Lab Exercise No. 14
Series Resonance

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Abstract—**The goal of this lab exercise is to analyze voltage relationships in a series resonant circuit, focusing on determining the resonant frequency and quality factor based on the resistance, inductance, and capacitance values.**

Keywords-frequency; resonance; capacitance; inductance; resistance; series; voltage

I. INTRODUCTION

Series resonance of a RLC circuit occurs when the inductive and capacitive reactances are equal in magnitude but cancel each other because they are 180 degrees apart in phase and whose frequency response characteristics change with changes in frequency. It provides a low impedance path to harmonic currents and results in unexpected harmonic current flow through the system equipment. During these conditions, excessive current flow may lead to burning of cables, fuses, and unnecessary relay operations.

This is characterized by the Quality Factor of the circuit, which is defined as the resonant frequency to bandwidth ratio. The higher the Q value is, the narrower the bandwidth becomes and the greater the selectivity means that the circuit filters out the frequency more precisely around its resonance point. The Q factor is controlled by changing the resistance values of the circuit.

Understanding these dynamics is critical in applications such as tuning circuits in radios and televisions, which require accurate frequency selection. However, in power systems, unwanted resonance can cause low impedance routes for harmonic currents, resulting in unexpected and potentially destructive current flows across system equipment.

II. PROCEDURE

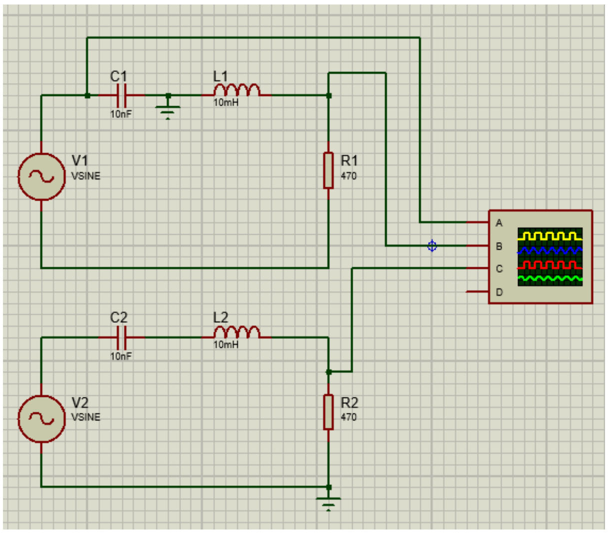


Figure 2.1: Low Q Circuit

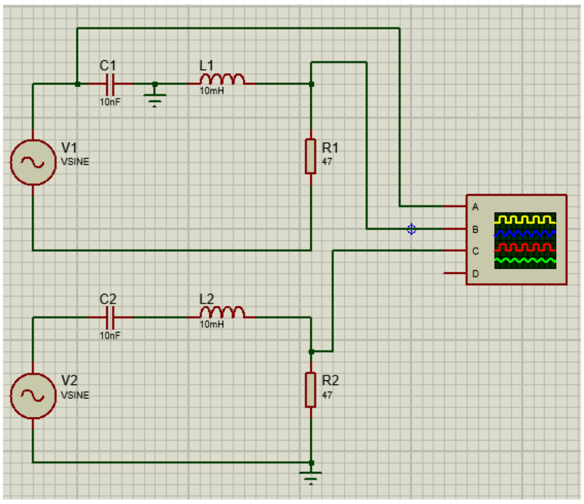


Figure 2.2: High Q Circuit

First, we calculated the theoretical resonance frequency (f_0) and quality factor (Q) for the Low Q Circuit using the given values: R = 470 Ω, L = 10 mH, and C = 10 nF And we recorded the results in Table 3.1, while determining the upper (f_1) and lower (f_2) frequencies defining the bandwidth based on the Q factor and added them to the same table.

Next, we built the circuit according to Figure 2.1 and connected a probe across the resistor and set the function generator to output a 1V p-p sine wave at the theoretical resonance frequency. We ensured that the bandwidth limit on the oscilloscope was engaged for both channels to reduce noise and improve measurement accuracy.

Afterward, we adjusted the frequency to find the experimental resonance frequency (f_0). We slowly swept the frequency up and down until we located the maximum voltage and recorded the value in Table 13.1. We then swept the frequency above and below f_0 to identify the half-power points (f_1 and f_2), where the voltage amplitude was approximately 0.707 times the resonant voltage, and we recorded these in Table 13.1. Using these experimental values, we calculated and recorded the experimental Q factor.'

Once we determined the experimental resonance, we transcribed the frequencies into Table 13.2. We measured the voltage across the resistor at each frequency and recorded the results, and then swapped the resistor with the inductor and capacitor to measure their respective voltages, ensuring proper grounding for the oscilloscope each time. After collecting the data, we plotted VR, VC, and VL as functions of frequency.

For the High Q Circuit, we repeated the same steps with R replaced by 47 Ω. We recorded the new data in Tables 3.3 and 3.4 and created new plots to analyze the results.

Finally, in the computer simulation, We built the circuit in a simulator and performed an AC Analysis, plotting the voltage across the resistor from 1 kHz to 100 kHz for both the high and low Q cases. We then compared the simulated plots to the experimental results from Tables 3.2 and 3.4, ensuring the inclusion of the 50 Ω source resistance and coil resistance in the simulation. Together, we evaluated the consistency between the experimental and simulated data.

III. RESULTS AND ANALYSIS

A. Low Q Circuit

	Theory	Experimental	% Deviation
f_o	15915.49	15915.49	0
Q	2.13	2.13	0
f_1	12612.08	12612.08	0
f_2	20084.14	20084.14	0

Table 3.1

As shown above, it contains the recorded theoretical and experimental values of the resonant frequency, quality factor, and bandwidth for the low Q circuit.

Frequency	V_R	V_C	V_L
f_o	2.06	2.07	0.926
f_1	1.88	1.24	0.71
f_2	1.12	1.83	0.680
1 kHz	0.0296	1.0035	0.004
5 kHz	0.1617	1.0949	0.1081
8 kHz	0.3014	1.2759	0.3224
12 kHz	0.6346	1.7909	1.0181
20 kHz	0.714	1.2089	1.9091
30 kHz	0.3278	0.37	1.3148
50 kHz	0.164	0.1112	1.0976
100 kHz	0.0765	0.0259	1.023

Table 3.2

As shown above, it displays the experimental voltage values of the capacitor, inductor, and resistor for each frequency ranging from 1 kHz to 100 kHz, along with the frequencies of the quality factor and bandwidth for the low Q circuit.

B. High Q Circuit

	Theory	Experimental	% Deviation
f_o	15915.49	15915.49	0

Q	21.28	21.28	0
f_1	11253.95	11253.95	0
f_2	20577.49	20577.49	0

Table 3.3

As shown above, it contains the recorded theoretical and experimental values of the resonant frequency, quality factor, and bandwidth for the high Q circuit.

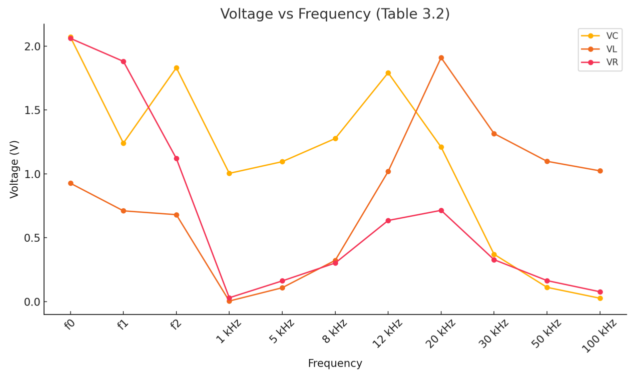
Frequency	V_R		V_L
f_o	12.63	17.02	0.781
f_1	2	1.07	0.068
f_2	1.35	2.38	0.0858
1 kHz	0.003	1.004	0.004
5 kHz	0.0164	1.1094	0.1095
8 kHz	0.0316	1.3374	0.3379
12 kHz	0.0818	2.3097	1.313
20 kHz	0.1015	1.7178	2.7126
30 kHz	0.0347	0.3915	1.3909
50 kHz	0.0166	0.1127	1.1126
100 kHz	0.0077	0.0260	1.0260

Table 3.4

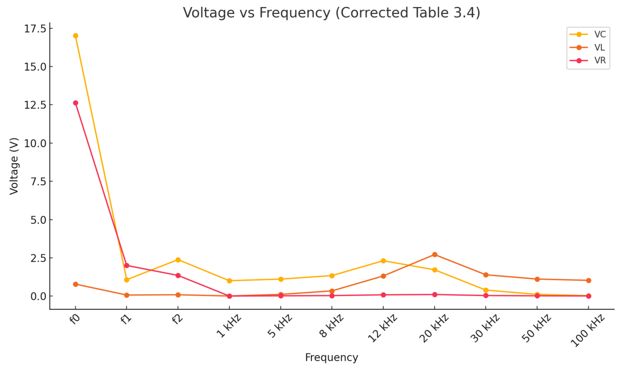
As shown above, it displays the experimental voltage values of the capacitor, inductor, and resistor for each frequency ranging from 1 kHz to 100 kHz, along with the frequencies of the quality factor and bandwidth for the high Q circuit.

C. *Plot*

- *Low Q Circuit*



- *High Q Circuit*



D. *Questions*

1. What is the effect of changing resistance on Q?
   - The quality factor (Q) is **inversely proportional to resistance**. When resistance decreases, Q increases, resulting in a sharper resonance and narrower bandwidth. For example, in the **Low Q circuit** with R=470 Ω, the Q value was 2.13, while in the **High Q circuit** with R=47 Ω, the Q value increased significantly to 21.28. This shows that reducing resistance improves the circuit's ability to focus on the resonant frequency.

2. Are the V_C and V_L curves the same as the V_R curve? If not, why?
   - No, the V_C and V_L curves differ from the V_R curve because of how reactive components behave in the circuit. At resonance, V_R peaks due to maximum current flow, while V_C and V_L each much higher values as energy

oscillates between the capacitor and inductor. Outside resonance, V_C and V_L shift with frequency changes, while V_R remains proportional to the current.

3. In practical terms, what sets the limit on how high Q may be?
   - The practical constraints on Q are caused by non-idealities in circuit components and external influences. Resistive losses in inductors and capacitors, as well as source resistance, create damping and lower Q. Additionally, parasitic effects like stray capacitance and inductance limit Q. Because real components are not flawless, their defects limit the greatest attainable Q in practical systems.

IV. CONCLUSION

This experiment showed the function of resistance in affecting the quality factor.
Example of a series RLC circuit. Lower resistance resulted in increased Q, reducing the bandwidth and intensifying the resonance. While *VR* peaks at resonance due to maximum current, *VC* and *VX* behave differently and exhibit substantially higher voltages due to energy oscillation between the reactive components. However, practical constraints, like resistive losses and parasitic elements, limit how high Q may be in real-world applications. This understanding is crucial for applications such as filters, tuning circuits, and reducing resonance in power systems.

REFERENCES

[1] Series Resonance in a Series RLC Resonant Circuit. (n.d.). Electronics Tutorials. Retrieved December 14, 2024, from https://www.electronics-tutorials.ws/accircuits/series-resonance.html