UM–SJTU Joint Institute

Physics Laboratory
(VE215)

Laboratory Report

Exercise 4
AC Lab

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1 Goal

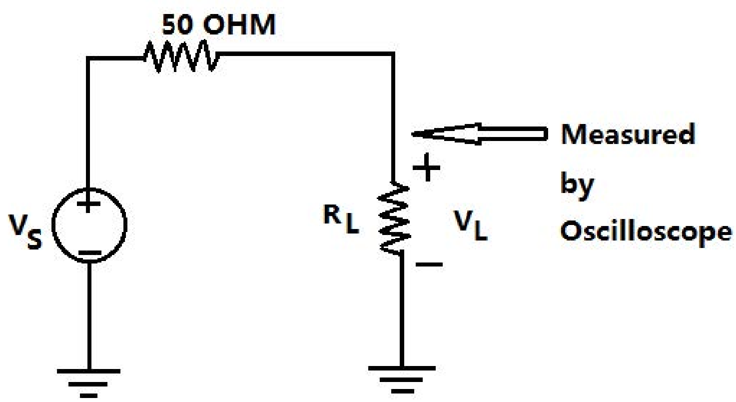
1. Learn how to define, calculate, and measure the amplitude of a sinusoidal signal
2. Learn how to define, calculate, and measure the Rise Time and Fall Time of a signal
3. Learn how to observe FFT spectra of signal and measure their parameters with cursors
4. Measure the waveforms and FFT spectra of various signals
5. Compare your theoretical results obtained in the Pre-Lab with your In-Lab data.

2 Introduction

2.1 High-Z mode

Here I want to introduce you what is the High-Z mode we have kept emphasizing during the previous Labs.

You have already learnt Thevenin equivalent of a circuit. You can think the function generator in terms of its Thevenin equivalent circuit, which includes the voltage source and V_S and the equivalent resistance of 50 Ω as shown below.

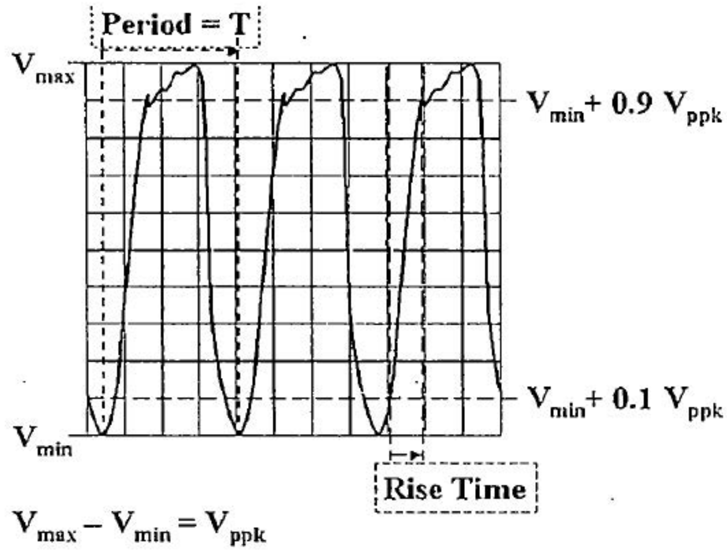


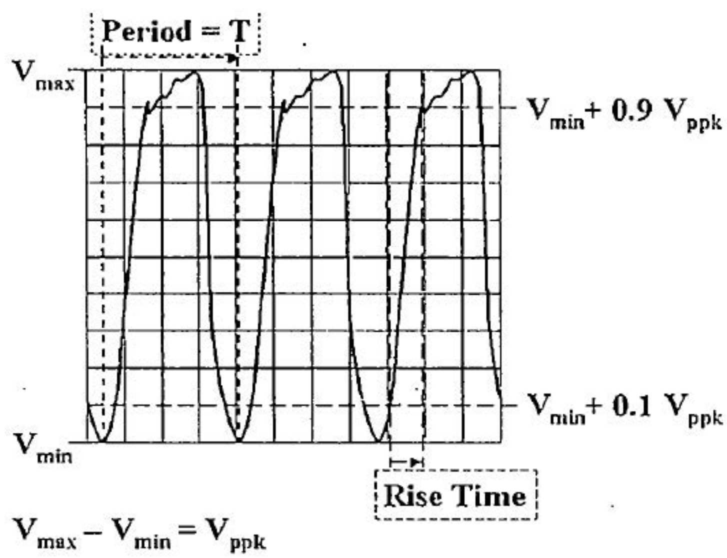
When the load R_L is 50 Ω , according to voltage division, we know that the VL measured will be $0.5V_S$. In this case, we use the 50 OHM mode, in which the function generator produces voltage V_S but displays voltage $0.5V_S$. In that way, if you set $2V_{ppk}$ for the function generator, the actual V_S will be $4V_{ppk}$ to make sure the load get a voltage of $2V_{ppk}$.

In our lab measurements, the load resistance R_L is very highthe input resistance of the oscilloscope is about 1 $M\Omega$. The V_L measured across R_L practically equals V_S. So we use High Z mode, in which the function generator produce voltage V_S and displays V_S.

2.2 The Rise Time and Fall Time of signals

The Rise time is the interval between the moment of the time when the signal reaches its 10% level and the moment of time when the signal reaches its 90%. We have already used this concept in our Lab3.





The above two figures illustrate the rise time of a sinusoidal like wave and a saw-tooth wave. If you do not know what is V_{ppk}, you can refer to part 4 of this section.

Take the sinusoid wave as an example to calculate the rise time.

$$y = \frac{V_{ppk}}{2}\sin(2\pi ft)$$

$$V_{min} = \frac{-V_{ppk}}{2}, V_{max} = \frac{V_{ppk}}{2}$$

$$Rise\ Time = \frac{\arcsin\left(\frac{V_{min}+0.9V_{ppk}}{0.5V_{ppk}}\right) - \arcsin\left(\frac{V_{min}+0.1V_{ppk}}{0.5V_{ppk}}\right)}{2\pi f}$$

2.3 Fourier Series Representation of a Signal

Here I am going to give you a general idea of Fourier Series to help you understand some parts of this lab. You will learn Fourier Series in details in your math course this semester.

Fourier series is a way to represent a wave-like function as a combination of simply sine waves. It decomposed and period function into the sum of a (possibly infinite) set of simple oscillation functions.

Let $x(t)$ be a periodic signal with fundamental period T_0. It can be represent by the following synthesis equation,

$$x(t) = \sum_{k=-\infty}^{\infty} c_k e^{jk\omega_0 t}, \text{where} \omega_0 = \frac{2\pi}{T_0}$$

The coefficients c_k in the above equation can be calculated by the analysis equation,

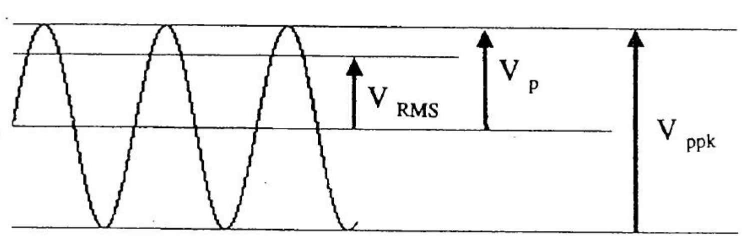
$$C_k = \frac{1}{T_0}\int_0^{T_0} x(t)e^{-jk\omega_0 t}dt, k = 0, \pm 1, ...$$

2.4 Four ways to measure the amplitude of a sinusoid

a) $\mathrm{V_{peak}} = \mathrm{V_p} = \mathrm{V_{pk}} = \mathrm{V_0}$ is the peak amplitude of the sinusoid measured in V or mV.

b) $\mathrm{V_{peak-to-peak}} = \mathrm{V_{ppk}} = \mathrm{V_{max}} - \mathrm{V_{min}} = 2\mathrm{V_0}$ is the value we often use in the lab to determine the overall size of the waveform. We have used it many times in the previous Labs.

c) $\mathrm{V_{RMS}}$ is the Root-Mean-Square, or RMS amplitude of the sinusoid. The sinusoidal voltage $V = V_0 \sin(\omega t + \theta)$ dissipates as much power in the load resistor as does the DC voltage equals to V_{RMS}



For any periodic function f(t) that has period T, the RMS amplitude is defined as

$$Amplitude, RMS = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} f^2(t)dt}$$

In the case of sinusoid $f(t) = V_0 \sin(\omega t + \theta)$,

$$V_{RMS} = \frac{V_0}{\sqrt{2}} = \frac{V_{peak}}{\sqrt{2}} = \frac{V_{ppk}}{2\sqrt{2}}$$

d) The above three ways all study the signal in time domain, plotted as voltage vs. time. In this Lab, we also need to study the frequency domain, when you measure their spectra displayed as amplitude vs. frequency. In frequency domain, the oscilloscope measures the amplitude of on a logarithmic scale, using decibels.

$$Amplitude\ in\ decibels(dBv) = 20\log\left(\frac{Amplitude\ in\ V_{RMS}}{1V_{RMS}}\right)$$

Decibels are used to calculate ratios of two amplitudes on a logarithmic scale.

$$Ratio, in\ decibels(dB) = 20\log\left(\frac{Amplitude\ of\ signal\ \sharp 2, RMS}{Amplitude\ of\ signal\ \sharp 1, RMS}\right)$$

3 In-Lab Procedure

3.0.1 Part 1

1. On the function generator, set a sine wave at 1 [kHz] and keep its amplitude at 3 [Vpp]. The load must be High-Z mode.
2. Record the parameters on the datasheet. Fill the table with the data set on the function generator and displayed on the oscilloscope.
3. Repeat the Step 2 with a sine wave at 1.5 [kHz] and 5 [Vpp] on the function generator. The load should remain High-Z mode.
4. In post-report, calculate the rise time in theory and compare it with the values displayed on the oscilloscope.

3.0.2 Part 2

1. First, we set a sine wave and a square wave, respectively. The frequency is 1 [kHz] and the amplitude is 3 [Vpp].
2. On the oscilloscope, set 1 [V/div] and 5 [ms/div].
3. Push the MATH button and select FFT function.
4. Push the cursor button and select trace mode to trace the spectrum.

5. When the cursor reach a peak of the spectrum, record the Frequency in [kHz] and the Amplitude in [dBV].
6. Set another sine wave and a square wave. The frequency is 2 [kHz] and the amplitude is 6 [Vpp]. Repeat the steps above.
7. In post-report, you need to calculate the theoretical amplitude of sine wave in [dBV]. Besides, you need to calculate the Vpeak of each square wave measured in Part II. You should give a brief conclusion on what you learn from this lab.

4 Results and Discussion

4.1 Part 1

	Set on Function Generator	Measured with Oscilloscope
Amplitude in Vpp [V]	3.00	3.10
Frequency [kHz]	1.000	0.999
Rise Time [μs]	295.2	292
Amplitude in Vpp [V]	5.00	5.16
Frequency [kHz]	1.500	1.499
Rise Time [μs]	196.8	199

Table 1: Rise Time Measurement.

For the 3V Vpp,

$$t = 292\,\mu\text{s}$$

Theoretically,

$$t = \frac{\arcsin\left(\frac{V_{min}+0.9V_{ppk}}{0.5V_{ppk}}\right) - \arcsin\left(\frac{V_{min}+0.1V_{ppk}}{0.5V_{ppk}}\right)}{2\pi f} = 295.2\,\mu\text{s}$$

The relative error is 1.1%

For the 5V Vpp,

$$t = 199\,\mu\text{s}$$

Theoretically,

$$t = \frac{\arcsin\left(\frac{V_{min}+0.9V_{ppk}}{0.5V_{ppk}}\right) - \arcsin\left(\frac{V_{min}+0.1V_{ppk}}{0.5V_{ppk}}\right)}{2\pi f} = 196.8\,\mu\text{s}$$

The relative error is 1.1%

We can find that relative error is very small.

4.2 Part 2

4.2.1 Set the wave at 3 [Vpp] 1 [kHz]

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	1.000	0.16

Table 2: FFT spectrum for Sine wave.

$$A_{dBV} = 0.16$$

Theoretically,

$$A_{dBV} = 20 \log \left(\frac{A_{RMS}}{1 V_{RMS}} \right) = 0.51$$

The relative error is 218.8%

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	1.000	1.76
$3f_0$	3.000	-5.28
$5f_0$	5.000	-8.16
$7f_0$	6.996	-10.4
$9f_0$	9.008	-10.4

Table 3: FFT spectrum for Square wave.

4.2.2 Set the wave at 6 [Vpp] 2 [kHz]

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	5.000	5.60

Table 4: FFT spectrum for Sine wave.

$$A_{dBV} = 5.6$$

Theoretically,

$$A_{dBV} = 20 \log \left(\frac{A_{RMS}}{1 V_{RMS}} \right) = 6.53$$

The relative error is 16.6%

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	2.000	1.76
$3f_0$	6.020	-1.20
$5f_0$	10.020	-5.20
$7f_0$	14.000	-6.00
$9f_0$	18.000	-8.40

Table 5: FFT spectrum for Square wave.

5 Conclusion

In the lab, we learn how to define, calculate, and measure the amplitude of a sinusoidal signal. We learn how to define, calculate, and measure the Rise Time and Fall Time of a signal. We learn how to observe FFT spectra of signal and measure their parameters with cursors. We measure the waveforms and FFT spectra of various signals

We compare the theoretical results obtained in the Pre-Lab with the In-Lab data.

6 Reference

Lab 4 Manual.

7 Pre-lab and Data sheet