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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TECHNOLOGY SYSTEM OPTIMIZATION I

BERL 2222	SEMESTER 2	SESI 2024/2025

ASSIGNMENT: LOW PASS FILTER

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PROGRAMME	2 BERL
SECTION / GROUP	S11
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EXAMINER'S COMMENT(S)	TOTAL MARKS

1.0 INTRODUCTION

1.1 Overview of Filters in Electronic Systems

Filters are essential components in electronic systems that are used to control and manipulate signal frequencies. In general, filters allow certain frequency ranges to pass through while attenuating others. There are four basic types of filters: low-pass, high-pass, band-pass, and band-stop, each serving different functions based on the desired frequency response.

Among these, **low-pass filters (LPFs)** are commonly used to allow low-frequency signals to pass through while attenuating high-frequency noise or interference. They are widely applied in audio processing, communication systems, sensor signal conditioning, and power supplies.

Filters can be implemented using passive components (resistors, capacitors, and inductors) or active components (operational amplifiers in addition to passive components). Active filters offer advantages such as gain, better input/output impedance matching, and more precise control over frequency characteristics.

1.2 Purpose of the Assignment

The purpose of this assignment is to design, simulate, and analyze an **active low-pass filter** with a **cut-off frequency of 2 kHz**. This involves selecting appropriate component values, building the circuit using an operational amplifier, performing frequency response analysis, and identifying real-world applications where such a filter is applicable. The assignment aims to enhance understanding of active filter design principles and their practical applications in signal processing systems.

2.0 FILTER DESCRIPTION

2.1 Type of Active Filter Used

In this project, an **active first-order low-pass filter** is designed using a **non-inverting operational amplifier (op-amp) configuration**. The filter consists of a resistor-capacitor (RC) network that sets the cut-off frequency, and an op-amp (such as the LM741 or TL081) that provides amplification and buffering.

An alternative design approach for higher performance is the **second-order low-pass filter** using **Sallen-Key topology**. The Sallen-Key configuration provides a sharper frequency roll-off (−40 dB/decade) compared to a first-order design (−20 dB/decade), making it more suitable for applications that require better signal filtering.

For this assignment, the first-order active low-pass filter is chosen due to its simplicity and ease of implementation while still achieving the desired cut-off frequency of 2 kHz.

2.2 How the Filter Operates

The RC network acts as a frequency-dependent voltage divider. At low frequencies (below the cut-off frequency), the capacitor's reactance is high, allowing most of the input voltage to appear across the op-amp input. At high frequencies, the capacitor's reactance decreases, shunting more of the input signal to ground, thus reducing the output voltage.

The op-amp is configured in a non-inverting mode, which ensures that the output signal is in phase with the input and provides gain, depending on the feedback resistor configuration. This active design not only filters high-frequency signals but also amplifies the low-frequency signals, improving signal strength and maintaining signal integrity.

The **cut-off frequency** (f_c) is determined by the values of the resistor R and capacitor C, using the formula:

$$f_c = \frac{1}{2\pi RC}$$

At this frequency, the output voltage drops to approximately **70.7%** (or −3 dB) of the input, marking the boundary between the passband and the attenuation region.

3.0 COMPONENT CALCULATION

Objective:

To design an active low-pass filter with a **cut-off frequency** (f_c) of **2 kHz** using standard resistor and capacitor values.

3.1 Relevant Formula:

For a **first-order active low-pass filter**, the cut-off frequency is determined by the formula:

$$f_c = \frac{1}{2\pi RC}$$

Where:

fc = Cut-off frequency (in Hz)

R = Resistor (in ohms, Ω)

C = Capacitor (in farads, F)

π\pi ≈ 3.1416

3.2 Step-by-step calculation on how resistor and capacitor values were chosen to achieve the desired cut-off frequency

Step 1: Set Target Cut-Off Frequency

Given:

$$f_c = 2000\text{Hz}$$

We need to find combinations of R and C such that:

$$RC = \frac{1}{2\pi f_c} = \frac{1}{2X3.1416X2000} = \frac{1}{12566.4} = 7.96\times10^{-5}$$

So, we want:

$$R\times C=7.96\times10^{-5}$$

Step 2: Choose Standard Resistor Value

We select a standard resistor value for ease of implementation.
Let’s choose:

$$R=10\text{k}\Omega=10{,}000\ \Omega$$

Now solve for C:

$$C = \frac{7.96X10^{-5}}{10{,}000} = 7.96 \text{ x } 10^{-9}\text{F} = 7.96\text{nF}$$

Step 3: Select Nearest Standard Capacitor

Standard capacitor values from the E12 series include:

6.8 nF

8.2 nF

Since **7.96 nF** is not a standard value, we can use **8.2 nF**, which is the nearest.

Final Component Values Used:

Resistor (R) = 10 kΩ

Capacitor (C) = 8.2 nF

Now, check actual cut-off frequency using these:

$$f_c = \frac{1}{2\pi \text{ x } 10{,}000 \text{ x } 8.2 \text{ x } 10^{-9}} = \frac{1}{2\pi \text{ x } 8.2 \text{ x } 10^{-5}} = \frac{1}{5.125 \text{ x } 10^{-4}} =$$

1941Hz

Conclusion:

Using **R = 10 kΩ** and **C = 8.2 nF**, the filter has a practical cut-off frequency of approximately **1941 Hz**, which is acceptably close to the desired **2 kHz**, and suitable for real-world implementation using available components.

4.0 CIRCUIT DESIGN IN MULTISIM

4.1 Screenshot of the simulated circuit.

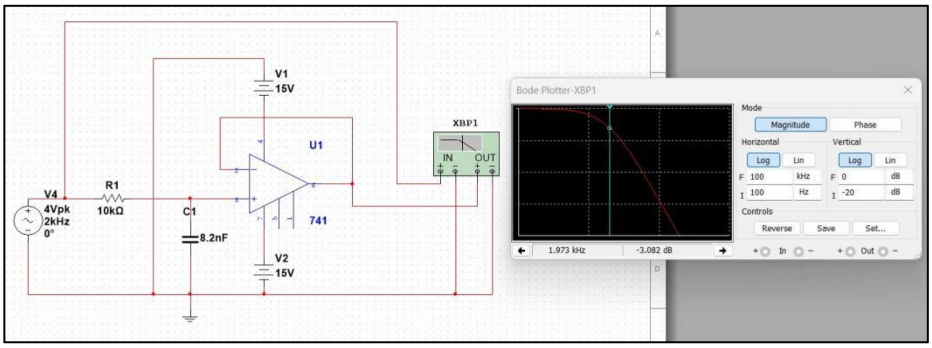


Figure 4.1: Blode Plotter

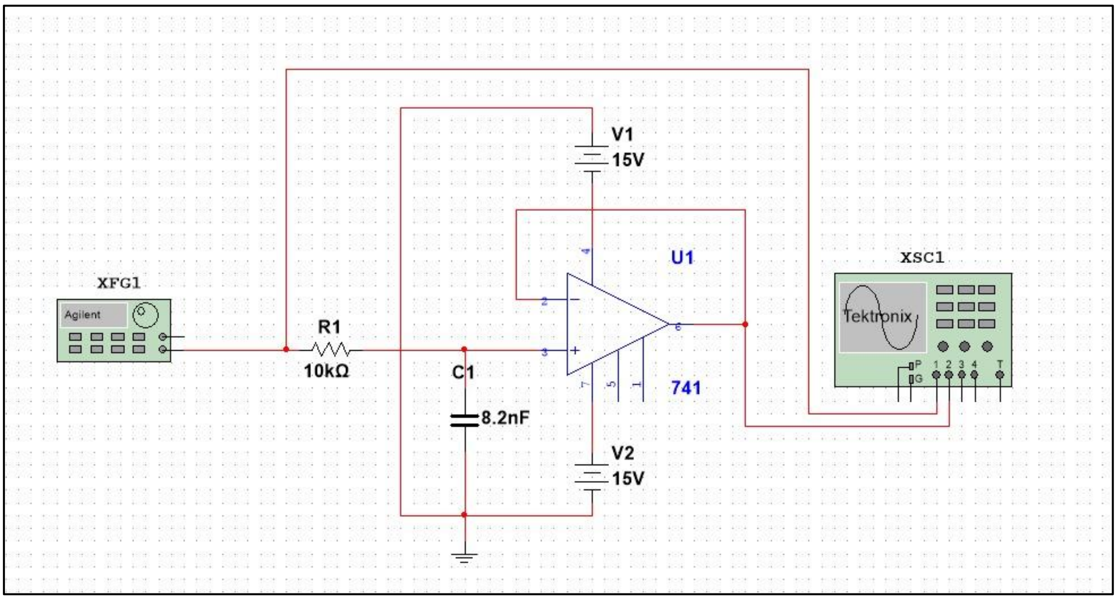


Figure 4.1.1: Circuit design in multisim

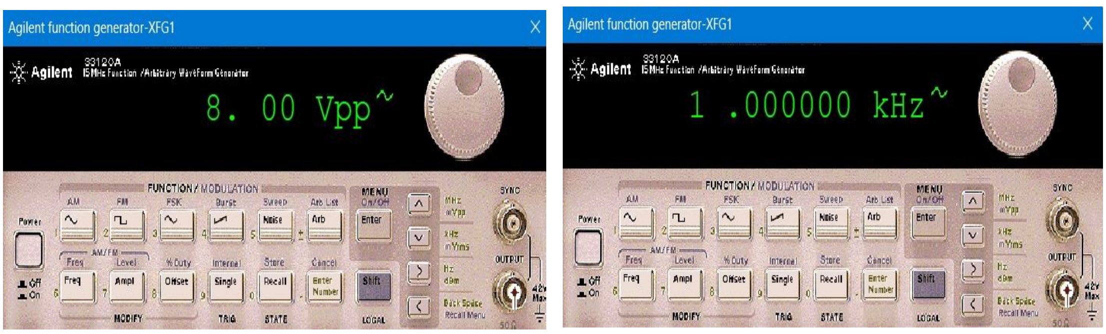


Figure 4.1.2: Amplitude and Frequency setup

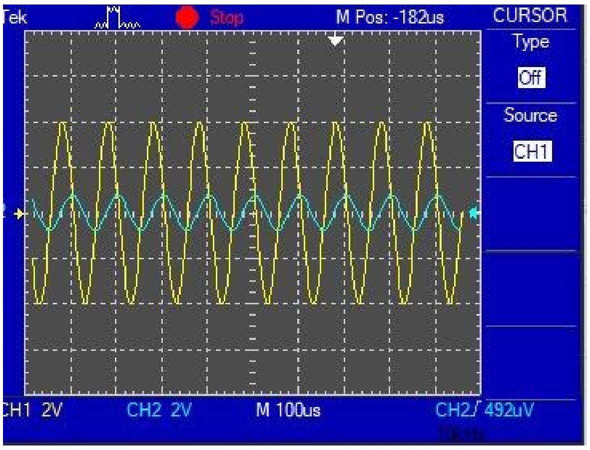
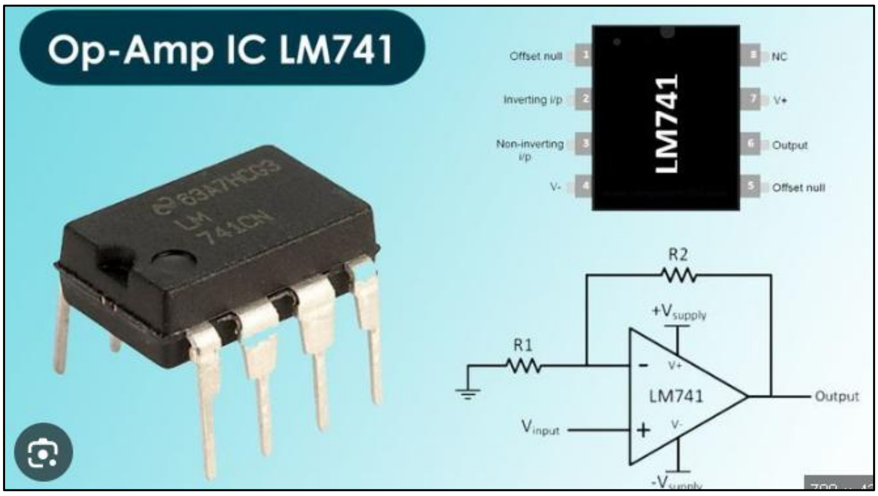


Figure 4.1.3: V_{in} (Yellow) and V_{out} (Blue) Wave

4.2 Op-Amp Model Used

For this simulation, the operational amplifier model used is the **LM741**, a commonly available general-purpose op-amp that is widely supported in Multisim. The LM741 provides sufficient bandwidth and gain for basic active filter applications such as this low-pass filter.



5.0 SEMI-LOG PLOT OF FREQUENCY RESPONSE

Table 5.1: Result for Low Pass Frequency

f	V_{in} Max	V_{out} Max	$A_v = V_{out}/V_{in}$	$[A_v]_{dB}$
100 Hz	4V	3.99V	1	0
200 Hz	4V	3.96V	0.99	-0.09
400 Hz	4V	3.92V	0.98	-0.2
800 Hz	4V	3.7V	0.93	-0.6
1 kHz	3.99V	3.55V	0.89	-1.0
2 kHz	3.99V	2.78V	0.7	-3.1
4 kHz	3.99V	1.74V	0.44	-7.1
8 kHz	3.99V	0.94V	0.24	-12.4
10 kHz	3.99V	0.76V	0.1	-20

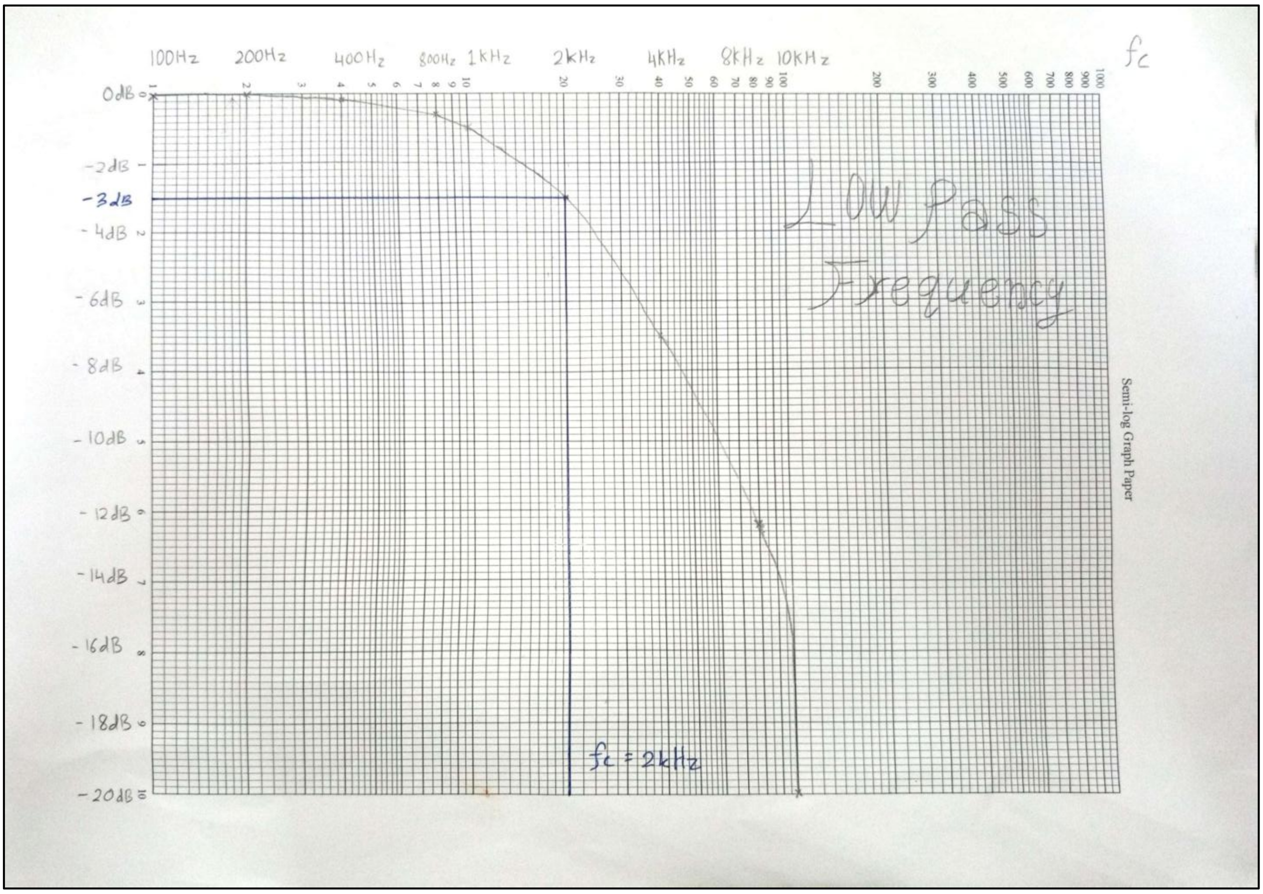


Figure 5.1: Semi-Log Plot For Frequency Response

6.0 REAL-WORLD APPLICATION

6.1 Application: Audio Crossover Network in Speaker Systems

A practical and common application of a **first-order active low-pass filter with a 2 kHz cut-off frequency** is in an **audio crossover network** used in **multi-driver speaker systems**.

Explanation:

In a multi-way speaker system (such as a 2-way or 3-way speaker), the audio signal is divided into frequency bands so that each speaker driver only handles the range it is designed for:

Woofer: handles low frequencies (bass)

Tweeter: handles high frequencies (treble)

To achieve this separation, **a low-pass filter** is used to send only the **low-frequency signals** to the woofer, while high-pass filters are used for the tweeter.

6.2 why the cut-off is suitable for that application (2KHz)

The **2 kHz cut-off frequency** is commonly chosen as the **crossover point** between the woofer and tweeter:

- Frequencies **below 2 kHz** are directed to the **woofer**
- Frequencies **above 2 kHz** are directed to the **tweeter**

This is because 2 kHz lies within the transition zone between the bass and treble ranges in human hearing. Setting the crossover at 2 kHz helps avoid distortion and allows each driver to work within its optimal frequency range.

6.2.2 Why Use Active Filters?

Active filters provide **signal amplification** and buffering, unlike passive filters which may attenuate the signal.

They offer better control over the filter's performance, especially in audio systems where sound quality is critical.

Conclusion:

An active low-pass filter with a **2 kHz cut-off frequency** is highly suitable for use in audio crossover networks to direct low-frequency signals to woofers. This ensures better sound separation, improves clarity, and protects the speakers from receiving signals outside their design range.

7.0 CONCLUSION

In this project, a **first-order active low-pass filter** was successfully designed, simulated, and analyzed with a target **cut-off frequency of 2 kHz**. The design involved selecting appropriate standard values for the resistor and capacitor, specifically **10 kΩ** and **8.2 nF**, which resulted in a practical cut-off frequency of approximately **1941 Hz** — sufficiently close to the target.

The filter was implemented using an **LM741 operational amplifier** in a non-inverting configuration. Simulation in Multisim confirmed the expected behavior, where low-frequency signals passed through the filter with minimal attenuation, while higher frequencies were effectively reduced.

A real-world application of this filter was identified in **audio crossover networks** within speaker systems, where a 2 kHz cut-off is commonly used to direct low-frequency signals to woofers, ensuring improved sound quality and system efficiency.

7.1 Challenges Faced

- ✧ Choosing component values that closely match the theoretical calculations while remaining within **standard component ranges**.
- ✧ Understanding how **frequency response behaves in simulation**, especially in interpreting roll-off behavior.
- ✧ Setting up the **Multisim circuit correctly**, including op-amp power supply connections.

7.2 Lessons Learned

- ✧ Gained a better understanding of **filter design principles**, especially how **RC values affect the frequency response**.
- ✧ Learned how to use **Multisim for circuit simulation**, which helped visualize theoretical concepts in practice.
- ✧ Recognized the **importance of active filters** in real-world electronic applications such as audio and signal conditioning.