Basic Instrumentation Skills

Lab Assignment #2

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Assignment 2: Q Meter Simulation

Aim: To determine accurate Quality Factor of an unknown coil.

Apparatus: VLAB IIT-KGP SIMULATOR

Theory:

The determination of the storage factor Q is one of the most widely used means in the laboratory for testing radio frequency coils, inductors and capacitors.
The storage factor is equal to $Q = \frac{w_0 L}{R}$ where w_o is the resonant frequency, L is the inductance and R is the effective resistance of the a coil. The effective resistance R, is never determined directly since its value depends upon the value of frequency.

PRINCIPAL OF WORKING:

The principle of working of this useful laboratory instrument is based upon the well-known characteristics of a resonant series $R - L - C$ circuit.
At resonant frequency f_o, we have $X_C = X_L$ where capacitive reactance $X_C = \frac{1}{2\pi f_o C}$,inductive reactance $X_L = 2\pi f_o L$, resonant frequency $f_o = \frac{1}{2\pi\sqrt{LC}}$ and current at resonance $I_o = \frac{E}{R}$.
The voltage across the capacitor $E_C = I_o.X_C = I_o.X_L = I_o.w_o L$ and input voltage $E = I_o.R$ then $\frac{E_C}{E} = \frac{w_o L}{R} = Q$ and $E_C = QE$.
If the input voltage is kept constant the voltage across capacitor is Q times E and a voltmeter connected across the capacitor can be calibrated to read the value of Q directly.

Practical Circuit:

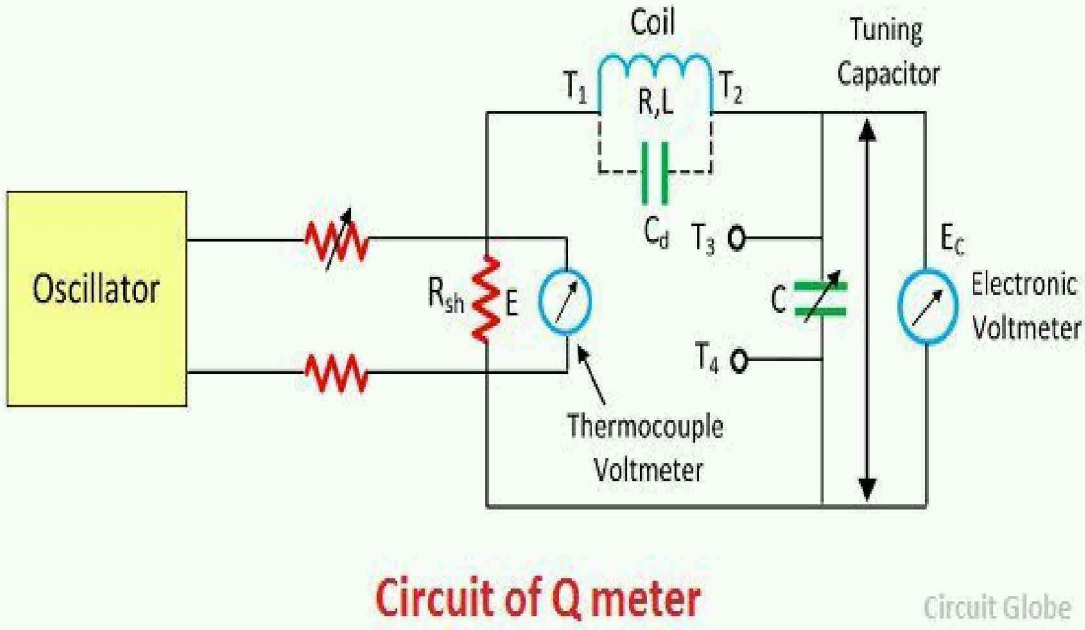


Figure 1: The Practical Circuit

The practical circuit is shown in Figure 1. It consists of self contained variable frequency RF oscillator. This oscillator delivers current to a low value shunt resistance R_{sh} : value may be 0.02 Ω The small value of input voltage E is injected into circuit that would be measured by thermocouple voltmeter. An electronic voltmeter is connected across this capacitor. The coil under test is connected to terminals T_1 and T_2.

Measurement of Q:

The circuit for measurement of Q shown in Figure 1. The oscillator is set to the desired frequency and then the tuning capacitor is adjusted for maximum value E_0. The input voltage E is kept constant then the voltage across capacitor is calibrated to read the value of Q directly. The measured value of Q is defined whole circuit not of the coil. There are errors caused due to shunt resistance and distributed capacitance of the circuit.

Correction of Shunt Resistance:

$$Q_{mes} = \frac{\omega_o L}{R + R_{sh}}$$

$$Q_{true} = \frac{\omega_o L}{R} = Q_{mes}(1 + \frac{R_{sh}}{R})$$

Correction of Distributed Capacitance:

$$Q_{true} = Q_{mes}(1 + \frac{C_d}{C})$$

Where, C_d=distributed capacitance and C= tuning capacitance.

Measurement of Self Capacitance:

The value of Inductance is given by $L = \frac{1}{4\pi^2 f_o^2 C}$
The values of f_o and C are known and therefore the value of inductance may be calculated.

Measurement of Effective Resistance:
The value of effective resistance may be computed from the relation $R = \frac{\omega_o L}{Q_{true}}$.

Measurement of Self Capacitance:
The self capacitance is measured by making two measurements at different frequencies. The capacitor is set to a high value and the circuit is resonated by adjustment of the oscillator frequency. Resonance is indicated by the circuit Q meter. Let the values of tuning capacitor be $C_1$and that of frequency be f_1 under these condition. Therefore,

$$f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

The frequency is now increased to twice its initial value and the circuit is resonated again this time with the help of the tuning capacitor. Let the values of tuning capacitor be C_2 and that of frequency be f_2 under these condition. Therefore,

$$f_2 = \frac{1}{2\pi\sqrt{L(C_2 + C_d)}}$$

Now , $f_2 = 2.f_1$
The Distributed Capacitance, $C_d = \frac{C_1 - 4C_2}{3}$

Procedure:

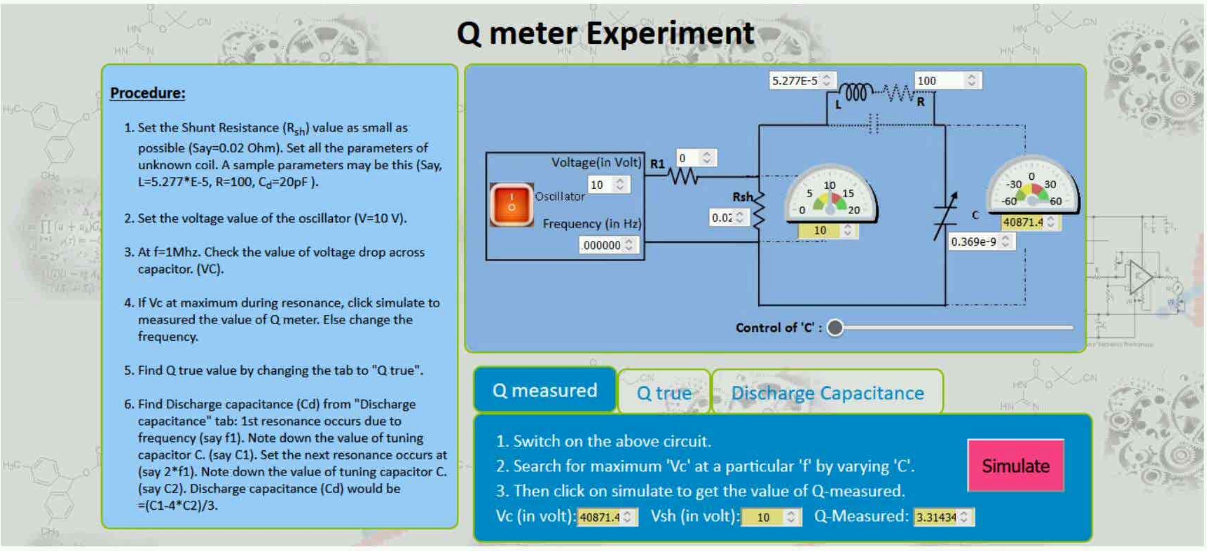
- Set the Shunt Resistance (R_sh) value as small as possible (Say 0.02 Ohm). Set all the parameters (R, L, C) by yourself.
- Set the voltage value of the oscillator (E=10 V).
- At $f = 100Hz$. Check the value of voltage drop across capacitor. (E_C).
- Change the frequency until EC reach at the maximum value. Then calculate the value Q measured using this formula $Q_{mes} = \frac{\omega_o L}{R+R_{sh}}$.
- Calculate the true value of unknown coil by using this formula $Q_{true} = \frac{\omega_o L}{R}$
- First resonance occurs due to frequency (say f_1). Note down the value of tuning capacitor C (say C_1). Double the input frequency (f_1)(say $f_2 = 2 * f_1$).Change the tuning capacitor value until resonance occurs. Note down the value of tuning capacitor C (say C_2).Discharge capacitance(C_d) would be $= \frac{C_1 - 4C_2}{3}$.

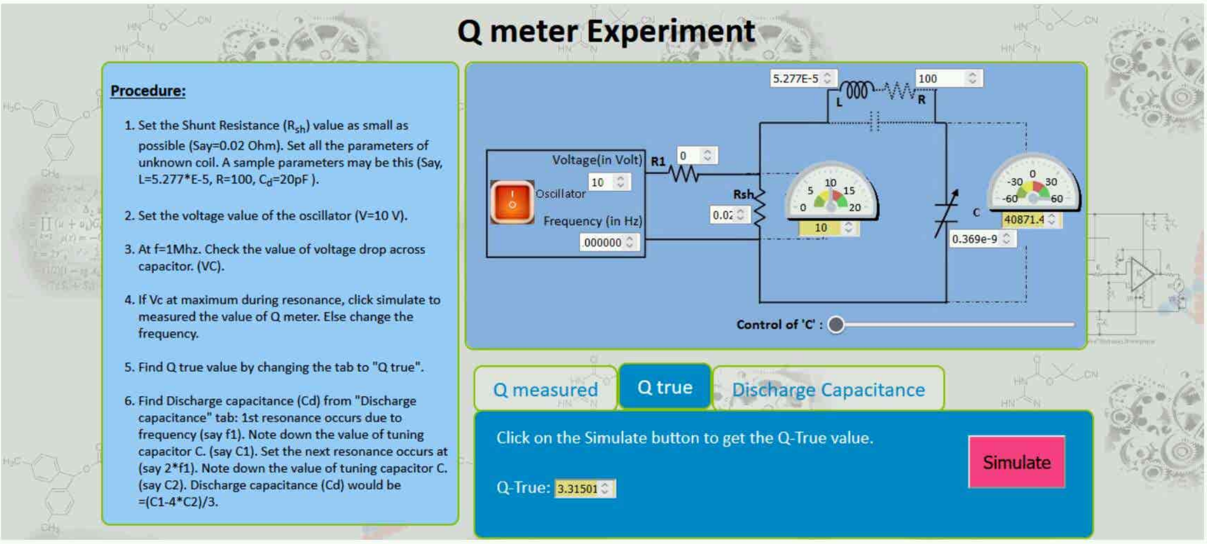
Observations:

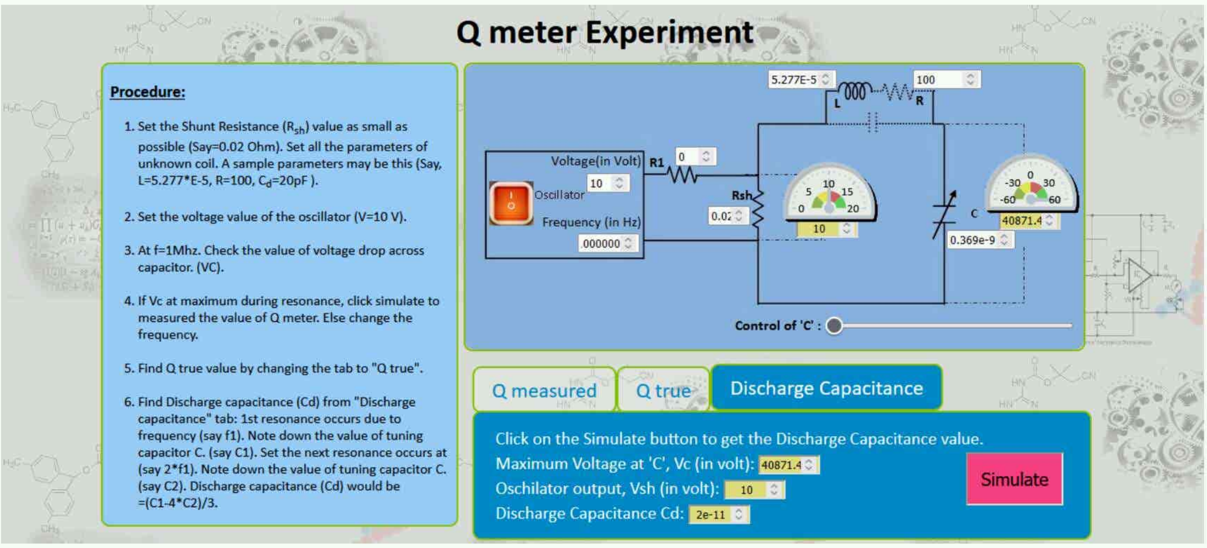
Values Given:

- $Voltage = 10V$
- $R_1 = 0\Omega$
- $R_{sh} = 0.02\Omega$
- $L = 5.277 \times 10^{-5}H$
- $R = 100\Omega$

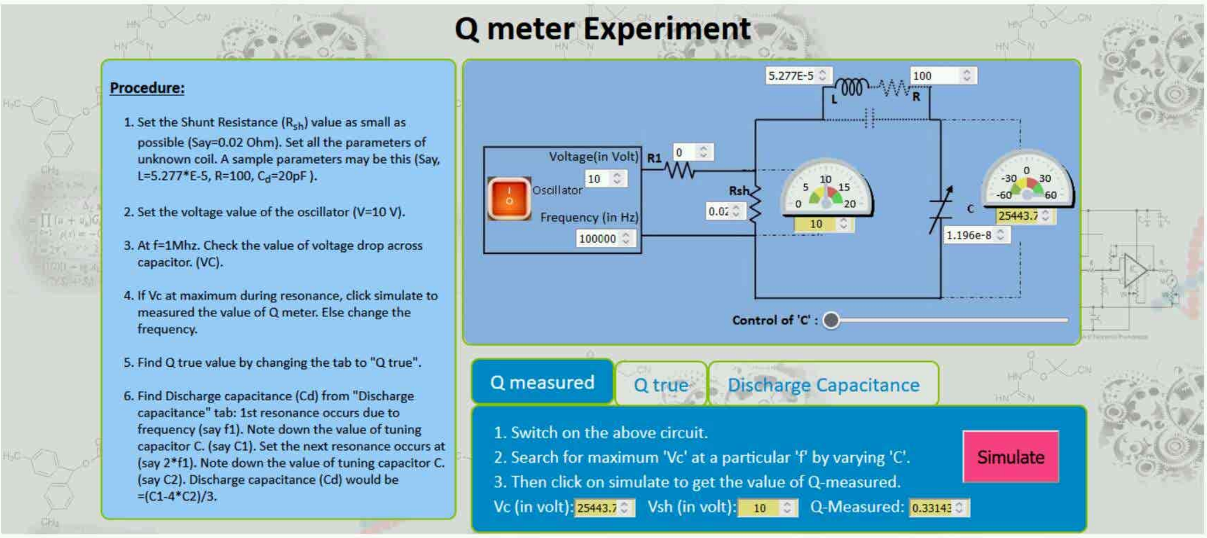
For Frequency 1 x 10^6 Hz:

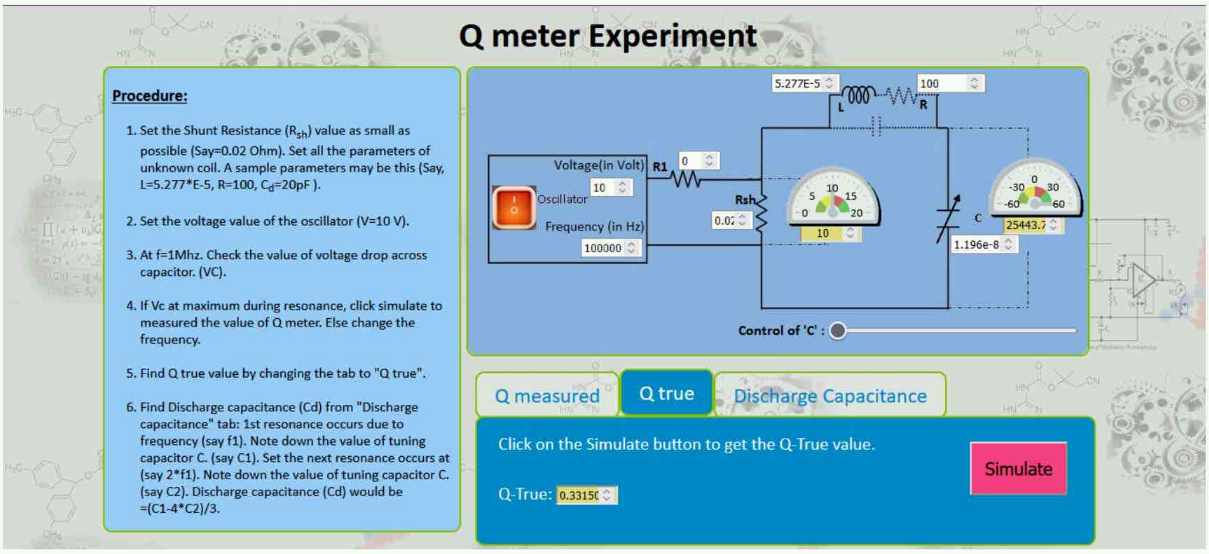


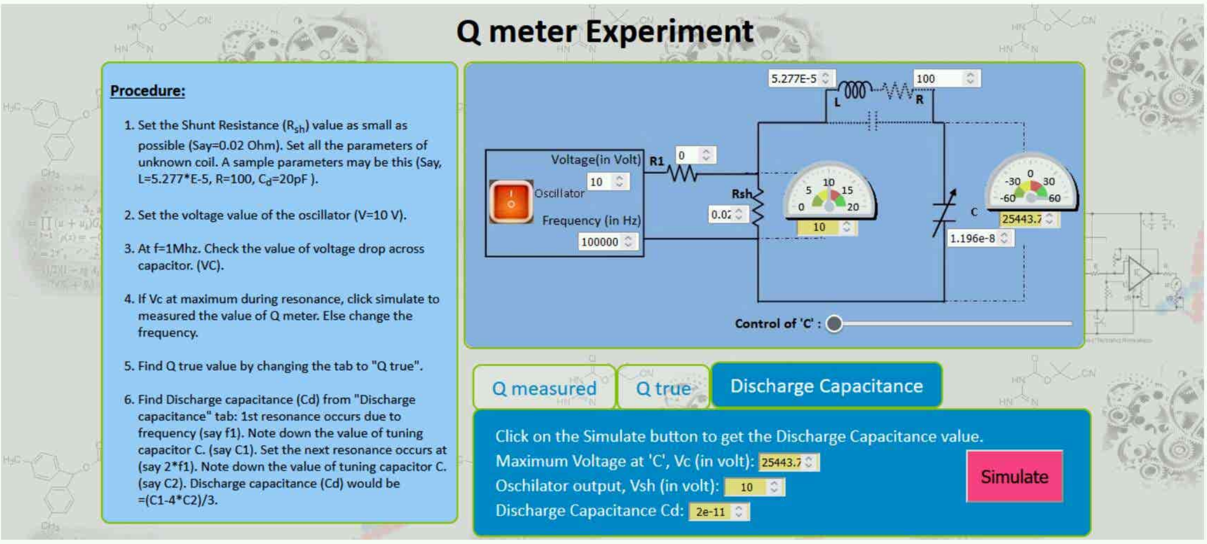




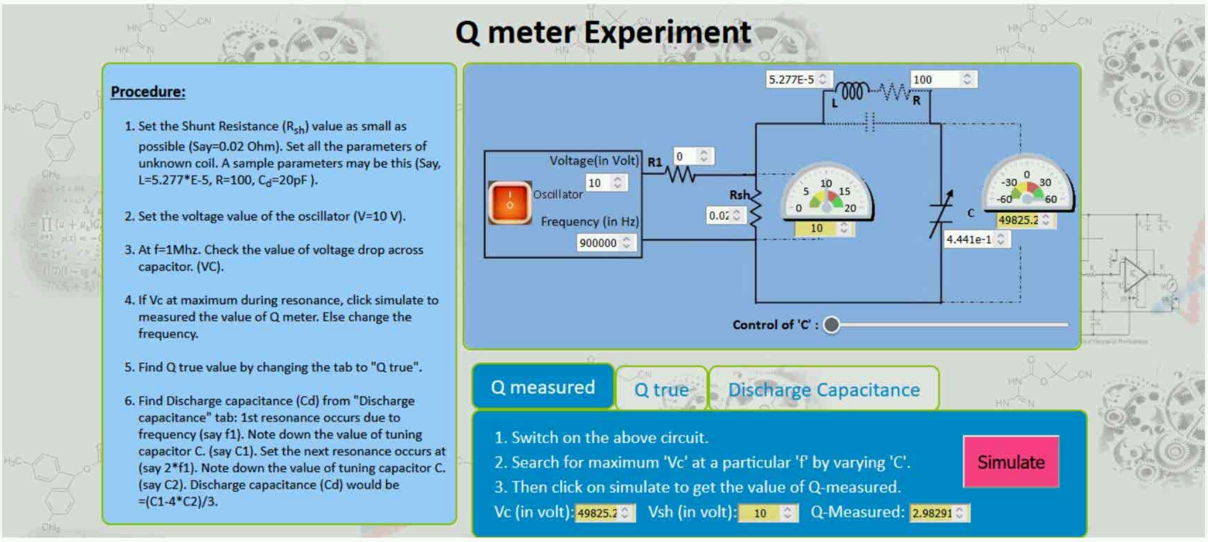
For Frequency 1 x 10^5 Hz:

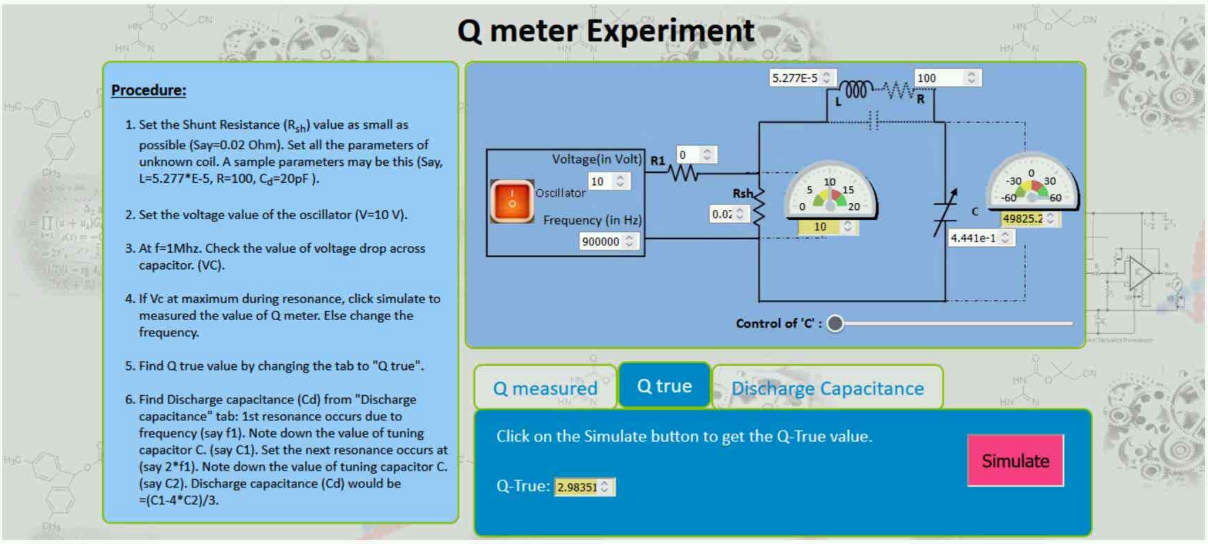


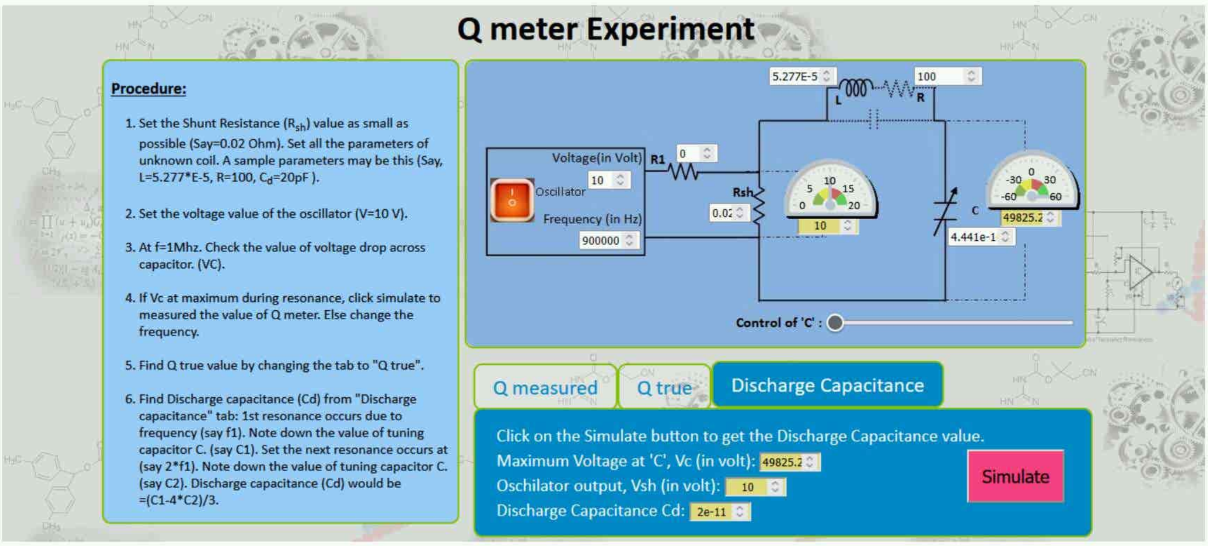




For Frequency 9×10^5 Hz:







Calculations:

1.For Frequency $1 \times 10^6 Hz$:

$$Q_{mes} = 3.31434$$

$$Q_{true} = 3.31501$$

$$\text{Absolute Error in } Q_{mes} = Q_{true} - Q_{mes}$$

$$= 3.31501 - 3.31434$$

$$= 0.00067$$

$$\text{Relative Error in } Q_{mes} = \frac{Q_{true} - Q_{mes}}{Q_{true}}$$

$$= \frac{3.31501 - 3.31434}{3.31501}$$

$$= 0.000202111$$

$$\text{Relative percentage Error in } Q_{mes} = \frac{Q_{true} - Q_{mes}}{Q_{true}} \times 100$$

$$= \frac{3.31501 - 3.31434}{3.31501} \times 100$$

$$= 0.02\%$$

2.For Frequency $1 \times 10^5 Hz$:

$$Q_{mes} = 0.33143$$

$$Q_{true} = 0.33150$$

$$\text{Absolute Error in } Q_{mes} = Q_{true} - Q_{mes}$$

$$= 0.33150 - 0.33143$$

$$= 0.00007$$

$$\text{Relative Error in } Q_{mes} = \frac{Q_{true} - Q_{mes}}{Q_{true}}$$

$$= \frac{0.33150 - 0.33143}{0.33150}$$

$$= 0.000211161$$

Relative percentage Error in $Q_{mes} = \frac{Q_{true}-Q_{mes}}{Q_{true}} \times 100$

$$= \frac{0.33150 - 0.33143}{0.33150} \times 100$$

$$= 0.02\%$$

3.For Frequency $9 \times 10^5 Hz$:

$$Q_{mes} = 2.98291$$

$$Q_{true} = 2.98351$$

Absolute Error in $Q_{mes} = Q_{true} - Q_{mes}$

$$= 2.98351 - 2.98291$$

$$= 0.0006$$

Relative Error in $Q_{mes} = \frac{Q_{true}-Q_{mes}}{Q_{true}}$

$$= \frac{2.98351 - 2.98291}{2.98351}$$

$$= 0.0002011054$$

Relative percentage Error in $Q_{mes} = \frac{Q_{true}-Q_{mes}}{Q_{true}} \times 100$

$$= \frac{2.98351 - 2.98291}{2.98351} \times 100$$

$$= 0.02\%$$

Results:

1.For Frequency $1 \times 10^6 Hz$:

- $V_C = 40871.4V$
- $V_{sh} = 10V$
- $Q_{mes} = 3.31434$
- $Q_{true} = 3.31501$
- $C_d = 2 \times 10^{-11}$
- Absolute Error in $Q_{mes} = 0.00067$
- Relative Error in $Q_{mes} = 0.000202111$
- Relative Percentage error in $Q_{mes} = 0.02\%$

2.For Frequency $1 \times 10^5 Hz$:

- $V_C = 25443.7V$
- $V_{sh} = 10V$
- $Q_{mes} = 0.33143$
- $Q_{true} = 0.33150$
- $C_d = 2 \times 10^{-11}$
- Absolute Error in $Q_{mes} = 0.00007$
- Relative Error in $Q_{mes} = 0.000211161$
- Relative Percentage error in $Q_{mes} = 0.02\%$

3.For Frequency $9 \times 10^5 Hz$:

- $V_C = 49825.2V$
- $V_{sh} = 10V$
- $Q_{mes} = 2.98291$
- $Q_{true} = 2.98351$
- $C_d = 2 \times 10^{-11}$
- Absolute Error in $Q_{mes} = 0.0006$
- Relative Error in $Q_{mes} = 0.0002011054$
- Relative Percentage error in $Q_{mes} = 0.02\%$