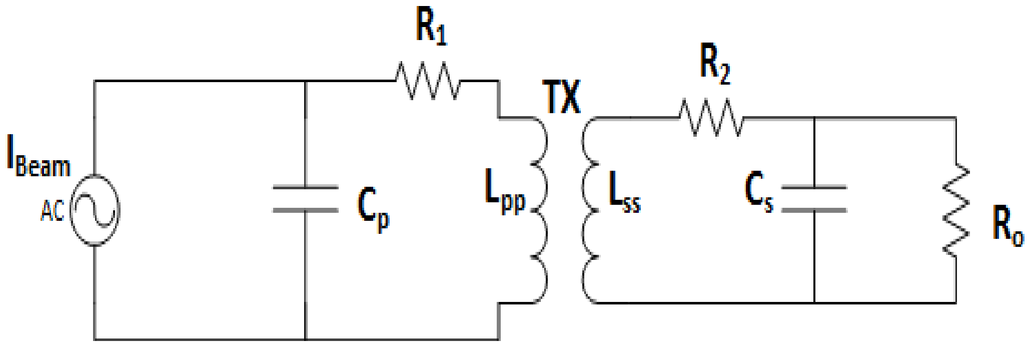






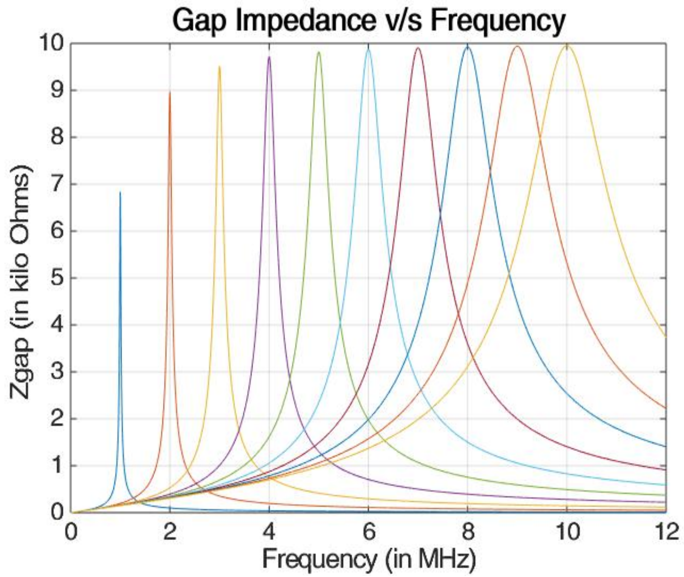
- Resonant circuit in an IOT extracts the kinetic energy of the modulated electron beam converting it into electromagnetic energy.
- The broad frequency range requires the circuit to be tunable.
- Need for a frequency independent decelerating voltage requires constant impedance.
- Connected parallel to the gap electrically in the IOT.

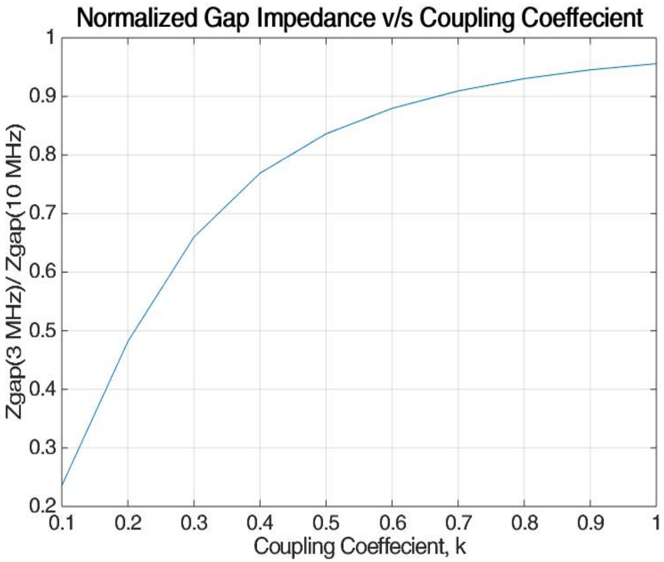
Constant Impedance Circuit



- Resonant Frequency, $\omega_0 = \frac{1}{\sqrt{L_0(N^2 C_p + M^2 C_s)}}$
- Gap Impedance, $Z_g = Z_0 \frac{N^2}{M^2}$
- Quality factor, $Q = \frac{Z_0}{\omega_o L_0 M^2}$
- Combining these gives, $C_p = \frac{Q}{\omega_o Z_g}$
- $\Rightarrow$ Changing **resonant frequency**, changes **Quality Factor**
- $\Rightarrow$ Changing **resonant frequency**, requires changing **Capacitance** on the **primary side**.
- Quality factor varies from 5 – 60
- Capacitance varies from 10 pF – 1 nF
- Inductances on primary and secondary are constant.

Constant Impedance Circuit

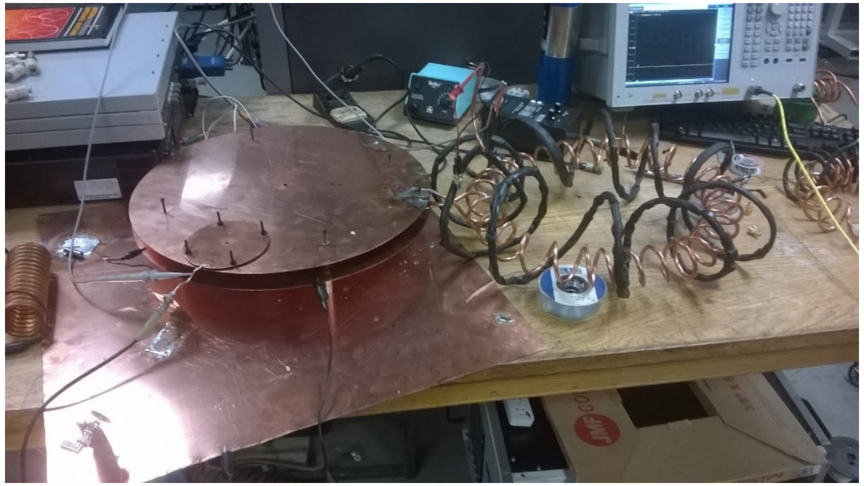




- Anticipated Beam Voltage: 70 kV
- Peak Beam current: 15 A
- Gap impedance: 9.8 kΩ
- Deceleration achieved: 66 kV
- As resonant frequency changes, gap impedance is mostly constant at the resonant peaks assuming perfectly coupling.
- As frequency is changed, capacitor on the primary side is tuned to keep the gap impedance constant.

Experiments with Transformers of different Coupling Coefficients

k = 0.29

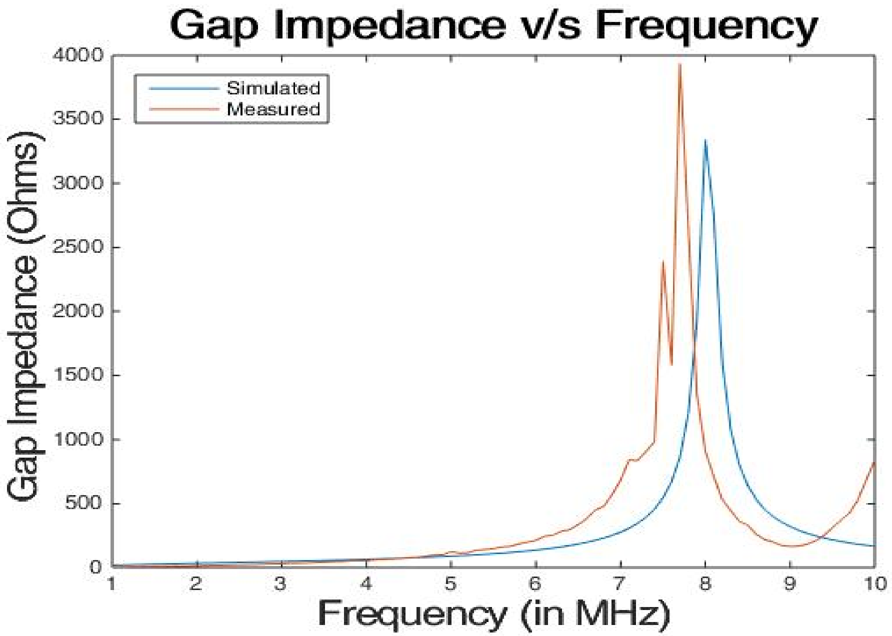


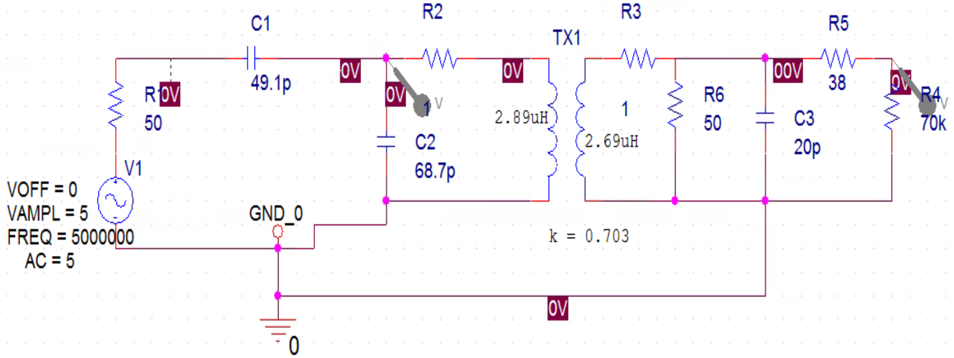
k = 0.38

k = 0.46

k = 0.70

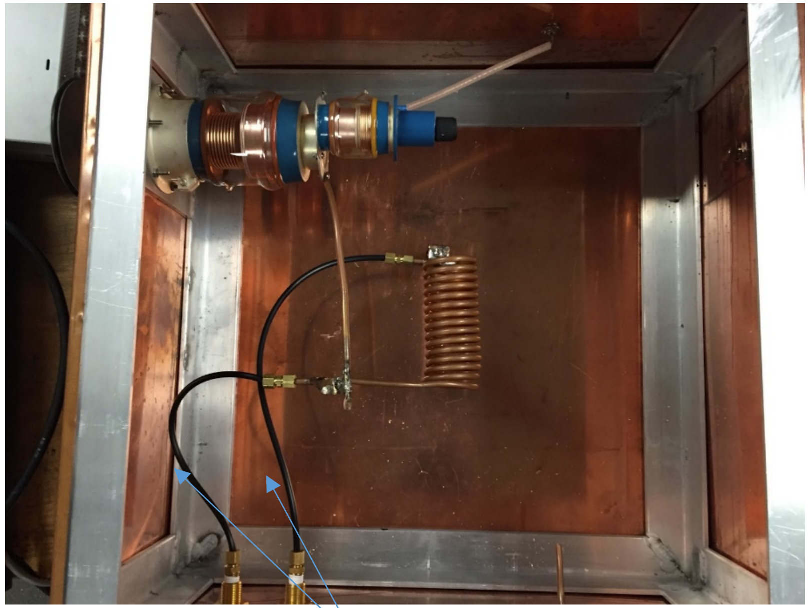
Measurements & Inferences for the circuit with a transformer of k = 0.70





- Gap impedance measurements showed leftward shift of resonance peak in comparison with the simulation model.
- Parasitic capacitances/lead inductances in the bench circuit shown above were responsible for shift in resonant frequencies.
- Need to isolate the circuit from all such parasitic effects

Improvements: Tunable Circuit, Shielded Box, Cooling Pipes & Better Transformer

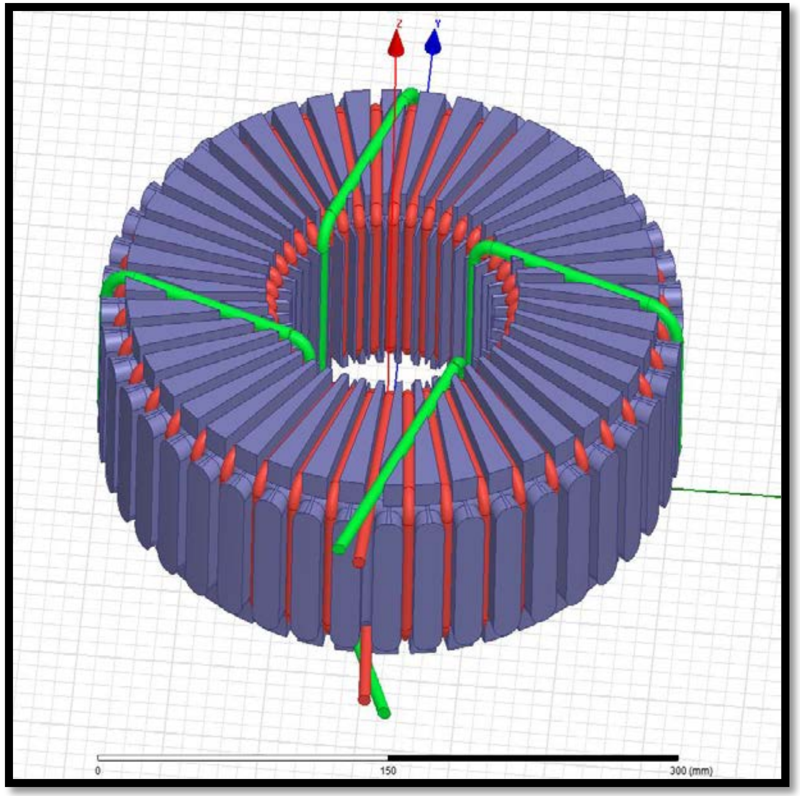


Water Cooling Pipes

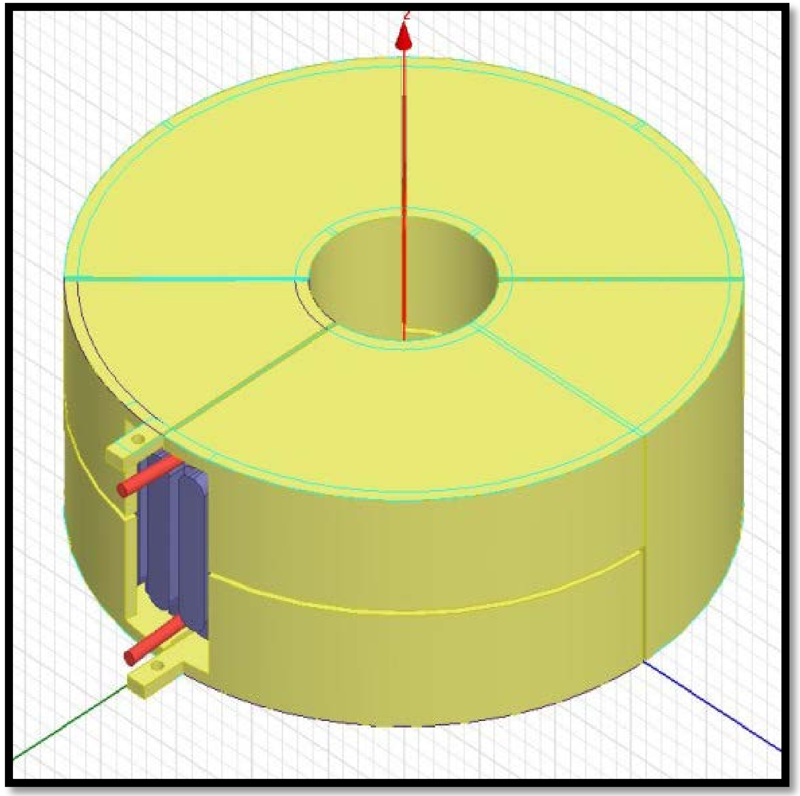
- The entire circuit to be housed inside a copper box to shield it from all types of parasitic capacitances/lead inductances.
- Tunable capacitors to be used instead of handmade fixed capacitors.
- Transformer model with appropriate turns ratio, is designed and machined.
- Water cooling mechanism for transformer coils are incorporated.

Transformer Designs for Improving the Coupling Coefficient

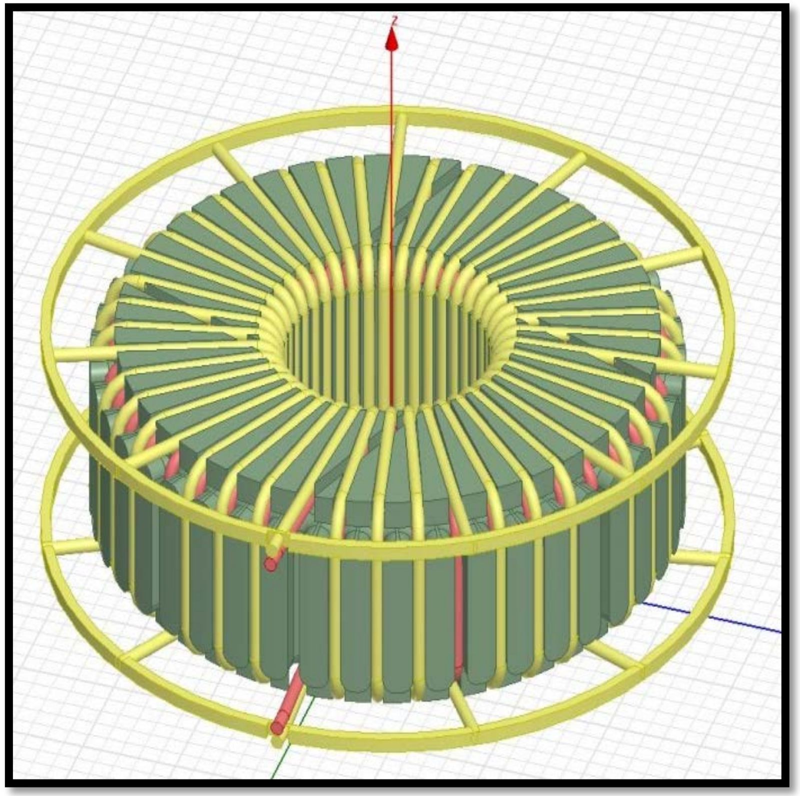
Model 1



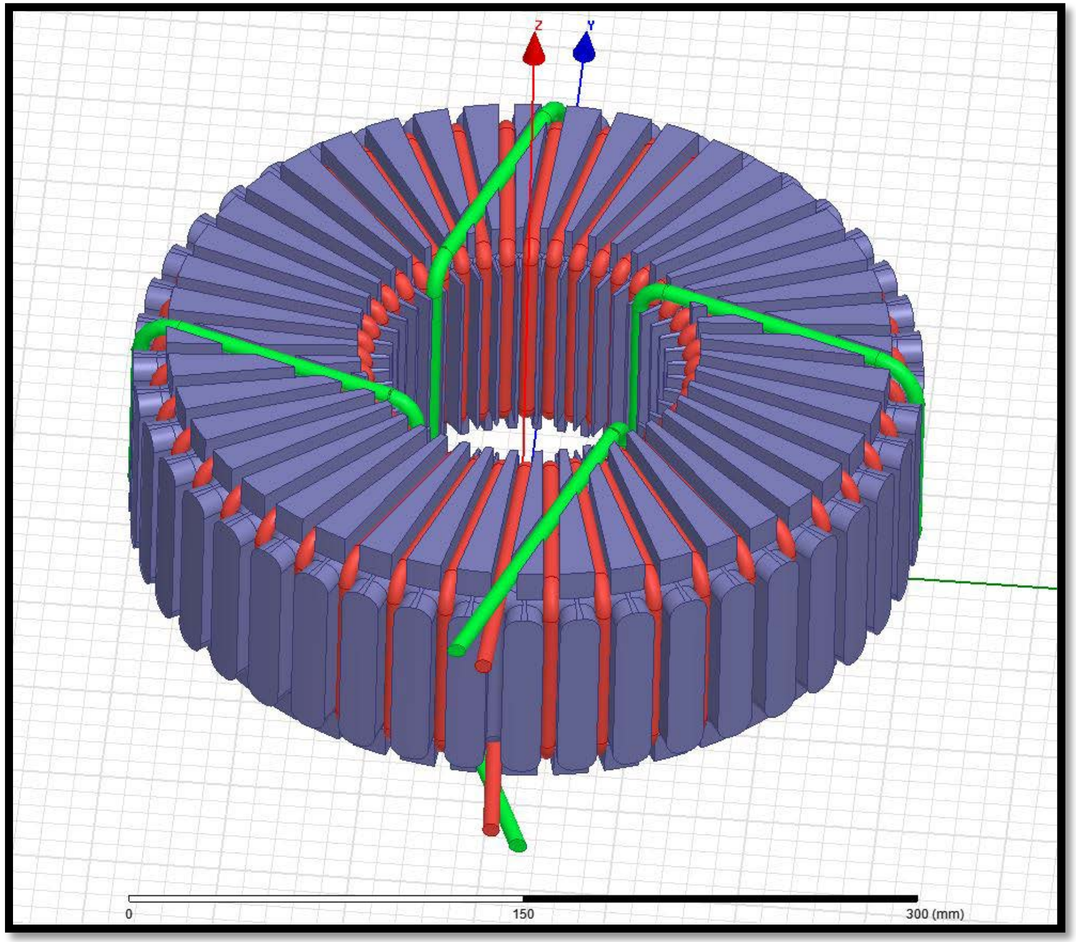
Model 2



Model 3

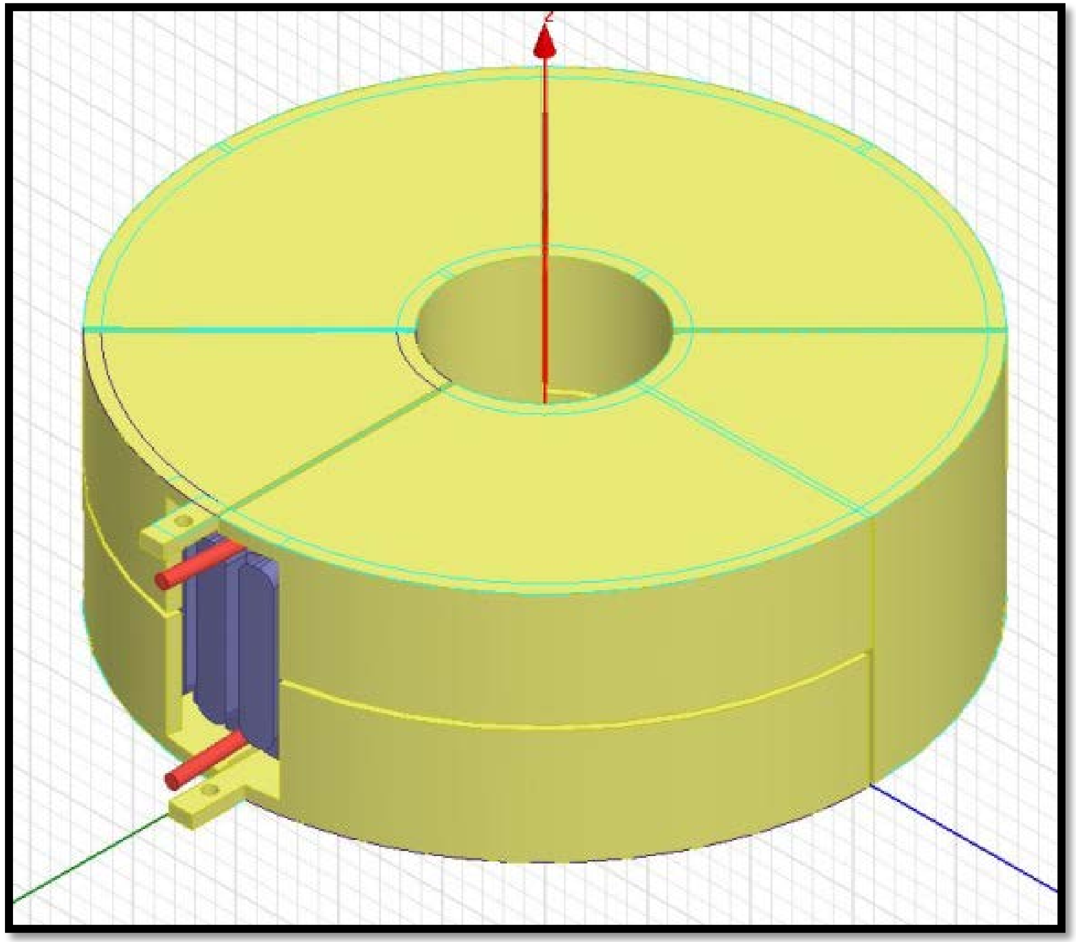


Model – 1, Coupling Coefficient, k= 0.476



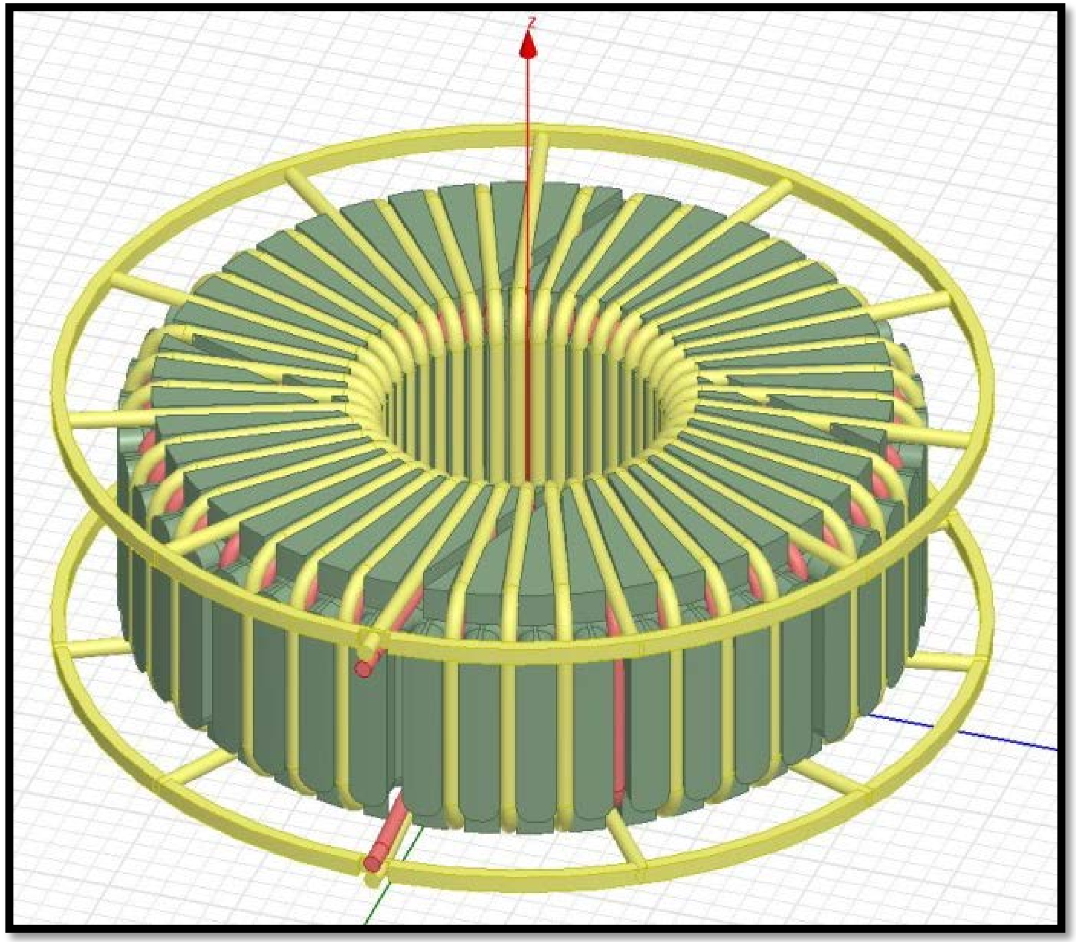
- Red is primary, Green is Secondary.
- Coefficient of Coupling: 0.476
- L(primary) = 25.838 uH
- L(secondary) = 1.0569 uH
- L(mutual) = 2.4977 uH
- N:M = 11:1

Model – 2, Coupling Coefficient k= 0.646



- Secondary coil made of copper sheets completely covering primary coils to reduce flux leakage. Red is Primary and Yellow is Secondary.
- Coefficient of Coupling: 0.646
- L(primary) = 25.855 uH
- L(secondary) = 566.942 nH
- L(mutual) = 2.3207 uH
- N:M = 11:1

Model – 3, Coupling Coefficient k= 0.714



- Secondary coils (11) connected in parallel to increase the flux linkage with primary coils
- Coefficient of Coupling: 0.714
- L(primary) = 25.833 uH
- L(secondary) = 437.914 nH
- L(mutual) = 2.4037 uH
- N:M = 11:1

Conclusion & Further Work

- Coupling coefficient as we speak is at 0.71. Need to achieve values closer to 1.
- Parasitic/stray capacitances and lead inductances changes the resonant frequency of circuits. Circuit isolation to be achieved by using a copper box.
- A stable feedback circuit to constantly adjust or tune the capacitor on the primary side needs to be designed.
- Simulations predict the primary inductance to be a good match with design. Need to measure the same in the experiment.