Accessible and Accurate Q-Meter to Evaluate High Frequency Magnetics for the Next Generation of Power Converters

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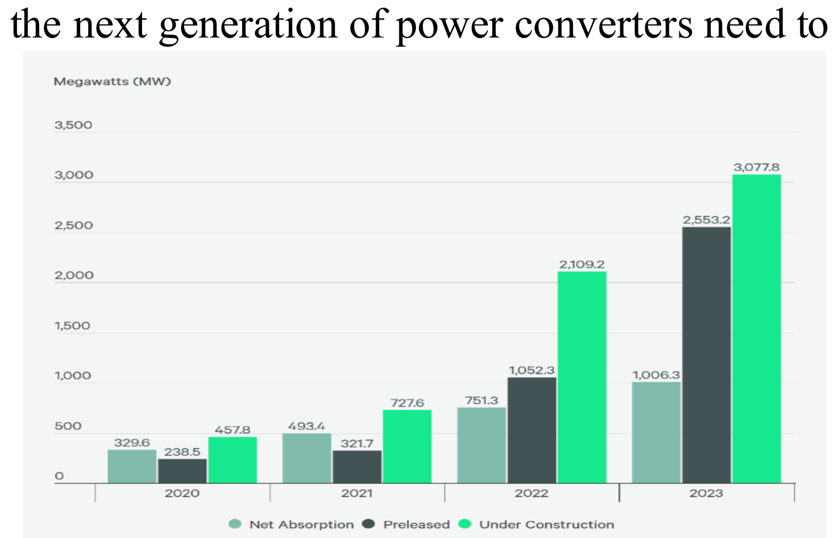
BACKGROUND

There is an ever-increasing power demand in industry and commercial sector such as electric vehicles and AI data centers. To meet benchmarks the next generation of power converters need to be fully realized.

Figure 1: AI Power Trends (2020 – 2023)



New wide bandgap semiconductor such as Gallium Nitride (GaN) can operate at higher frequencies for higher power efficiency and device size reduction. These new emerging technologies can make the next generation of power converters. However, high-frequency magnetic components like inductors are underdevelopment to operate at these frequencies. The quality factor, or Q, is a key parameter to characterize high-frequencies magnetic components. Q can be defined as a ratio of energy stored to energy losses. The higher the Q value the better an inductor's ability to transfer energy is at high frequencies.

$$Q = \frac{\text{Energy Stored}}{\text{Energy Losses}}$$

Accurate and available Q measurements are needed to further research. Unfortunately, current measurement tools have various undesirable traits.

PURPOSE

An accurate and accessible Q-meter device is proposed, designed to be low-cost, automated, accurate (up to 20% tolerance), to measure Q factor in the 1 to 20 MHz frequency range. The goal is to make high-frequency magnetic material evaluation available for students, researchers, and labs working on next generation power converters.

Figure 2: Legacy HP4342A Meter
- Manually Operated
- Limited Access
- Outdated

Figure 3: Keysight E4990A Meter
- Inaccessible to Students
- Difficult to Use
- Expensive (41k)

Figure 4: LCR Meters
- Lacks Accuracy & Precision
- Limited Measuring Abilities

MATERIALS AND METHODS

The system uses a series LC resonance technique to measure Q Factor. A known capacitor is placed in series with inductor under load. Once driven at the correct frequency, the resonance condition is met, $X_L = X_C$, the reactance of both the inductor and the capacitor cancel each other out. Resulting in absolute minimum in impedance that creates the resonant valley at, $F_R = \frac{1}{2\pi\sqrt{LC}}$. The quality factor can the be calculated from this relationship at that specific frequency. Using the following equation, $Q = \frac{f_0}{f_2 - f_1}$, the bandwidth method to calculate Q.

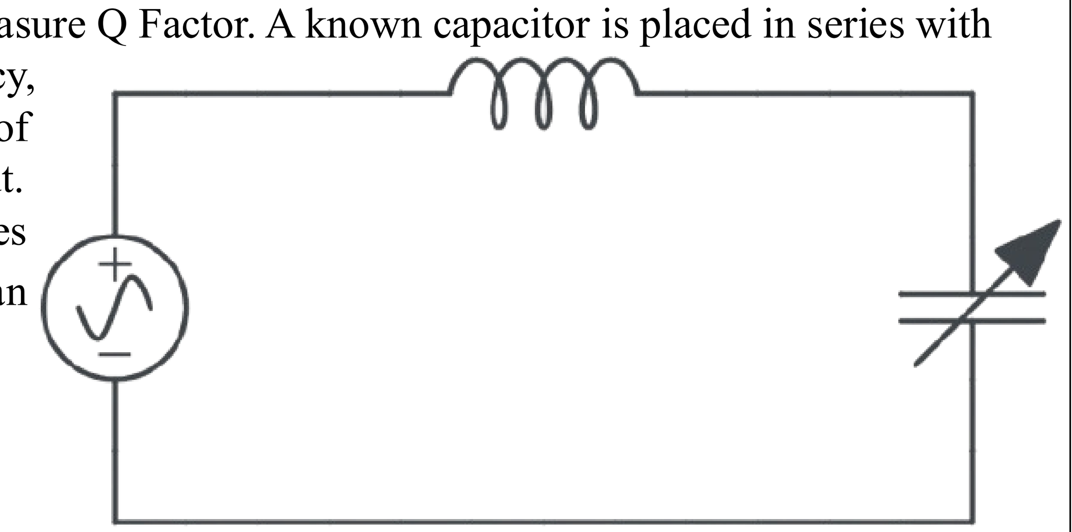


Figure 6: LC Series Circuit (Inductor & Capacitor)

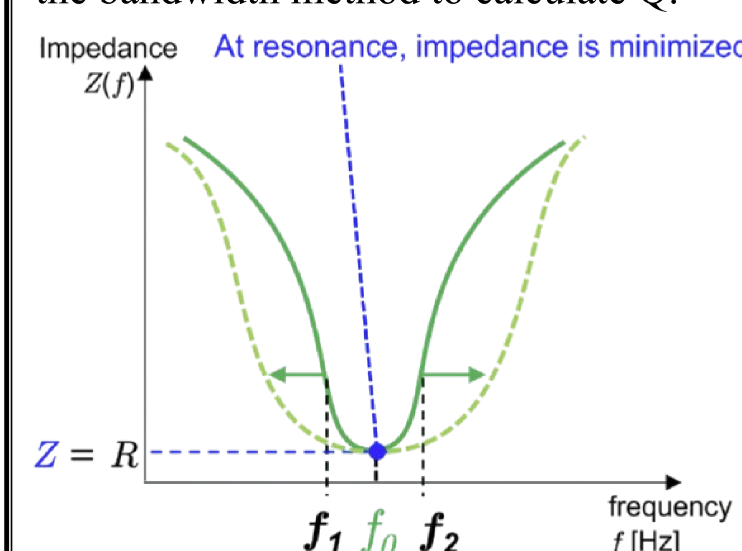


Figure 7: Resonant Valley

A Vector Network Analyzer (VNA) is used to reliable understand how the circuit responds across different frequencies. The VNA supplies a known signal and measuring the resulting signal to grasp the characteristics of the circuit. This can be used to visualize the resonant valley and extract data to calculate Q.

For early testing, connection were made directly to the air-tuned capacitor using brass-plated screws to minimize parasitic. This approached minimizes patristics reasonably for early testing purposes and to confirm the general setup works. Results will be used to understand the patriciates tolerances needed to skew data.

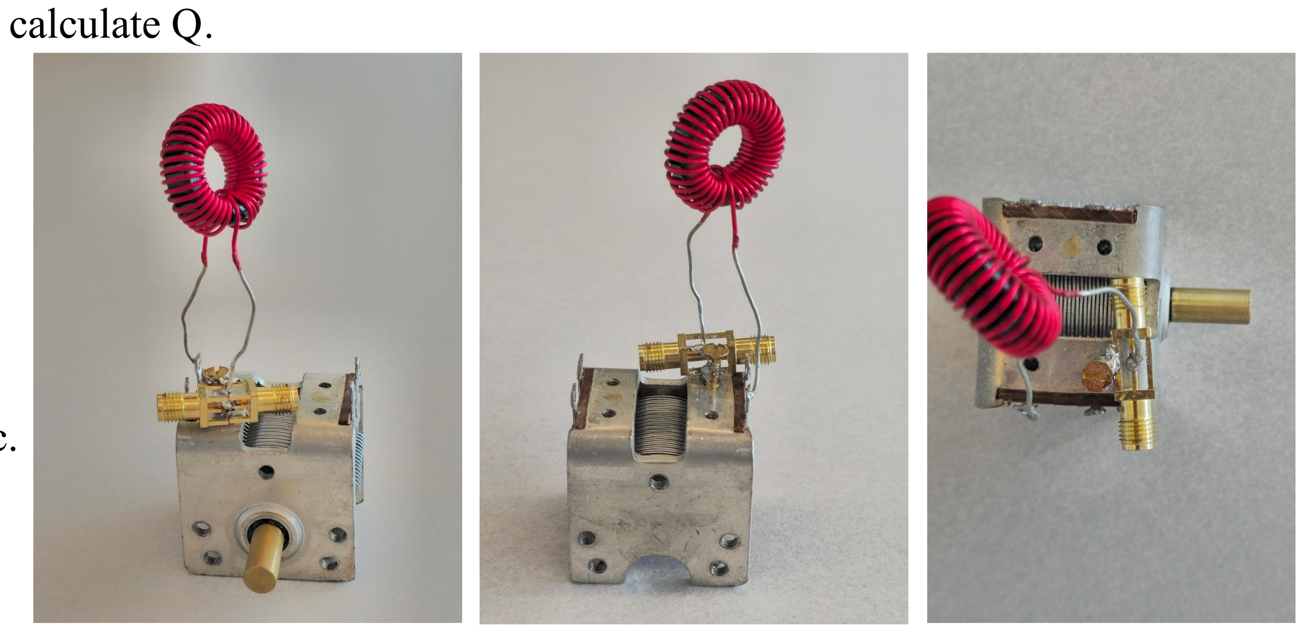


Figure 8: Early Testing Jig (Left & Mid – Side, Right – Top)

RESULTS

The early testing jig is tested across the entire range of the air-tuned capacitor ($14.9pF$ to $384.2pF$) to measure all possible Q factor values. Experimental measurements are tested against the industry standard, Legacy HP4342A meter for comparison. On one hand, on the left shows an inductor with a high-frequency mix material. On the other hand, below shows a mix material that behaves poorly at high frequencies. The setup was proven as it follows the Q curve.

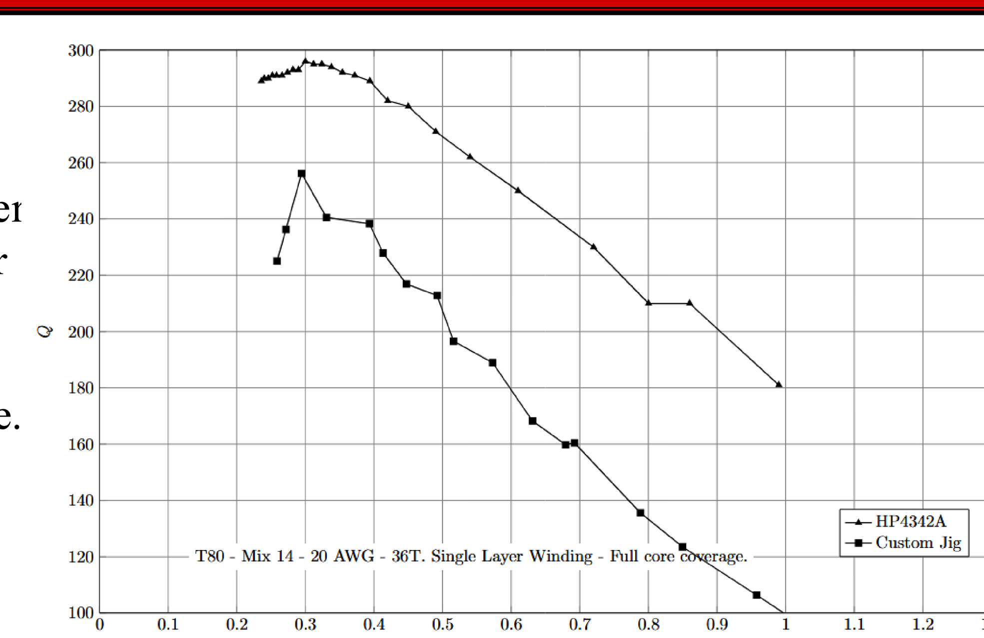


Figure 9: High Q Curve

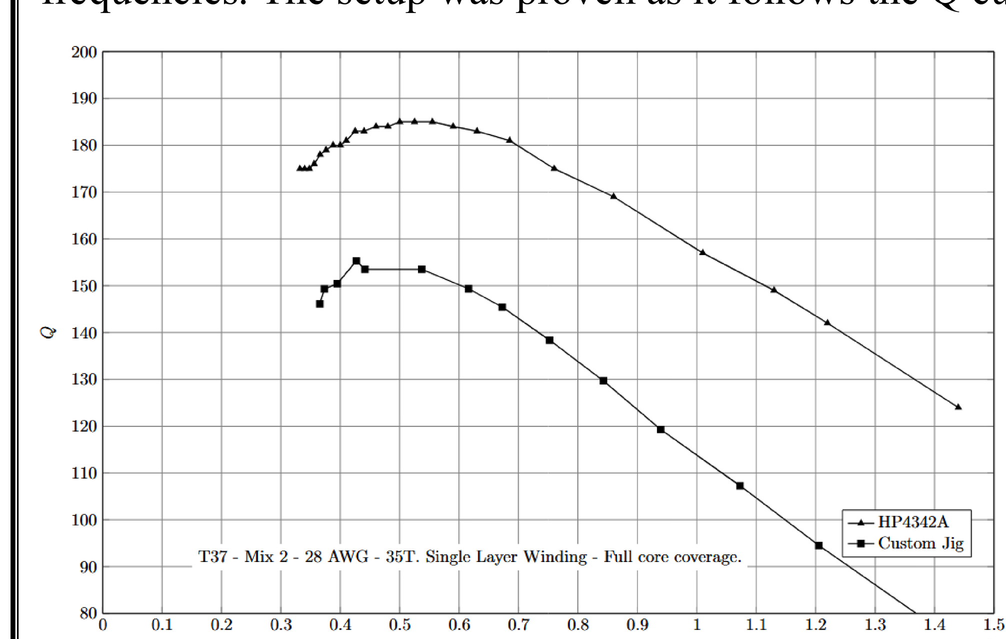


Figure 10: Low Q Curve

Upon analysis, these experimental data sets measured within 20% to 30% tolerance compared to standard values, with the worst case at 35%. Differences can be abirritated to patristics in the measurement setup. This behavior is seen at higher frequencies where the patristics are more produced resulting in larger inaccuracies. Additionally, the setup limits high Q values due to the device's noise floor

FUTURE WORKS

Testing and verification of a custom Printed Circuit Board (PCB) apparatus for results are planned. The PCB was designed as small as possible to minimize parasitic that can heavily askew measurements at high frequencies (1Mhz - ⇧). An advantage of using a PCB is controlled impedance traces which provide the best possible connection for the VNA. The Legacy HP4342A Meter is used for inspiration in design and component choices: binding posts for easy testing, and the capacitor position to minimize parasitic.

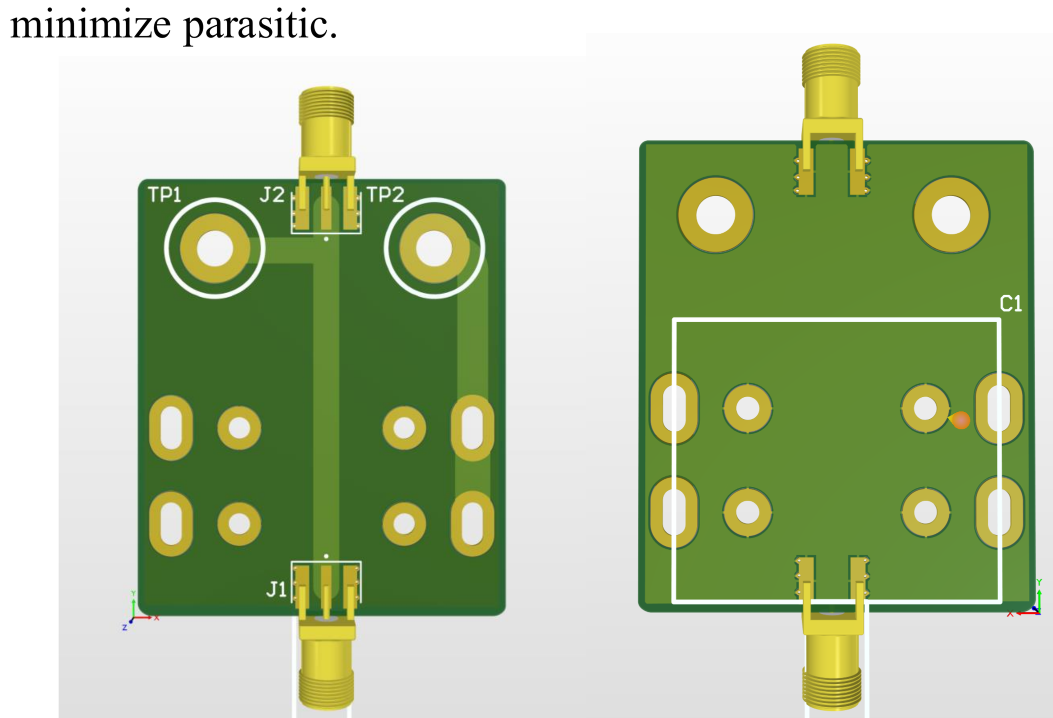


Figure 11: PCB Apparatus (Front – Left, Back – Right)

CONCLUSIONS

In summary, this work shows an early version for an accessible, accurate, and low-cost measurement system to evaluate high frequency magnetic materials for next generation of power converters. Early testing showed the importance of minimizing parasitic such as connection length, component layout, and shielding for reliable data. These factors became more profound at higher frequencies, skewing data. Moreover, accurate measurements within 20% - 30% tolerance between 1-20 MHz range was achieved. The VNA was used to visualize resonant valley and extract Q values using the bandwidth method efficiently. These initial results confirm the method and feasibility of the proposed device. Overall, these efforts aim to provide all students and any researcher the tools to contribute to progress high-frequency magnetic material.

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