UM-SJTU Joint Institute

Physics Laboratory

(VE215)

Laboratory Report

Exercise 4

AC LAB

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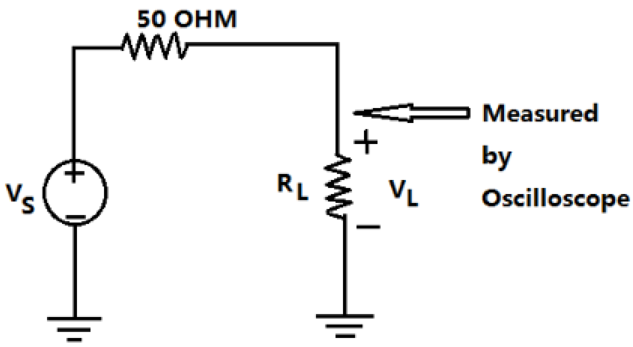

Figure 1: Function generator

I 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.

II Introduction

A High-Z mode

We have already learnt Thevenin equivalent of a circuit. The function generator can be seen 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 V_L 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 we 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 high–the 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.

B 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%.

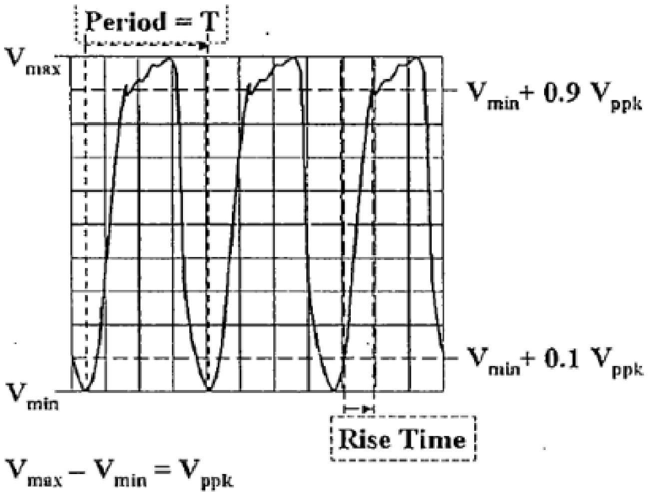

Figure 2: Rise time of sinusoidal like wave

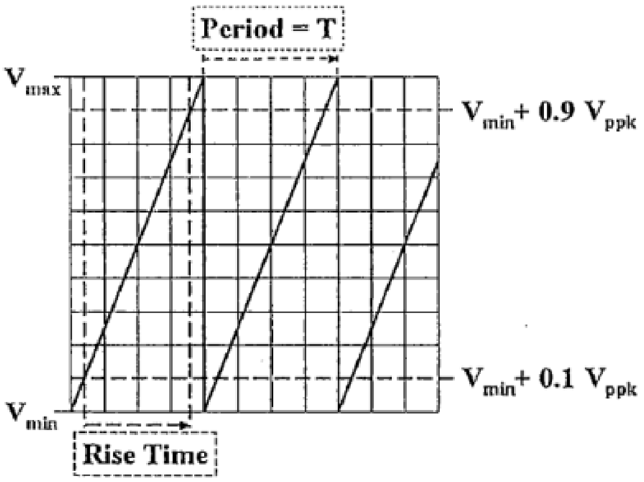

Figure 3: Rise time of a saw-tooth wave

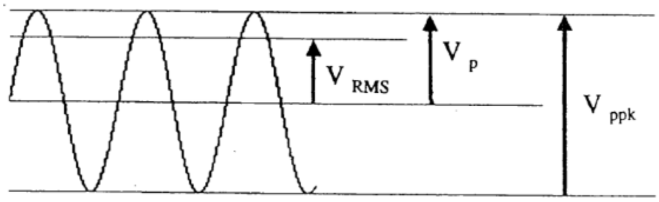

Figure 4: Different voltages

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

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

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

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

C Fourier Series Representation of a Signal

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,

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

D Four ways to measure the amplitude of a sinusoid

1. $\mathrm{V_{peak}} = \mathrm{V_p} = \mathrm{V_{pk}} = \mathrm{V_0}$ is the peak amplitude of the sinusoid measured in V or mV.
2. $\mathrm{V_{peak-to-peak}} = \mathrm{V_{ppk}} = \mathrm{V_{max}} - \mathrm{V_{min}} = 2\mathrm{V_0}$ 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.
3. $\mathrm{V_{RMS}}$ 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 $f(t) = V_0 \sin(\omega t + \theta)$,

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

4. 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.

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

III In-Lab Procedure

.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.

.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.

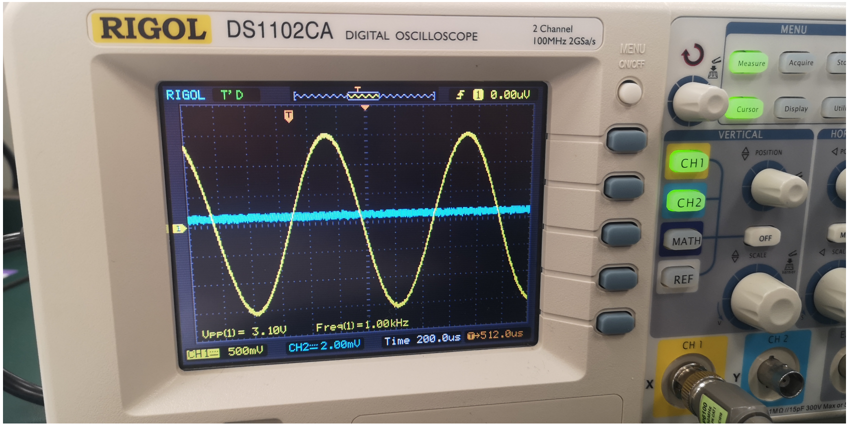

Figure 5: Part 1

IV Results and Discussion

A Part 1

	Set on Function Generator	Measured with Oscilloscope
Amplitude in Vpp [V]	3.00	3.10
Frequency [kHz]	1.000	1.00
Rise Time [μs]	295.2	300
Amplitude in Vpp [V]	5.00	5.12
Frequency [kHz]	1.500	1.50
Rise Time [μs]	196.8	200

Table 1: Rise Time Measurement.

The graph of the experiment is shown in the Figure 5.

For the 3V Vpp, the experimental rise time is

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

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 1.6%

For the 5V Vpp, the experimental rise time is

$$t = 200\,\mu\text{s}$$

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 1.6%

We can find that relative error is small enough to prove that the experiment is correct.

B Part 2

B.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.

According to the experiment, the amplitude is

$$A_{dBV} = 0.16$$

Theoretically,

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

The relative error is 218.75%

Change the signal from sine wave to square wave and we get

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	1.000	1.60
$3f_0$	3.000	-4.80
$5f_0$	5.000	-11.20
$7f_0$	6.996	-11.20
$9f_0$	9.008	-14.4

Table 3: FFT spectrum for Square wave.

The graph of this experiment is shown in the Figure 6.

B.2 Set the wave at 6 [Vpp] 2 [kHz]

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	2.000	8.00

Table 4: FFT spectrum for Sine wave.

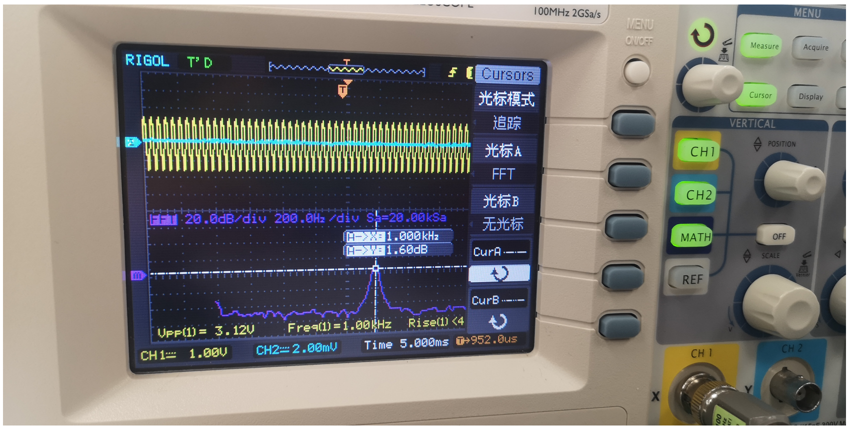

Figure 6: Part 2

According to the experiment, the amplitude is

$$A_{dBV} = 8.00$$

Theoretically,

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

The relative error is 22.5%

Change the signal from sine wave to square wave and we obtain

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	2.000	8.00
$3f_0$	6.000	1.60
$5f_0$	10.000	
$7f_0$	15.000	
$9f_0$	20.000	

Table 5: FFT spectrum for Square wave.

We found that the graph on the oscilloscope disappeared after the frequency 8KHz.

V Conclusion

In the lab, we learn how to define, calculate, and measure the amplitude of a sinusoidal signal. We also 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.

What's more, We measure the waveforms and FFT spectra of various signals. We compare the theoretical results obtained in the Pre-Lab with the data we get from the experiment.

VI Reference

Lab 4_ AC LAB.

VII Pre-lab and Data sheet