ELEN4006A: Measurements Systems Laboratory Exercise 2

Madimetja Sethosa (1076467)

School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg 2050, South Africa

I. INTRODUCTION

The term bandwidth can be defined as a range of frequencies within a given band,and is one of the determinants of the capacity of a given communication channel. The system bandwidth is the range of frequencies over which the system produces a specified level of performance, or the frequencies beyond which Performance is degraded. For example, the bandwidth of a scope specifies the range of frequencies it can reliably measure. The specified rise time of a scope defines the fastest rising pulse it can measure. The rise time of a scope is very closely related to the bandwidth [1].

II. MAIN LABORATORY

A. Aspects of Bandwidth

***Pre-lab 1**:* The rise time is specified as the transition time for a signal to go from the 10% to the 90% level of the steady maximum value. However, bandwidth describes the range of frequencies over which the majority of the energy of a signal is contained. Specifically, it is defined as the frequency range over which the frequency response of a signal degrades by 3 dB. The wider the bandwidth of the measuring instrument, the faster is its response time. Both are related using the following equation :

$$Rise\ \ Time = \frac{0.35}{Bandwidth} \tag{1}$$

The relationships between the -3dB point and the measured signal are as follows:

- The -3dB point is the point at which frequency at which the output signal level is decreased to a value of -3 dB below the input signal level (0 dB). The -3 dB corresponds to a factor of $\sqrt{\frac{1}{2}} = \frac{1}{\sqrt{2}} = 0.7071$, which is 70.71% of the input signal.
- The frequency at which the output power level is decreased to a value of -3 dB below the input power level (0 dB). The -3 dB corresponds to a factor of $\frac{1}{2} = 0.5$, which is 50% of the input power (half the value) [1].

The overall relationship between the -3 dB and the measured signal can be depicted in Figure 1. If the measured signal has a frequency that is bellow the cut-off frequency (f_c), the measured signal will not be attenuated.

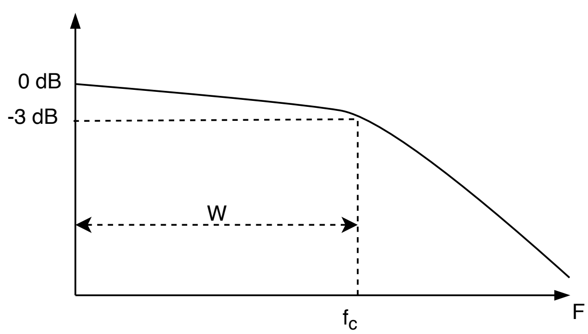

Fig. 1. Low pass filter.

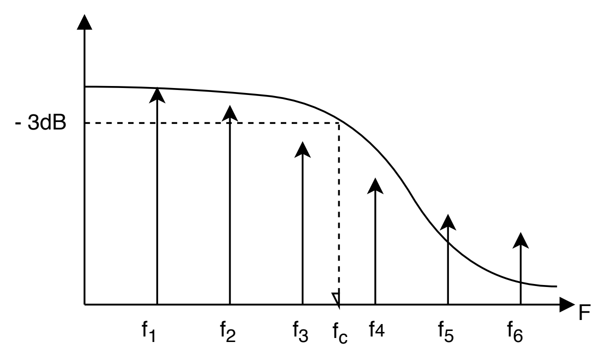

Fig. 2. Square wave frequency spectrum.

Main-Lab

The main lab is about exploring the aspects of bandwidth, this was achieved by using an oscilloscope and a signal generator. The oscilloscope had an internal filter set to 25 kHz and different signals were fed to the oscilloscope using the signal generator as indicated in Table I.

TABLE I
SETTINGS FOR OSCILLOSCOPE AND SIGNAL GENERATOR.

Oscilloscope setting	Signal Generator
Set filter to 25 kHz	5 kHz, 10 kHz, 25 kHz sine waves
Set filter to 25 kHz	0.5 Hz, 2 kHz, 10 kHz square waves

The signals measured using the oscilloscope can be observed in the Appendix, Figure 5 to 10. From the results, the following observations were made:

- As the frequency of the sine wave was increased, the signal began to attenuate and drop in strength. This is because the filter inside the oscilloscope is not a perfect filter and therefore the signal gets slowly attenuated as its frequency moves towards the cut-off frequency.

- The square wave at 0.5 Hz looks like a perfect square wave because most of its high frequency components are below the cut-off frequency as depicted in Figure 2.
- The square wave at 10 kHz is looking almost like the sine wave due to almost all of its high frequency components being attenuated since the its fundamental frequency is close to the cut-off frequency. The size of the signal increased as compared to the sine wave at 10 kHz which is still in prefect condition, this is because, as the high frequency components get attenuated, the sine wave with the fundamental frequency unfolds, hence the amplitude.

Lastly, one of the observation made was that, given that the bandwidth of a measurement system (oscilloscope) is not known, it's bandwidth can easily be determined by making use of a signal generator and Equation 2.

$$signal(dB) = 20\log_{10}\left(\frac{V_{Measured}}{V_{Actual}}\right) \tag{2}$$

Firstly a sine wave with a known amplitude is to be fed to the oscilloscope, the frequency of the sine wave is to be increased until the measured signal has an amplitude which is approximately $70.1\ \%$ of the original signal. At that frequency the signal's power should have dropped to about $50\ \%$ which corresponds to the $-3\ dB$ point which can be calculated using Equation 2 to be sure. This frequency is called the cut-off frequency which the same as the bandwidth for a low-pass filter for the oscilloscope.

B. The use of the measurement tool

Pre-lab 2 : Given the circuit in Figure 3(i), with 20V as the dc source and $R_1 = R_2 = 10\ M\Omega$ and the output to the load is across a and b.

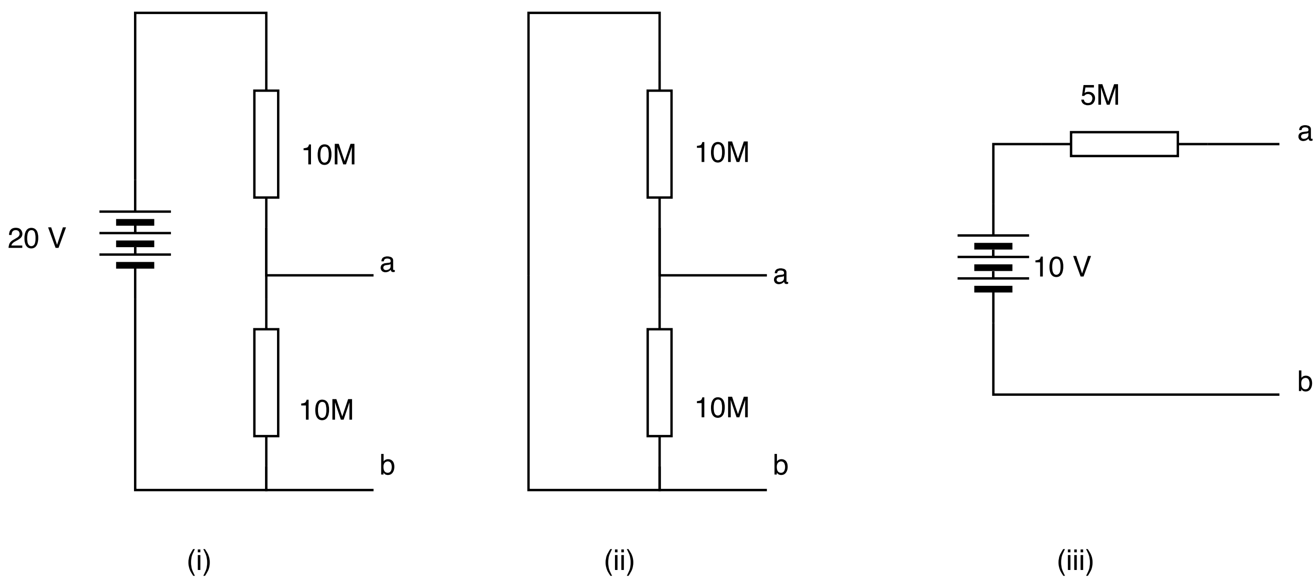

Fig. 3. (i) Original circuit, (ii) The equivalent resistance, and (iii) The equivalent circuit.

The Thevinin equivalent circuit is presented in Figure 3(iii), and the Thevinin resistance and Thevinin voltage values are calculated as follows:

$$R_{TH} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{10\ M\Omega \times 10\ M\Omega}{10\ M\Omega + 10\ M\Omega} = 5\ M\Omega \tag{3}$$

$$V_{TH} = V_s \times \frac{R_2}{R_1 + R_2} = 20\ V \times \frac{10\ M\Omega}{10\ M\Omega + 10M\ \Omega} = 10\ V \tag{4}$$

Main Lab

The resistors used in the lab where measured before they were used and they are indicated bellow as R_1 and R_2, and the supply voltage as V_s. The voltage across a-b (R_2) was measured to be V_{TH}, a-b was then short-circuited to measure I_{SC}. The measurements are as follows:

$$R_1 = 10.06\ M\Omega$$
$$R_2 = 10.12\ M\Omega$$
$$V_s = 20.06\ V$$

$$V_{TH} = 6.72\ V\ \ (Multimeter)$$
$$V_{TH} = 1.60\ V\ \ (Oscilloscope)$$
$$I_{SC} = 0.65\ mA$$

The R_{TH} was calculated using the two different V_{TH} as indicated in Equations 5 and 6.

$$R_{TH} = \frac{V_{TH}}{I_{SC}} = \frac{6.72\ V}{0.65\ mA} = 10.338\ M\Omega\ \ (Multimeter) \tag{5}$$

$$R_{TH} = \frac{V_{TH}}{I_{SC}} = \frac{1.60\ V}{0.65\ mA} = 2.46\ M\Omega\ \ (Oscilloscope) \tag{6}$$

When measuring the voltage drop across a-b (R_2), the voltmeter was placed in parallel across R_2. Ideally, the insertion of the voltmeter would not affect the operation of the circuit in Figure 3 (i), and the voltage reading obtained by the voltmeter would be the true value of V_{TH} as in Equation 4. However, in general, any instrument used to make physical measurements extracts energy from the system in question while making measurements. The effect of this extraction of energy is to change the quantity being measured. This effect is known as the loading effect of a meter, which indicates the limitations of the capabilities of the meter. The effects are already clear from the measurements obtained using the multi-meter and the oscilloscope [2].

By modeling the measuring device as a resistor the effects can be noticed (see Figure 4), where the resistance of the measuring device is denoted by R_m. By using the voltage divider rule, and with the measuring device in the circuit, the voltage V_{TH} is given by :

$$V_{TH} = \frac{R_2||R_m}{R_1 + R_2||R_m} \times V_s \tag{7}$$

Since all the quantities are known except for R_m, Equation 7 can be re-arranged to determine resistance of the measuring device.

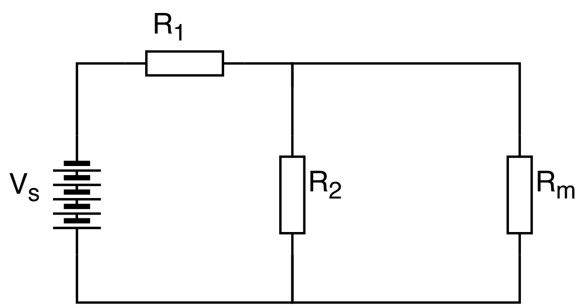

Fig. 4. Circuit with Measuring device modeled as a resistor.

When comparing Equation 4 and 7, it can be seen that the measuring device will introduce a small measurement error when its resistance (R_m) is large relative to R_2. As R_m approaches infinity, $R_2||R_m$ will approach R_2, which means Equation 4 and 7 will become equal (i.e., no measurement error will be introduced). However, if R_m approaches the same order of magnitude as R_2, the error can become significant. Thus, in order to minimizes the measurement error, R_m must be as large as possible.

The resistance of the multi-meter and the oscilloscope were calculated to be approximately $10.24\ M\Omega$ and $0.958\ M\Omega$ respectively. It is clear that the resistance of both the multi-meter and the oscilloscope are not large enough as compared to the resistance of R_2, as a results the answer for actual Thevenin voltage (V_{TH}) and resistance (R_{TH}) deviate from the ideal values. The error introduce are as follows:

$$error\% = \frac{V_{TH_Actual} - V_{TH_Ideal}}{V_{TH_Ideal}} \times 100\% = \frac{6.72\ V - 10\ V}{10\ V} \times 100\% = -32.8\%\ \ (Multimeter) \tag{8}$$

$$error\% = \frac{V_{TH_Actual} - V_{TH_Ideal}}{V_{TH_Ideal}} \times 100\% = \frac{1.60\ V - 10\ V}{10\ V} \times 100\% = -84.0\%\ \ (Oscilloscope) \tag{9}$$

The Multimeter has a less error compare to the oscilloscope, but they both have unacceptable errors. for them to give proper results, the measured resistor must be at least 100 times smaller that the measuring device's internal resistance.

III. Conclusion

The rise time of a measuring device is related to is bandwidth, the faster the rise time, the bigger the bandwidth. The bandwidth for a system indicates the range of frequencies which the system operates, it helps with determining the bandwidth needed for measuring the system. The bandwidth of a measuring device is important since it indicates the capabilities of the measuring device. The concept of bandwidth also applies to other measuring devices like a multi meter. however, the multi meters are not clearly marked when it comes to the measuring a voltage across a resistor in a circuit.

References

[1] R. Keim, "What Is Bandwidth?," All About Circuits, 26-Nov-2018. [Online]. Available: https://www.allaboutcircuits.com/technical-articles/what-is-bandwidth/. [Accessed: 09-Apr-2019].

[2] "LATEST," All About Circuits. [Online]. Available: https://www.allaboutcircuits.com/textbook/direct-current/chpt-8/voltmeter-impact-measured-circuit/. [Accessed: 08-Apr-2019].

APPENDIX

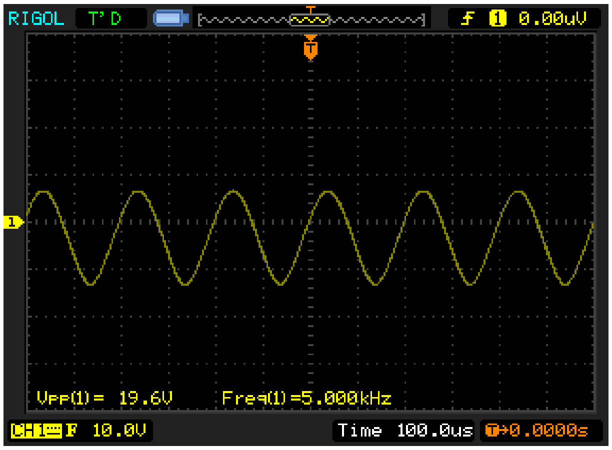

Fig. 5. Oscilloscope capture of a Sine wave at 5 kHz.

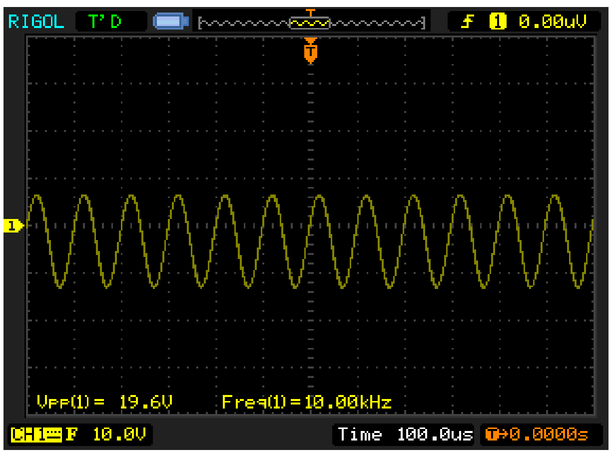

Fig. 6. Oscilloscope capture of a Sine wave at 10 kHz.

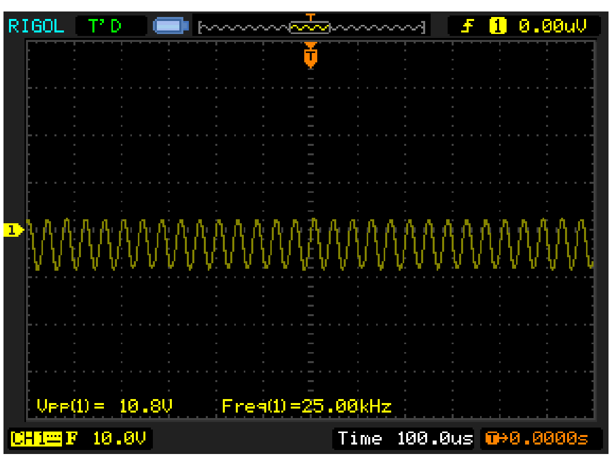

Fig. 7. Oscilloscope capture of a Sine wave at 25 kHz.

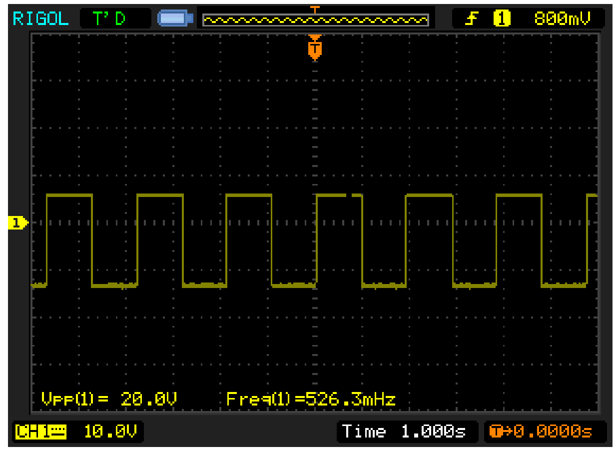

Fig. 8. Oscilloscope capture of a square wave at 0.5 Hz.

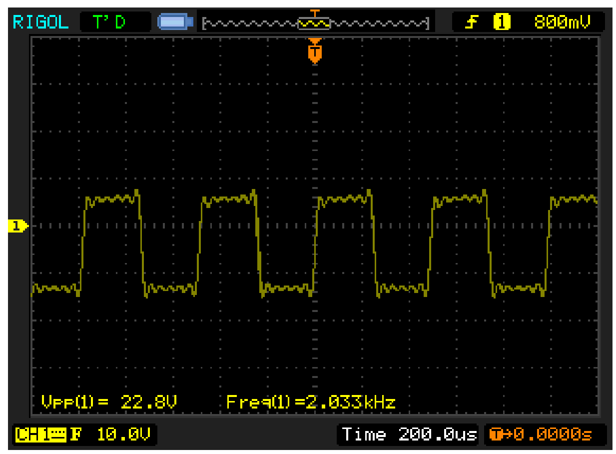

Fig. 9. Oscilloscope capture of a square wave at 2 kHz.

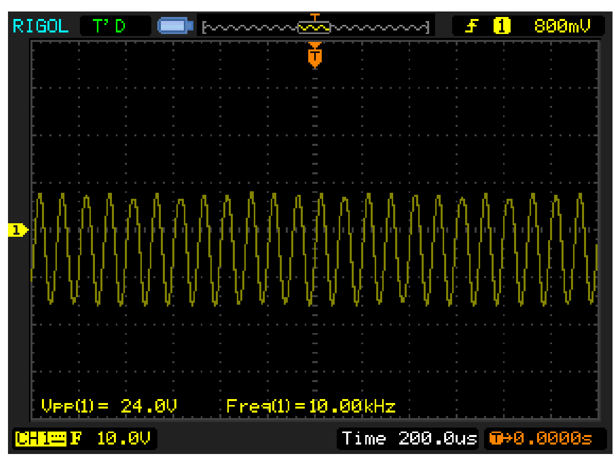

Fig. 10. Oscilloscope capture of a square wave at 10 kHz.