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, \( Q = \frac{Z_0}{\omega_0 L_0 M^2} \)

Combining these gives, \( C_p = \frac{Q}{\omega_0 Z_g} \)

⇒ Changing resonant frequency, changes Quality Factor
⇒ 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

• 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
- $L(\text{primary}) = 25.838$ $\mu$H
- $L(\text{secondary}) = 1.0569$ $\mu$H
- $L(\text{mutual}) = 2.4977$ $\mu$H
- $N:M = 11:1$
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 $\mu$H
- $L$(secondary) = 566.942 nH
- $L$(mutual) = 2.3207 $\mu$H
- $N:M = 11:1$
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
• $L_{\text{primary}} = 25.833$ uH
• $L_{\text{secondary}} = 437.914$ nH
• $L_{\text{mutual}} = 2.4037$ 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.