
UM-SJTU JOINT INSTITUTE
INTRO TO CIRCUITS
(VE215)

LABORATORY REPORT

LAB 4

AC LAB

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1 Introduction

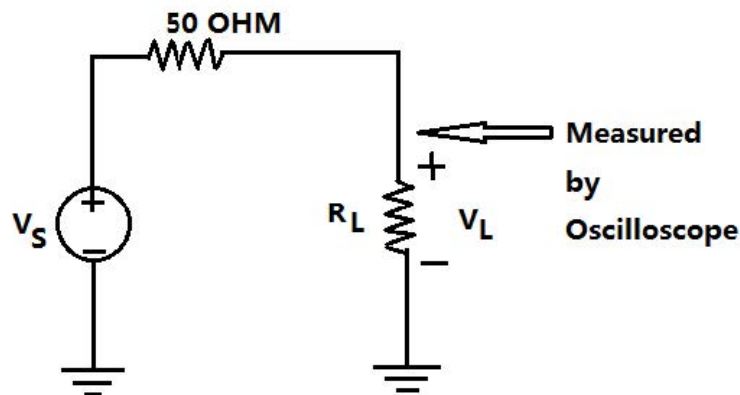
1.1 Objectives

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

We 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 $50\ \Omega$ as shown below.

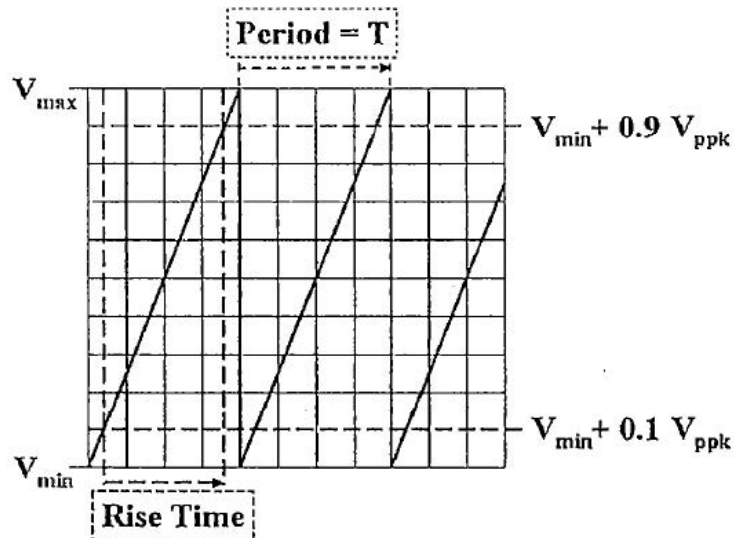
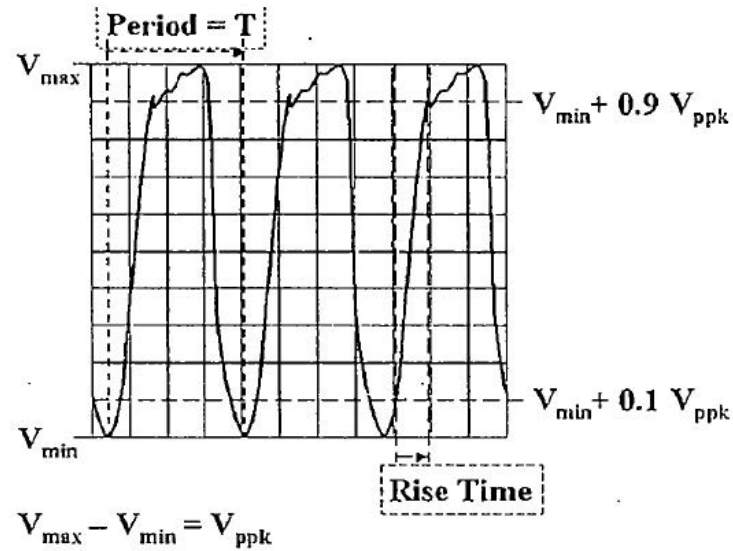


When the load R_L is $50\ \Omega$, according to voltage division, we know that the V_L measured will be $0.5V_S$. In this case, we use the 50 OHM mode, in which the function generator produces voltage V_S but displays voltage $0.5V_S$. In that way, if you set $2V_{\text{ppk}}$ for the function generator,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

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 .

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} , we can refer to part 4 of this section.

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

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

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

$$\text{Rise Time} = \frac{\sin^{-1}\left(\frac{V_{min}+0.9V_{ppk}}{0.5V_{ppk}}\right) - \arcsin^{-1}\left(\frac{V_{min}+0.1V_{ppk}}{0.5V_{ppk}}\right)}{2\pi f}$$

2.3 Fourier Series Representation of a Signal

We will learn Fourier Series in details in our 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,

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

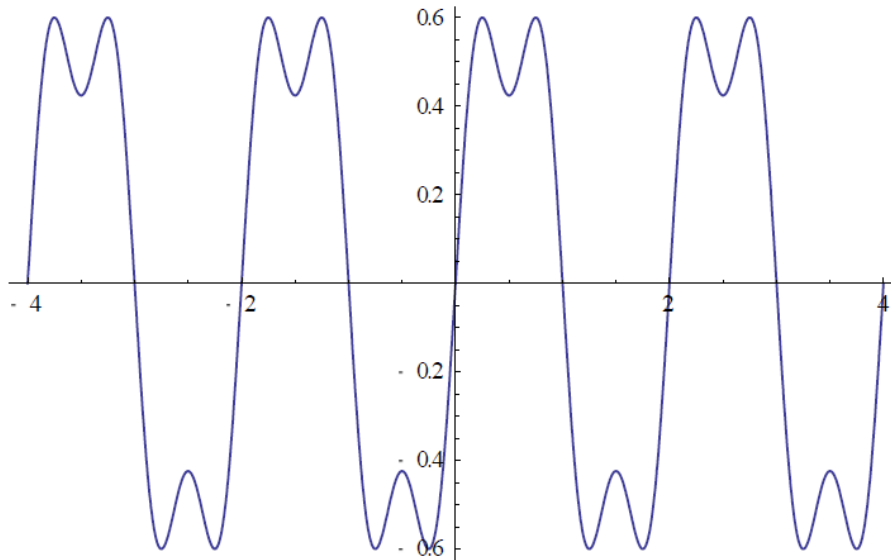
The coefficients c_k in the above equation can be calculated by the analysis equation,

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

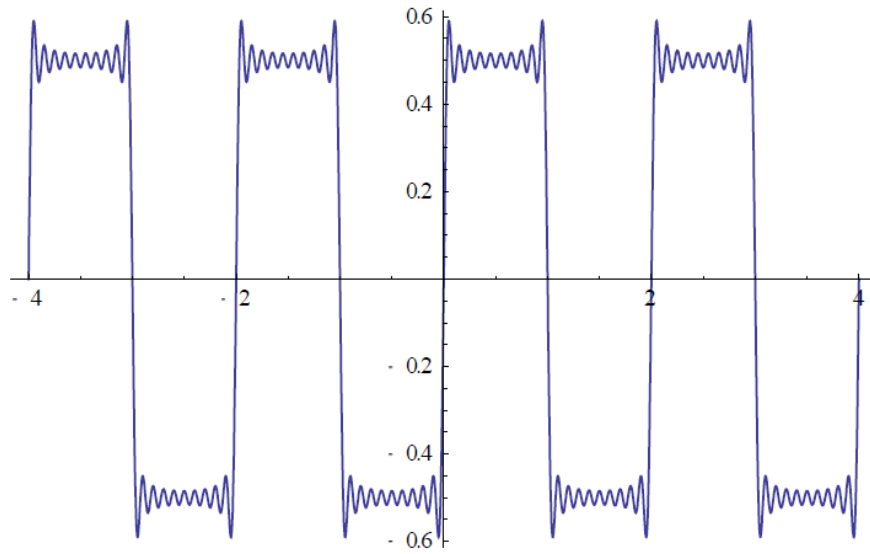
Plot[Sum[(-1)^(((k+1))/2) * 2/((k * Pi)) Cos[k * Pi * (t+0.5)], k, 1,100,2], t, -4,4]

We can use the above Mathematica code to get the feeling of how a series of sinusoidal waves can form a square wave (actually, any waveform). We can change the value in the red box, and the larger the value is, the more accurate the result will be.

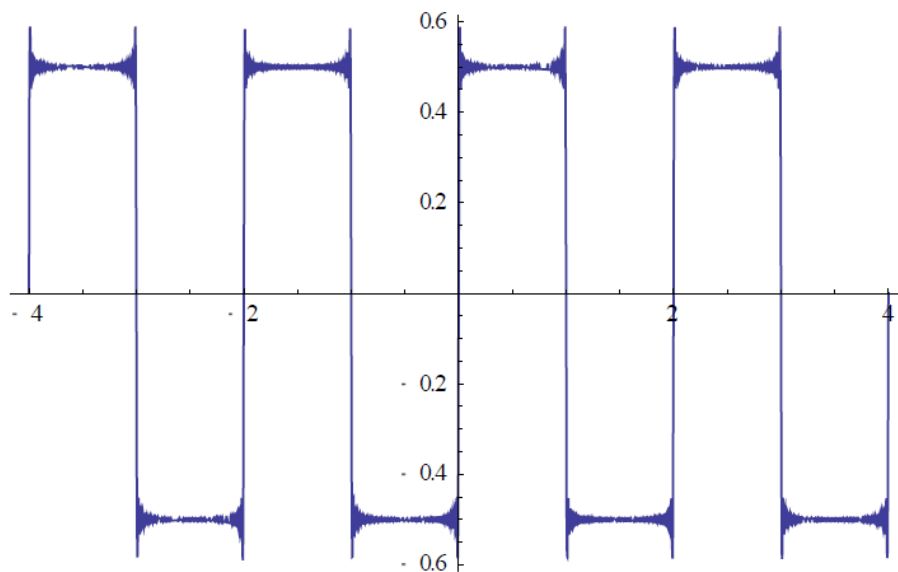
For value 3, we can get the following result.



For value 20, we can get the following result,

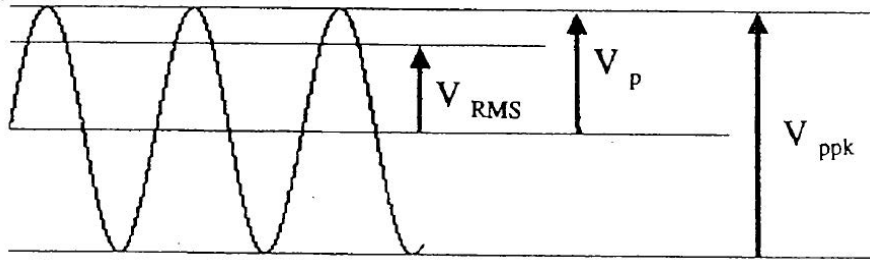


And for value 100, we get,



2.4 Four ways to measure the amplitude of a sinusoid

- a) $V_{\text{peak}} = V_p = V_{\text{pk}} = V_0$ is the peak amplitude of the sinusoid measured in V or mV.
- b) $V_{\text{peak-to-peak}} = V_{\text{ppk}} = V_{\text{max}} - V_{\text{min}} = 2V_0$ 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) 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

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

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

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

- 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.

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

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

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

3 Measurement

Part I

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.
5. Reminder: $\text{RiseTime} = \frac{\sin^{-1}\left(\frac{V_{\text{min}}+0.9V_{\text{pp}}}{0.5V_{\text{pp}}}\right) - \sin^{-1}\left(\frac{V_{\text{min}}+0.1V_{\text{pp}}}{0.5V_{\text{pp}}}\right)}{2\pi f}$

Part II

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, we need to calculate the theoretical amplitude of sine wave in [dBV]. Besides, you need to calculate the V_{peak} of each square wave measured in Part II. We would give a brief conclusion on what we learn from this lab.
8. Reminder: for sine wave. $\text{dBV} = 20 \log\left(\frac{\text{Amplitude in } V_{\text{RMS}}}{1 V_{\text{RMS}}}\right)$
9. Reminder: for square wave. $V_{\text{peak}} = \sqrt{2} \cdot 10^{\frac{\text{Amplitude in [dBV]}}{20}}$

4 Results and Calculations

4.1 Part I

	Set on Function Generator	Measured with Oscilloscope
Amplitude in Vpp [V]	3.000	3.14
Frequency [kHz]	1.000000000	1.0018
Rise Time [μs]	295.2	294.7
Amplitude in Vpp [V]	5.000	5.11
Frequency [kHz]	1.500000000	1.4999
Rise Time [μs]	196.8	189.5

Table 1. Rise Time Measurement.

For Vpp of 3V amplitude in the experiment,

$$\text{RiseTime}_{\text{exp}} = 294.7 \mu\text{s}$$

Theoretically,

$$\text{RiseTime}_{\text{theo}} = \frac{\sin^{-1}\left(\frac{V_{\text{min}}+0.9V_{\text{pp}}}{0.5V_{\text{pp}}}\right) - \sin^{-1}\left(\frac{V_{\text{min}}+0.1V_{\text{pp}}}{0.5V_{\text{pp}}}\right)}{2\pi f} = 295.2 \mu\text{s}$$

The relative error is -0.17% .

For Vpp of 5V amplitude in the experiment,

$$\text{RiseTime}_{\text{exp}} = 189.5 \mu\text{s}$$

Theoretically,

$$\text{RiseTime}_{\text{theo}} = \frac{\sin^{-1}\left(\frac{V_{\text{min}}+0.9V_{\text{pp}}}{0.5V_{\text{pp}}}\right) - \sin^{-1}\left(\frac{V_{\text{min}}+0.1V_{\text{pp}}}{0.5V_{\text{pp}}}\right)}{2\pi f} = 196.8 \mu\text{s}$$

The relative error is -3.7%

We find that these relative errors are small enough.

4.2 Part 2

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

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	1.000000000	-0.250

Table 2. FFT spectrum for Square Wave.

$$A_{\text{dBV,exp}} = -0.25$$

Theoretically,

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

The relative error is -149.0%

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	1.000000000	1.85
$3f_0$	3.000000000	-7.70
$5f_0$	5.000000000	-12.12
$7f_0$	7.000000000	-15.07
$9f_0$	9.000000000	-17.22

Table 3

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

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	2.000000000	5.76

Table 4. FFT spectrum for Sine wave.

In our experiment,

$$A_{\text{dBV}} = 5.76$$

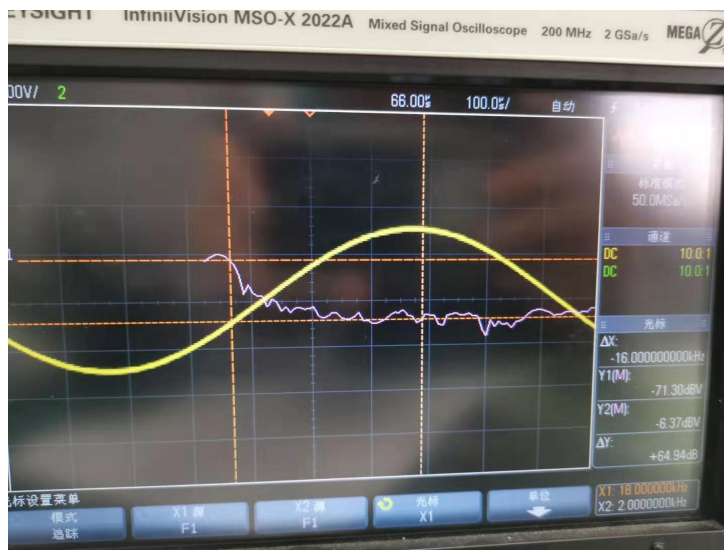
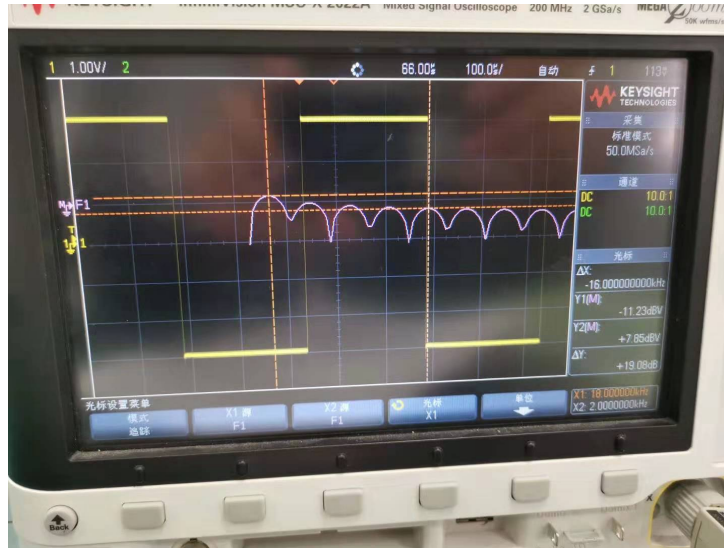
Theoretically,

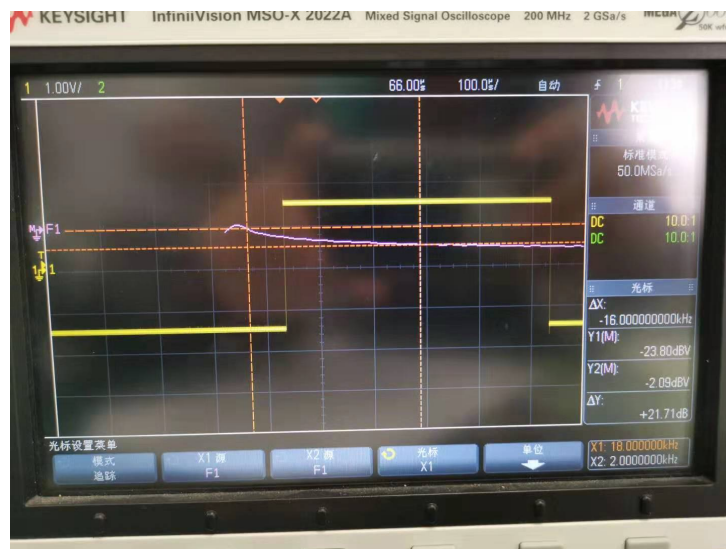
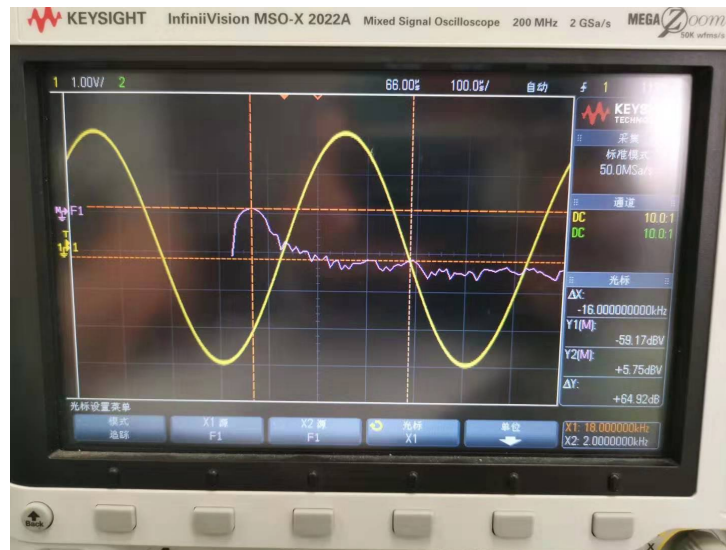
$$A_{dBV} = 20 \log \left(\frac{A_{RMS}}{1V_{RMS}} \right) = 6.53$$

The relative error is -11.8%

Peak	Frequency (measured) [kHz]	Amplitude (measured) [dBV]
f_0	2.000000000	7.85
$3f_0$	6.000000000	-1.71
$5f_0$	10.000000000	-6.13
$7f_0$	14.000000000	-9.09
$9f_0$	18.000000000	-11.22

Table 5. FFT spectrum for Square wave.





5 Conclusions and discussion

In the experiment, we learned how to define, calculate, and measure the amplitude, the Rise Time, and the Fall time of a sinusoidal signal. We learned how to observe FFT spectra of signal on the oscilloscope and measure their parameters by setting cursors. We observed and measured the waveforms and FFT spectra of various signals. From the results, we compared the theoretical results obtained in the Pre-Lab with the experimental In-Lab data.

For Part I, the relative errors are quite small, but in Part II, the relative errors are quite large. One of the reasons might be that the amplitudes were measured in [dBV] that is a logarithm, which will vary a lot near 0 in a small range. On the other hand, the machines are not stable, so that the same parameters would produce different measurements and calculation results.

Reference

Ve215 Fall 2016 Lab 4 AC Lab Manual.

Circuits make sense A new Lab Book for introductory Course In Electric Circuits. Fifth edition. Alexander Ganago.

Data sheet