EE203 - Electrical Circuits Laboratory

Experiment – 3 Laboratory Report

AC Measurements and Power

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Preliminary Work

1. Read the procedure given for this experiment, and make sure that you have the required knowledge about the laboratory equipment to perform the specified steps. If necessary, refer to **EELab_GuideBeginner.pdf** to refresh your memory.

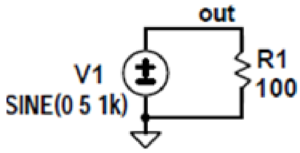
2.a) Calculate power dissipated on a **100 Ω** resistor as a function of time when the voltage across the resistor is **10 V *sin*(2*π* 1000 t)**.

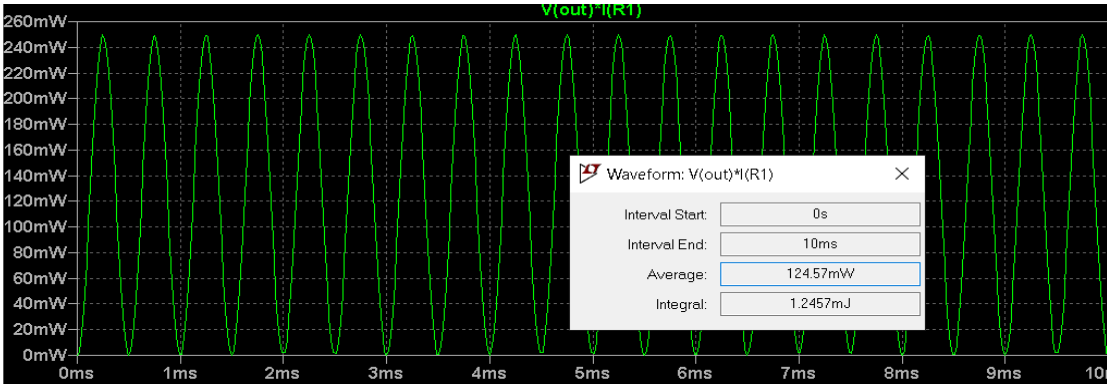
$$P_{avg} = \frac{1}{R_L} \cdot \frac{1}{T} \int_0^T v^2(t)\, dt = \frac{1}{R_L} V_{rms}^2$$

$$V_{rms} = \frac{V_p}{\sqrt{2}} \Rightarrow P_{avg} = \frac{1}{R_L} \cdot \frac{V_p^2}{2} = \frac{1}{100} \cdot \frac{(5)^2}{2} = \frac{1}{8} = 0{,}125\, W$$

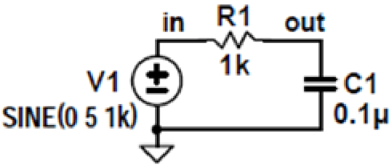
$$0{,}125\, W = 125\, mW$$

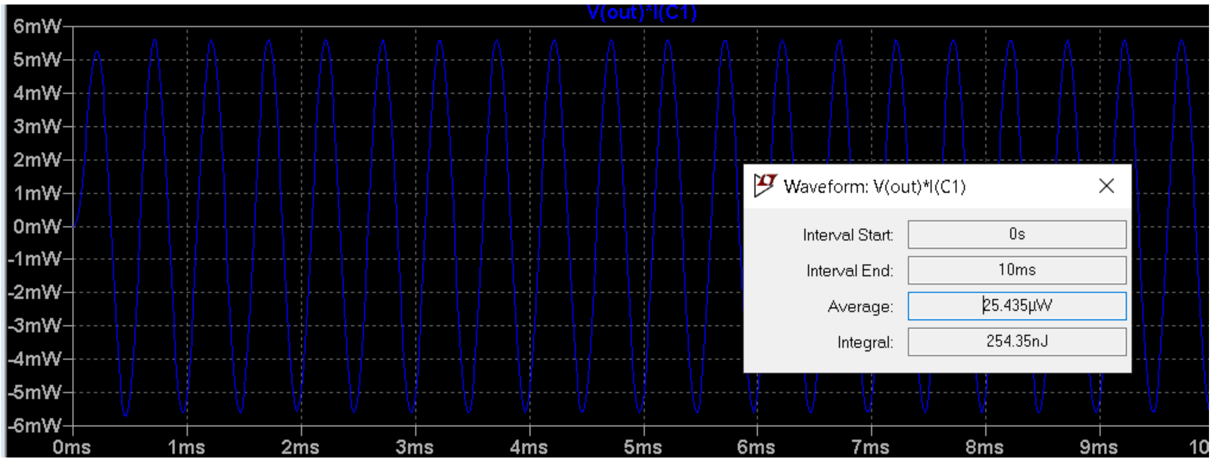
2.b) Verify your calculation by simulating the simple circuit given on the right on LTspice. To display the power on **R1**, Right-click on the waveform window, select the **Add Traces** option, and enter the expression `V(out) * I(R1)`. LTspice displays the power variation with a vertical scale in Watts.





2.c) Simulate the circuit shown on the right (used in Experiment-2) and display the power on **C1** by adding a trace with the expression `V(out) * I(C1)`. Identify the time intervals where **C1** stores and gives back energy.





3. Show that the RMS voltage of sinusoidal signal $\mathbf{V_P}\ \boldsymbol{sin}(\boldsymbol{\omega}\mathbf{t})$ is given by

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

$$V_{rms} = \sqrt{\frac{2}{T}\int_{t=0}^{T_{prd}} V_P^2\, sin^2(\omega t)\, dt} = \frac{V_P}{\sqrt{2}} \quad \text{by using} \quad sin^2(\omega t) = \frac{1 - cos(2\omega t)}{2}$$

$$V_{rms} = \sqrt{\frac{2}{t} * \int_{t=0}^{T/2} Vp^2\, \frac{1-cos(2wt)}{2}} = \sqrt{\frac{2}{t} * \frac{Vp^2 t}{4}} = \frac{Vp}{\sqrt{2}}$$

4. Calculate DC level and RMS voltage of a pulse waveform with **50 %** duty cycle, $\mathbf{V_{High} = +5\ V}$, and $\mathbf{V_{Low} = -5\ V}$.

$$V_{avg} = \frac{1}{T} \times V_{peak} \times T_{on} - \frac{1}{T} \times V_{min} \times T_{off}$$

$$= \frac{1}{10ms} \times 5V \times 5ms - \frac{1}{10ms} \times 5V \times 5ms = 0$$

$$V_{rms} = \sqrt{\frac{1}{T} \times (V_{peak})^2 \times T_{on} + \frac{1}{T} \times (V_{min})^2 \times T_{off}}$$

$$= \sqrt{\frac{1}{10ms}\ (5V)^2 \times 5ms + \frac{1}{10} \times (-5V)^2 \times 5ms} = 5V$$

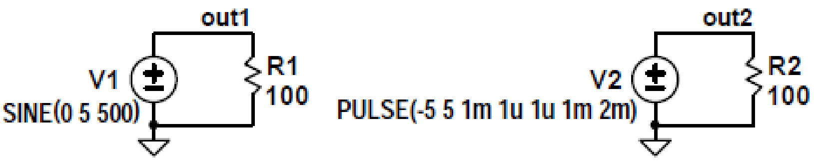
5. Calculate DC level and true RMS voltage of a pulse waveform with **25 %** duty cycle, $\mathbf{V_{High} = +10\ V}$, and $\mathbf{V_{Low} = 0\ V}$.

$$V_{avg} = \frac{1}{10ms} \times 10V \times \frac{100ms}{40} = 2.5V$$

$$V_{rms} = \sqrt{\frac{1}{10ms} \times (10V)^2\ \frac{10}{4}} = 5V$$

Result

1. Make the following circuit schematic on LTspice.



- Set **V1** source to obtain **500 Hz** sinusoidal signal with **10 Vp-p** amplitude and **0 V** DC offset.
- Set **V2** source to obtain **500 Hz** pulse signal with **10 Vp-p** amplitude, **0 V** DC offset and **1 μs** rise and fall time.
- Set simulation time to **10 ms**.

1.1 Measure the DC and RMS values of the voltages at **out1** and **out2** nodes and record them in the following table.

1.2 Change the **V1** and **V2** source parameters to obtain 5 V DC offset. Repeat the DC and RMS voltage measurements record them in the following table.

DC offset	**DC** voltage at **out1**	**RMS** voltage at **out1**	**DC** voltage at **out2**	**RMS** voltage at **out2**
0 V	23.244μV	3.5354V	3.5mV	4.9985V
5 V	5.0005V	6.1237V	5.0035V	7.0725V

2.1 Change the **V2** source timing parameters to obtain a **100 Hz** pulse signal with **20 %** duty cycle. Keep the **V2** source rise time and fall time settings at **1 μs**. Set simulation time to **50 ms**. Set the **V2** source low and high voltage levels listed in the following table. Measure DC and RMS voltages for each setting and record them in the following table.

Add a new trace on the waveform window and set the waveform expression to display the power dissipation on **R2** resistor. While holding down the **CTRL** key, left-click on the power trace label to display the average power. Record the measured average power values in the table given below for part **2.4**.

Low and high voltage levels with **20 %** duty cycle	voltage readings		calculated voltages		%Error	
	DC	**RMS**	**DC**	**RMS**	**DC**	**RMS**
0 V and **10 V**	2V	4.4718V	2V	4.472	0	0.001
-5 V and **+5 V**	-3V	4.9997V	-3V	5V	0	0.001
-10 V and **0 V**	8V	8.9441V	8V	8.9442	0	0.001

Our percentage of error between calculated and measure voltage is fewer than 1 because our simulation is ideal so we have little bit error because of decimal rounding.

2.2 Change the **V2** source timing parameters to obtain **80 %** duty cycle. Repeat the DC voltage, RMS voltage and average power measurements and record them in the following tables.

Low and high voltage levels with **80 %** duty cycle	voltage readings		calculated voltages		%Error	
	DC	**RMS**	**DC**	**RMS**	**DC**	**RMS**
0 V and **10 V**	8V	8.9441V	8V	8.9442V	0	0.001
-5 V and **+5 V**	3V	4.9997V	3V	5V	0	0.001
-10 V and **0 V**	-2V	4.4718V	-2V	4.472V	0	0.001

2.3 Calculate DC and RMS voltages according to the low and high voltage levels used in parts **2.1** and **2.2** and write the results in the tables above. Compare the measured voltages with the calculated values.

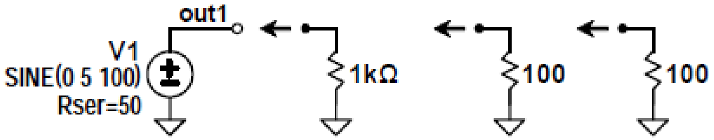
Our percentage of error between calculated and measure voltage is fewer than 1 because our simulation is ideal so we have little bit error because of decimal rounding.

2.4 Calculate the average power dissipated on **R2** with the pulse waveforms used in parts **2.1** and **2.2** and compare the measured average power values.

Low and high voltage levels	average power (mW) at **20 %** duty cycle		average power (mW) at **80 %** duty cycle		%Error	
	measured	**calculated**	**measured**	**calculated**	**20 %** duty cycle	**80 %** duty cycle
0 V and **10 V**	199.97mW	199.97mW	799.97mW	799.97mW	0	0
-5 V and **+5 V**	249.97mW	250mW	249.97mW	250mW	0.001	0.001
-10 V and **0 V**	799.97mW	799.97mW	199.97mW	199.97mW	0	0

Our percentage of error between calculated and measured voltages fewer than 1 because simulation is ideal so we have little bit error because of decimal rounding.

3.1 An ordinary signal generator used in the laboratory has **50 Ω** output resistance. Right-click on the **V1** source and enter the ***Series Resistance*** parameter as **50 Ω** to obtain a more realistic model of the laboratory signal generator. Set **V1** source to obtain **100 Hz** sinusoidal signal with **10 Vp-p** amplitude and **0 V** DC offset. Connect resistors to the **V1** source output as shown below, measure the output voltage for each resistance setting and write the measured voltages in the following table.



connected resistor	**peak-to-peak** voltage at **out1**	**RMS** voltage at **out1**
none	9.9833627V	3.5357V
1 kΩ	9.5097602V	3.3674V
100 Ω	6.6537285V	2.3572V
100 Ω // 100 Ω	4.9903509V	1.7679V

3.2 Explain the changes in the measured amplitude depending on the connected resistance.

When total resistance increasing our peak to peak voltage increasing and coming to true value because our internal resistance be less effective so we get more accuracy results but when we use fewer resistors our internal resistance is more effective because of that we get more wrong results.

Questions

Q1. According to the measurements in parts **1.1** and **1.2,** what type of RMS values (AC-only or true RMS) are measured in LTspice?
We measured true RMS in LTspice.

What would happen to the average power dissipated on **R1** and **R2**, if the pulse frequency was **1 kHz** instead of **500 Hz**? Why?

Average power dissipated on **R1** and **R2** does not change because when we change frequency, our period change and both of them not effect on power because voltage or current does not change.

Q2. The true RMS value of a signal $\boldsymbol{v(t)} = \mathbf{V_{DC}} + \boldsymbol{v_{AC}(t)}$ is given by the following equation in terms of the DC level $\mathbf{V_{DC}}$ and the RMS value $\mathbf{V_{ACrms}}$ of the pure AC signal $\boldsymbol{v_{AC}(t)}$. Show that this equation is valid for any periodic AC waveform under ideal conditions.

$$V^2_{\text{true-rms}} = V^2_{DC} + V^2_{ACrms}$$

Hint: DC (average) value of $\boldsymbol{v_{AC}(t)}$ is zero by definition, and this implies

$$\frac{1}{T}\int_{t=0}^{T} v_{AC}(t)\,dt = 0$$

If think about a sine signal v(t)=a1sin(wt) ,under ideal conditions we have no off-set, then Vtrue-rms becomes as:

$$V_{rms} = \sqrt{\frac{1}{T_{prd}}\int_{t=0}^{T_{prd}} v^2(t)dt} = \sqrt{\frac{1}{T}\int_0^T a_1\sin(wt)\,dt} = \frac{a_1}{\sqrt{2}}$$

and if we have off-set so it is DC signal,V(t)=a0 +a1sin(wt), then,

$$V_{true-rms} = \frac{1}{T_{prd}}\int_{t=0}^{T_{prd}} v^2(t)dt = \frac{1}{T}\int_{t=0}^{T} (a_0 + a_1\sin(wt))^2 dt$$

$$V^2_{true-rms} = V^2_{DC} + V^2_{AC-rms}$$

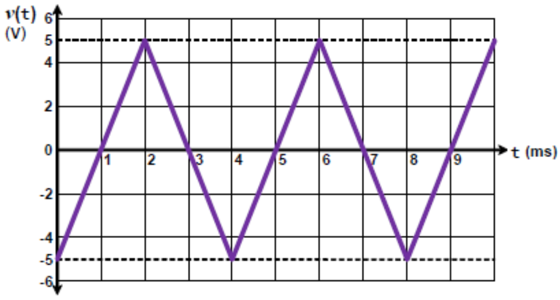
Q3. Describe a method to find the average power dissipated on a **1 kΩ** resistor by using a multimeter. The resistor cannot be disconnected to make measurements, and current through the resistor has both AC and DC components.

The method for finding the average dissipated power on a 1kΩ resistor is to write the power in terms of square of voltage divided by resistance. Since the current has both AC and DC compotents, so it can be found via the true rms equation.

$$V^2_{true-rms} = V^2_{DC} + V^2_{ACrms}$$

$$p(t) = \frac{V^2_{true-rms}(t)}{R}\ , \qquad P_{avg} = \int_0^T p(t)dt$$

Q4.a) Calculate power dissipated on a **100 Ω** resistor as a function of time when the voltage across the resistor is a triangular function as shown below.



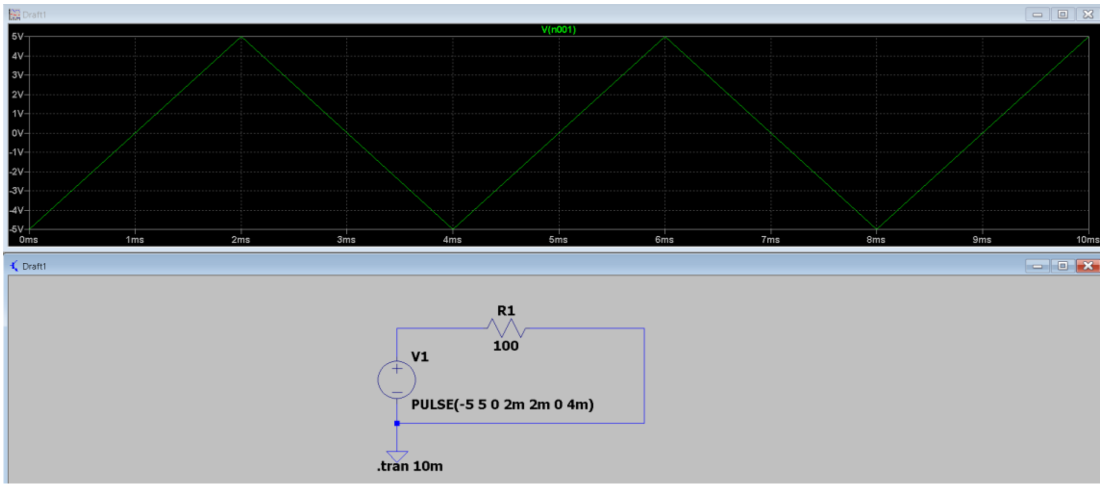
According to simulation we can say:

$$v(\mathrm{t}) = \begin{cases} 5t - 5\,, & 0 \le t \le 2 \\ -10t + 25\,, & 2 \le t \le 4 \end{cases}$$, and we know that $P(t)=V^2(t)/R$ so that, so

$$v^2(\mathrm{t}) = \begin{cases} 25t^2 - 50t + 25\,, & 0 \le t \le 2 \\ 100t^2 - 500t + 625\,, & 2 \le t \le 4 \end{cases}$$ and then, we should divided by resistor.

$$p(\mathrm{t}) = \frac{v^2(\mathrm{t})}{\mathrm{R}} = \begin{cases} 0.25t^2 - 0.5t + 0.25\,, & 0 \le t \le 2 \\ t^2 - 5t + 6.25\,, & 2 \le t \le 4 \end{cases}$$

Q4.b) Verify your calculation by simulating a simple circuit on LTspice. Select the **PULSE** option for the voltage source and enter **Trise**, **Tfall**, **Period**, and other parameters to obtain the triangular output.



We can see our function of time with voltage is true in previous step.

Q4.c) Calculate average power dissipated on the resistor. It is sufficient to calculate the average power for **1/4** of the period because of symmetry in the voltage waveform.
By using average power dissipated on the resistor formula

$$P_{avg} = \frac{1}{T_{prd}} \int_{t=0}^{T_{prd}} p(t)dt$$ It is necessary to use 1⁄4 of the period, that is 1ms due to symmetry in the voltage waveform.

$$P_{avg} = \frac{1}{1} \int_{t=0}^{1} 0.25t^2 - 0.5t + 0.25\,dt = 0.083\ W$$ and then we should multiply this result by 4 to find the Pavg. So P_{avg}=0.083*4=0.332W

Conclusion

In this experiment, in preliminary work, we calculate power dissipated on resistor and we showed that as a function of time then, we verify that using simulation. We set a circuit using 100Ω resistor and sine voltage source with 1kHz frequency and 5 V amplitude then we measured power dissipated on resistor. Then we setted another circuit using same voltage source, 1k Ωresistor and 0.1u capacitor. Then we evaluated power dissipated on capacitor. Then we calculated DC and RMS voltage of a pulse waveform for different dutycycle and different V_{high} and V_{low} values. In first part we built two circuit using 100 Ω resistor and of them with sine voltage source with 500 Hz frequency and 10 Vp-p amplitude and another one pulse voltage wave with 500 Hz Frequency with 10 Vp-p amplitude, 0 DC offset. Then we measured their DC voltage and RMS voltage. After that we give 5V DC offset both of them and we repeated same calculations. In second part we use same pulse voltage source circuit we changed 100Hz frequency with 20%duty cycle and we measured DC,RMS voltage and average power values for different Vin and Von(0V and10V, -5V and +5V,-10V and 0V). Then we compared them with our calculated values in preliminary work. Then we change our voltage source to obtain 80% duty cycle and we repeated DC voltage, RMS voltage and average power measurements. In third part, we built a circuit using same voltage source and we measured peak to peak and rms voltages for different resistors. We observed for fewer resistance our measured values more wrong because internal resistance is more effective.

To sum up in this experiment, we learnt how to calculate and measure RMS voltage and DC voltage. We practiced power calculations and simulations with time-varying signals. We learnt significance of average and RMS amplitudes.