EE203 - Electrical Circuits Laboratory

Experiment - 8 Laboratory Report
RLC Circuits

Name: Korkut Emre Arslantürk **Number: 250206039**
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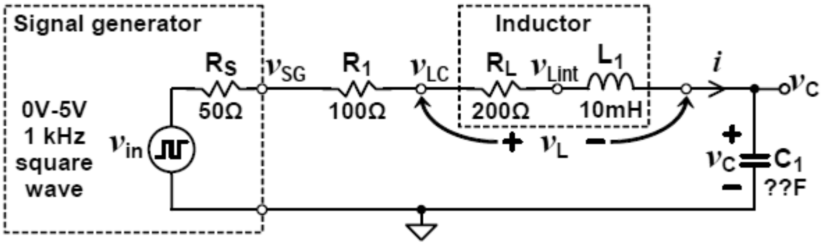
Preliminary Work

1. In the following circuit internal resistance of the inductor is shown as $\mathbf{R_L = 200\ \Omega}$. Output resistance $\mathbf{R_S = 50\ \Omega}$ of the signal generator and $\mathbf{R_L}$ should be included in the calculations when they are comparable to the external resistance $\mathbf{R_1}$.



1.a) Calculate the capacitance $\mathbf{C_1}$ that gives the resonance frequency $\mathbf{f_o = 50\ kHz}$.

a) $f_o = \frac{1}{2\pi\sqrt{LC}} = 50\ kHz$, also we know $L = 10\ mH$

So we can find C easily.

$C \times 10\times10^{-3}\ H = \frac{1}{(100\pi \times 10^2)^2}$ => $C = 1.01\ nF$

1.b) Calculate the damped oscillation frequency $\mathbf{f_d = \omega_d/2\pi}$, and the decay time constant $\boldsymbol{\tau}$ for $\mathbf{R_1 = 0\ \Omega}$, **100 Ω**, and **1 kΩ**.

b) For $R_1 = 0\ \Omega$,

$\tau = \frac{2L}{R} = 80\times10^{-6}\ s$

=> $f_d = \frac{\sqrt{\left(\frac{1}{(0.01)(1.01\times10^{-9})}\right) - \left(\frac{250}{4(0.01)^2}\right)^2}}{2\pi} = 50.3\ kHz$

For $R_1 = 100\ \Omega$,

$\tau = \frac{2L}{R} = 57.1\times10^{-6}\ s$

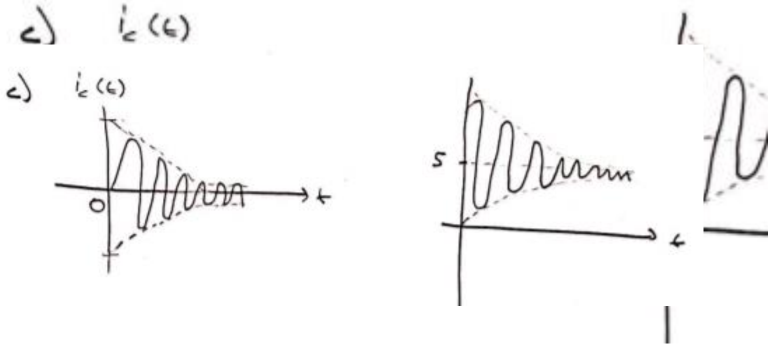
$f_d = \frac{\sqrt{1.013\times10^{11} - \left(\frac{350}{4(0.1)^2}\right)^2}}{2\pi} = 50.26\ kHz$

For $R_1 = 1k\ \Omega$

$\tau = \frac{2L}{R} = 1.6\times10^{-6}$

$f_d = \frac{\sqrt{1.13\times10^{11} - \left(\frac{1250}{4(0.1)^2}\right)^2}}{2\pi} = 49.5\ kHz$

1.c) Draw ***i*(t)** and $v_C(t)$ as a function of time after v_{in} switches from **5 V** to **0 V**, for



1.d) Calculate the R_1 value that gives the critically damped response.

d) For critically damped response,

$\alpha = w_o \rightarrow R = 2\sqrt{\frac{L}{C}} = 2\sqrt{\frac{0.01}{1.013\times10^{-9}}} = 6.2k\Omega$

2. Consider the **RLC** circuit given above when $v_{in} = 2.5V \sin(\omega_d t)$.
Calculate steady state ***i*(t)**, $v_C(t)$, and $v_{LC}(t)$ when $R_1 = 0\ \Omega$, **100 Ω**, and **1 kΩ**.

For $R_1 = 0\Omega$

$Q = \frac{\sqrt{L/C}}{R} = \frac{\sqrt{(1.032\times10^{-9})/(10\times10^{-3})}}{250} = \frac{0.312\times10^3}{250}$

So, $V_{LC}(t) = 0$ for average.

$i_c(t) = \frac{2.5}{250} = 10mA$, $V_c(t) = Q \times 2.5 \sin(wt) \times \angle -90°$

$= \frac{810.5}{250}\cos(w_d t) = 32.42\cos(w_d t)V$

For $R_1 = 100\Omega$

$V_{LC}(t) = 1.39 \cos(wt) V$

$Q = \frac{\sqrt{L/C}}{R} = \frac{1}{350} \times \sqrt{\frac{1.032\times10^{-3}}{10\times10^{-3}}} = 0.917$

$i(t) = \frac{2.5}{350} \cdot \sin(w_d t) = 7.15 \sin(w_d t) mA$

$V_c(t) = Q \times 2.5 \sin(w_d t) = 22.945 \cos(w_d t)$, $V_{LC}(t) = 1.4\cos(w_d t)V$

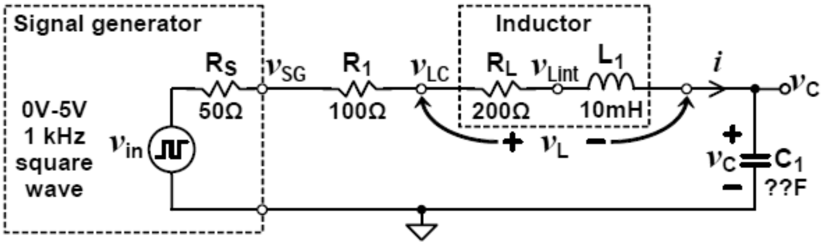
For $R_1 = 1k\Omega$

$Q = \frac{\sqrt{L/C}}{R} = \frac{1}{1250} \cdot \sqrt{\frac{1.032\times10^{-9}}{10\times10^{-3}}} = 2.6$, Thus $V_c(t) = 6.42\cos(w_d t)$

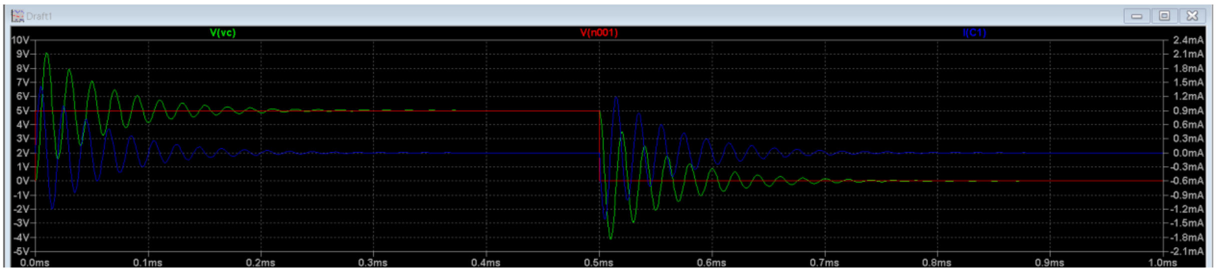
$i(t) = \frac{2.5}{1250} = 2\sin(w_d t) mA$ $V_{LC}(t) = 0.4 \cos(w_d t) V$

Procedure

1. Set up the circuit given below using the capacitance $\mathbf{C_1}$ calculated in the preliminary work and set the $\boldsymbol{v_{in}}$ signal source to obtain **1 kHz** square wave that switches between **0 V** and **5 V** with the timing parameters, `Trise = 1n`, `Tfall = 1n`, `Ton = 500u`, and `Tperiod = 1m`. Set simulation time to **1 ms**.



1.1 Display $\boldsymbol{v_{in}}$, $\boldsymbol{v_C(t)}$ and $\boldsymbol{i(t)}$ waveforms and plot $\boldsymbol{v_C(t)}$ and $\boldsymbol{i(t)}$ waveforms.

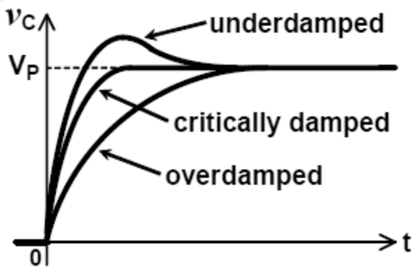


1.2 Measure the $\boldsymbol{v_C}$ oscillation frequency $\mathbf{f_d = 1/T_d}$, and the decay time constant $\boldsymbol{\tau}$ for the $\mathbf{R_1}$ values given in the following table.

$\mathbf{R_1}$	$\mathbf{f_d}$ (Hz)	$\boldsymbol{\tau}$ (μs)
0 Ω	50.00KHz	75.28μs
100 Ω	50.05KHz	55.10μs
1 kΩ	49.60KHz	15.79 μs

1.3 Observe $\boldsymbol{i(t)}$ and $\boldsymbol{v_C(t)}$ for several $\mathbf{R_1}$ values around the resistance calculated for critically damped response in the preliminary work step **1.d**.

Determine the $\mathbf{R_1}$ resistance that gives the critically damped response by changing $\mathbf{R_1}$ in **0.1 kΩ** steps. Monitor $\boldsymbol{v_C}$ as you increase the $\mathbf{R_1}$ resistance until the overshoot at the rising $\boldsymbol{v_C}$ edge disappears. Zoom into the $\boldsymbol{v_C}$ waveform to see the circuit response clearly.



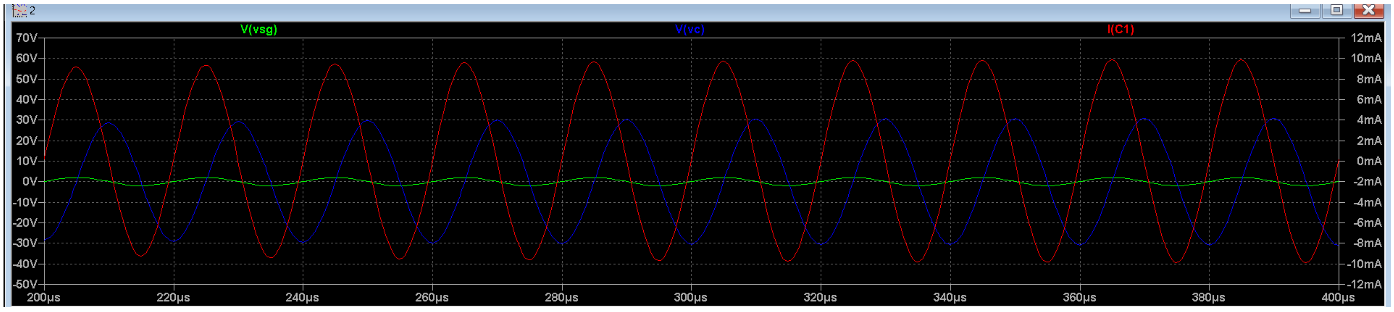
$\mathbf{R_1}$ **=** 5.9k Ω

$\mathbf{R_1}$ **+ 250 Ω =** 6150 Ω

2.b) Simulate the circuit in LTspice and verify your calculations.

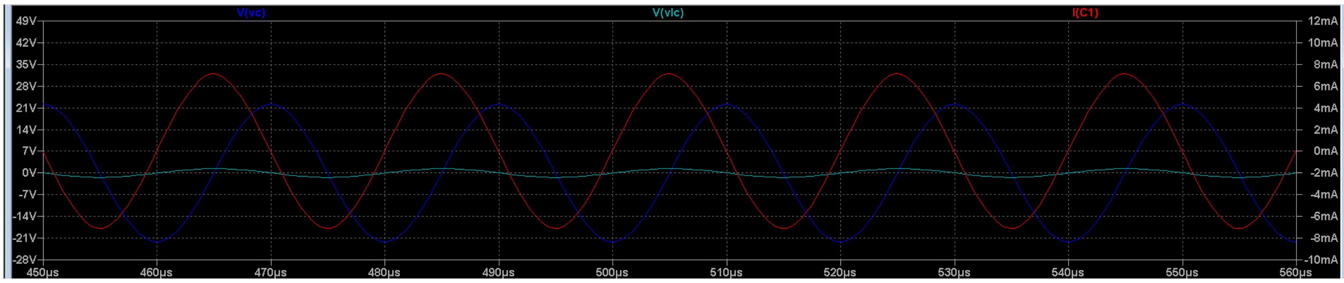
- Observe ***i*(t)**, ***v*$_C$(t)**, and ***v*$_{LC}$(t)** for **R_1 = 0 Ω**, **100 Ω**, and **1 kΩ**, and compare the steady state peak values with your calculations.

For R_1=0 Ω:



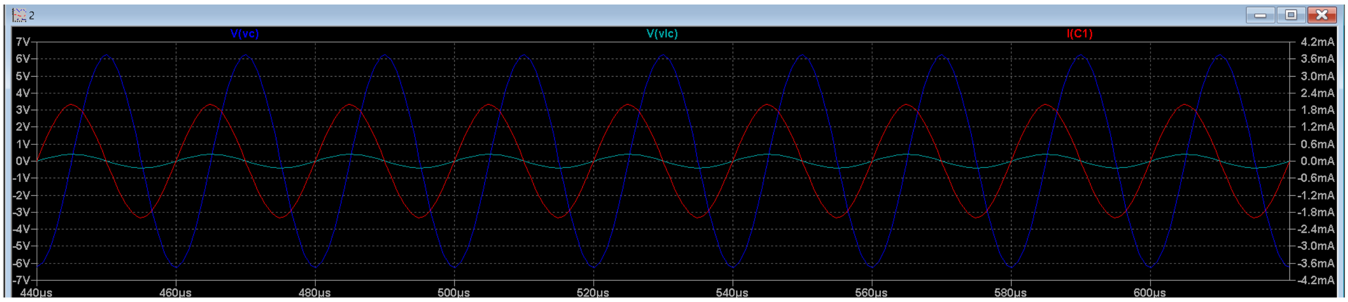
	Measured values in simulation	Calculated values in preliminary work	%error
***v*$_{LC}$** (V)	1.98V	1.99V	0.5
i (mA)	9.94mA	10 mA	0.6
***v*$_C$** (V)	31.08V	32.42 V	4.1

For R_1=100 Ω:



	Measured values in simulation	Calculated values in preliminary work	%error
***v*$_{LC}$**(V)	1.42V	1.4 V	1.4
i (mA)	7.11mA	7.15 mA	0.56
***v*$_C$** (Vp)	22.26V	22.94 V	3.05

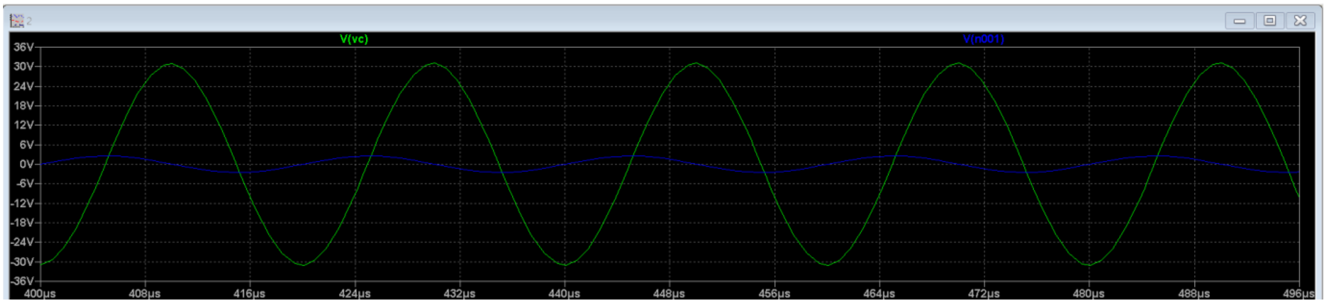
For R_1=1k Ω:



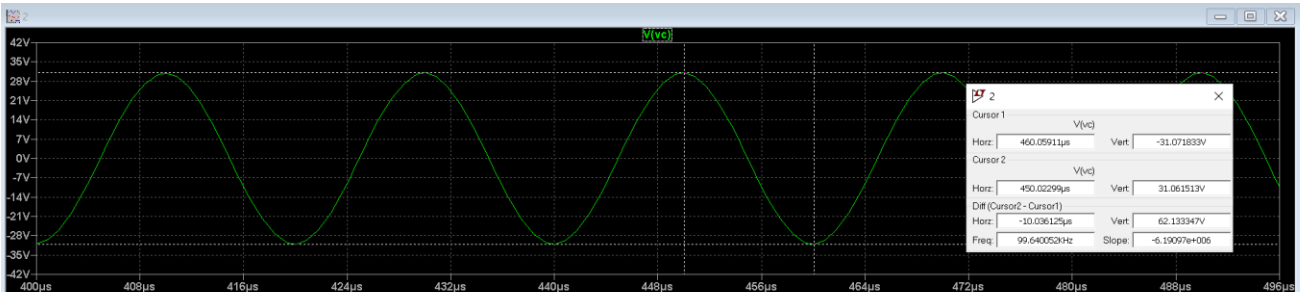
	Measured values in simulation	Calculated values in preliminary work	%error
v_{LC}(V)	0.395V	0.4 V	1.25
i (mA)	1.99mA	2 mA	0.5
v_C(V)	6.225V	6.42 V	3.03

Our percentage of error is fewer than %5 for every values. This little bit error can be because of decimal rounding or cursor error while measuring.

2. Setup the circuit given for step-**1** with $\mathbf{R_1 = 0\ \Omega}$, and set the v_{in} signal source to obtain **5 Vp-p** sine wave at the resonance frequency found in step-**1**.



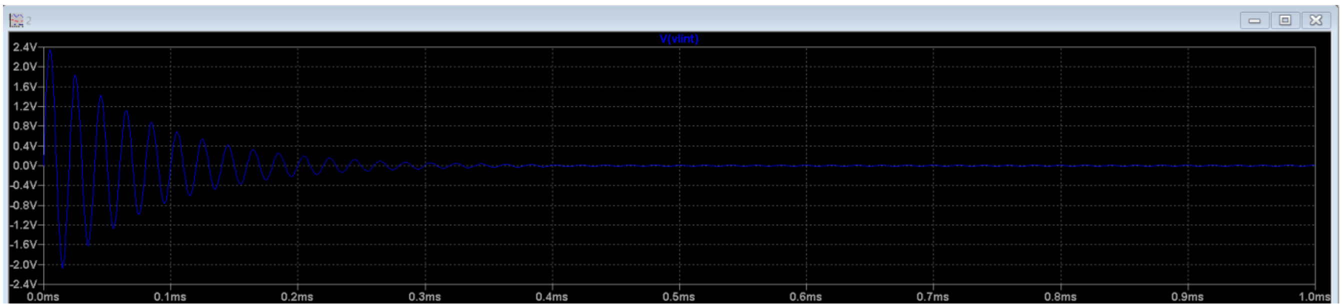
2.1 Observe v_C waveform and change the signal generator frequency in **100 Hz** steps to obtain the <u>maximum</u> peak-to-peak voltage at v_C.



Maximum v_C = 62.13V at frequency = 50kHz

2.2 Observe v_{Lint}**(t)** (voltage between $\mathbf{R_L}$ and **L** in the inductor), and find the v_{in} frequency that makes steady state amplitude of v_{Lint} **= 0**. Start with the frequency found in **2.1** and change v_{in} frequency in **50 Hz** steps.

Frequency where v_{Lint} **= 0** = 50050Hz



2.3 Measure the following peak-to-peak voltage and current values while the signal source voltage and frequency settings are kept the same.

R_1	v_{SG} (Vp-p)	v_{LC} (Vp-p)	i (mAp-p)	v_C (Vp-p)
0 Ω	3.98V	3.98V	19.88mA	62.17V
100 Ω	4.27V	2.84V	14.22mA	44.51V
1 kΩ	4.78V	0.79V	3.98mA	12.45V

Questions

Q1. Compare the oscillation frequency $\mathbf{f_d}$, and the decay time constant $\boldsymbol{\tau}$ measured in procedure step-**1.2** with values calculated in the preliminary work.

		Measured values in simulation step 1.2	Calculated values in preliminary work	%error
oscillation frequency $\mathbf{f_d}$	**0 Ω**	50.00KHz	50.3KHz	0.6
	100 Ω	50.05KHz	50.26KHz	0.4
	1 kΩ	49.60KHz	49.5KHz	1.01
decay time constant $\boldsymbol{\tau}$	**0 Ω**	75.28μs	80μs	4.9
	100 Ω	55.10μs	57.1μs	3.5
	1 kΩ	15.79μs	16μs	1.3

Our percentage of error is fewer than %5 for every values. This little bit error can be because of decimal rounding or cursor error while measuring.

Q2. Compare the resistance found in procedure step-**1.3** with the resistance calculated for critically damped response in the preliminary work.

	Measured values in simulation step 1.2	Calculated values in preliminary work	%error
resistance for critically damped response	6150Ω	6200Ω	0.8

Our percentage of error is fewer than %5 for every values. This little bit error can be because of decimal rounding or cursor error while measuring.

Q3. Compare the peak-to-peak voltage and current values measured in procedure step-**2** with the results found in the preliminary work (remember the difference between ***peak-to-peak*** and ***peak*** values).

For R_1=0 Ω:

	Measured values in simulation	Calculated values in preliminary work	%error
v_{LC} (V)	3.98V	3.98V	0.5
i (mA)	19.88mA	20 mA	0.6
v_C (V)	62.17V	64.84 V	4.1

For R_1=100 Ω:

	Measured values in simulation	Calculated values in preliminary work	%error
v_{LC}(V)	2.84V	2.8 V	1.4
i (mA)	14.22mA	14.3 mA	0.56
v_C (Vp)	44.51V	44.88 V	3.05

For R_1=1k Ω:

	Measured values in simulation	Calculated values in preliminary work	%error
v_{LC}(V)	0.79V	0.8 V	1.25
i (mA)	3.98mA	4 mA	0.5
v_C(V)	12.45V	12.84 V	3.03

Our percentage of error is fewer than %5 for every values. This little bit error can be because of decimal rounding or cursor error while measuring.

Q4. How is it possible to obtain a capacitor voltage much higher than the signal generator output in procedure step-**2**?

We know, impedance of capacitor is inversely proportional with frequency, also we know, impedance of inductor is directly proportional with frequency. The series circuit's inductive as: XL>XC, at higher frequency values. According to that we see lagging power factor and because of that we get much higher output voltage than input voltage.

Q5. The same resonance frequency can be obtained when $\mathbf{L_1}$ and $\mathbf{C_1}$ are replaced by **10** $\mathbf{L_1}$ and **0.1** $\mathbf{C_1}$, or by **0.1** $\mathbf{L_1}$ and **10** $\mathbf{C_1}$ in procedure step-**2**. In which of these cases a higher $v_C(t)$ amplitude is obtained? Why?

According to second situation(**0.1** $\mathbf{L_1}$ and **10** $\mathbf{C_1}$), the series circuit's inductive like: XL>XC, and because of this situation we get lagging power factor at higher frequency values.If the capacitance value is increased and the inductance value is reduced, the efficiency factor will be reduced. Therefore, we get the lower amplitude of V_c. In order to achieve a higher V_c amplitude, we can replaced L_1 and C_1 with $10L_1$ and $0.1C_1$.

Conclusion

In this experiment, firstly we set given circuit in figure 1 and we set the Vin signal source to obtain 1kHz square wave that switches between 0V and 5V. Then we displayed Vin, Vc(t) and i(t) waveforms. Then we measured oscillation frequency and decay time constant values for different R_1 values(0Ω,100Ω,1kΩ). Then we determined the R_1 resistance value that gives the critically damped response. We increased R_1 resistance until the overshoot at the rising Vc edge disappears to get that. Then we compared our simulation results and calculated values in preliminary work according to peak values of I(t),Vc(t) and V_{LC}(t). Then we set up the circuit given for step 1 with R_1=0 Ω and we set the Vin signal source to obtain $5V_{p-p}$ sine wave at the resonance frequency. After that, we observed maximum Vc peak to peak value and its frequency. After that we found frequency value of V_{Lint}=0. After that, we measured peak to peak values of V_{SG},V_{LC},i,V_C for different R_1 values(0Ω, 100Ω,1kΩ) and we compared them with preliminary work results.

To sum up in this experiment, we understood basics of resonance mechanisms. We observed RLC circuit response. We learnt how we can measure and calculate oscillation frequency f_d, and the decay time constant τ. We learnt how we find resistance for critically damped response.

Izmir Institute of Technology

Faculty of Engineering

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