MAKERERE UNIVERSITY

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DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
SCHOOL OF ENGINEERING
BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING
NETWORK THEORY LAB REPORT

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1 Experiment 1: Low Pass Filter

1.1 Objective

To determine the input/output characteristics of a low pass filter and calculate its cut-off frequency.

1.2 Instruments

- Oscilloscope
- Function generator
- EC2 MVM6 box

1.3 Theory

1.3.1 Introduction

Low-pass filters play a crucial role in signal processing, allowing the passage of low-frequency signals while attenuating higher frequencies. This experiment aims to analyze the input/output characteristics of a low-pass filter and determine its cut-off frequency (f_c), which signifies the point at which the filter starts attenuating the input signal significantly.

1.3.2 Low-Pass Filter Characteristics

The transfer function of a first-order low-pass filter is given by:

$$H(f) = \frac{1}{1 + j\left(\frac{f}{f_c}\right)}$$

where f is the input frequency, f_c is the cut-off frequency, and j is the imaginary unit.

1.3.3 Cut-Off Frequency

The cut-off frequency is a critical parameter in understanding low-pass filter behavior. It is related to the time constant (τ) of the filter by the equation:

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

A low-pass filter can be implemented using an operational amplifier (op-amp) as the active element and resistors and capacitors as passive elements. The generic filter diagram is shown in Figure **??**, where $Z1 - Z5$ indicate generic impedances. The input-output formula for the general diagram is given by:

$$\frac{Vo}{Vin} = \frac{Z2 \cdot Z4 \cdot Z5}{Z1 \cdot Z3 \cdot Z5 + Z1 \cdot Z2 \cdot Z5 + Z1 \cdot Z2 \cdot Z3 + Z2 \cdot Z3 \cdot Z5 - Z2 \cdot Z1 \cdot Z4} \tag{1}$$

This relation assumes ideal conditions such as infinite input impedance and infinite amplification of the operational amplifier, leading to a virtual ground.

For a specific low-pass filter with resistors ($Z1$, $Z3$, and $Z5$) and capacitors ($Z2$ and $Z4$), the input-output formula becomes:

$$\frac{Vo}{Vin} = \frac{R2 \cdot R3 \cdot C1 \cdot C2}{R3 + R2 \cdot (1 + j\omega R1 \cdot C1)} \tag{2}$$

where ω is the angular frequency of the input signal.

The cut-off frequency F_c is determined by the values of the passive components:

$$F_c = \frac{1}{2\pi R1 \cdot R2 \cdot C1 \cdot C2} \tag{3}$$

The gain G_0 of the filter at DC (frequency $f = 0$ Hz) is given by:

$$G_0 = -\frac{R3}{R1} \tag{4}$$

1.3.4 Experiment Setup

The experiment utilizes an oscilloscope, function generator, and the EC2 MVM6 box. The function generator provides the input signal, and the oscilloscope measures the output signal. The EC2 MVM6 box contains the low-pass filter circuit under investigation.

1.3.5 Procedure

1. Connect the function generator output to the input of the low-pass filter circuit.
2. Connect the output of the low-pass filter circuit to the input channel of the oscilloscope.
3. Set the function generator to produce a sine wave with varying frequencies.
4. Measure and record the amplitude of the output signal at different input frequencies.

1.3.6 Expected Results

The input/output characteristics of the low-pass filter are expected to show a gradual attenuation of the output amplitude as the input frequency increases. The cut-off frequency can be determined by analyzing the point at which the attenuation becomes significant.

1.3.7 Significance

Understanding low-pass filter behavior is crucial in applications such as audio signal processing, communication systems, and control systems. Determining the cut-off frequency allows for the design of filters tailored to specific frequency ranges, optimizing electronic system performance.

1.4 Results

1.5 Q1: What is the approximate amplification of the filter at 10 Hz?

1. 1
2. 9
3. 15
4. 50
5. Infinite

1.6 Q2: What is the main reason for this amplification value?

- 1 the value of $R22$
- 2 the value of $C10$
- 3 the value of $R23$
- 4 the value of the ratio $\frac{R23}{R20}$
- 5 the value of the product $R22 \cdot C10$

Input Frequency (Hz)	Output Amplitude (Vpp)
10	10.6
20	11.1
40	11.1
60	10.8
80	10.3
100	9.76
150	8.16
200	6.88
500	3.36

Table 1: Input frequency and output amplitude measurements.

Plot all the values obtained into figure A15.4 and draw the input/output characteristic of the filter

From this graph calculate the cut-off frequency of the filter, defined as the frequency at which the amplification drops to 0.707 times the maximum.

$$f_c = ?$$

$$power = 0.707 \cdot 11.1 = 7.84$$

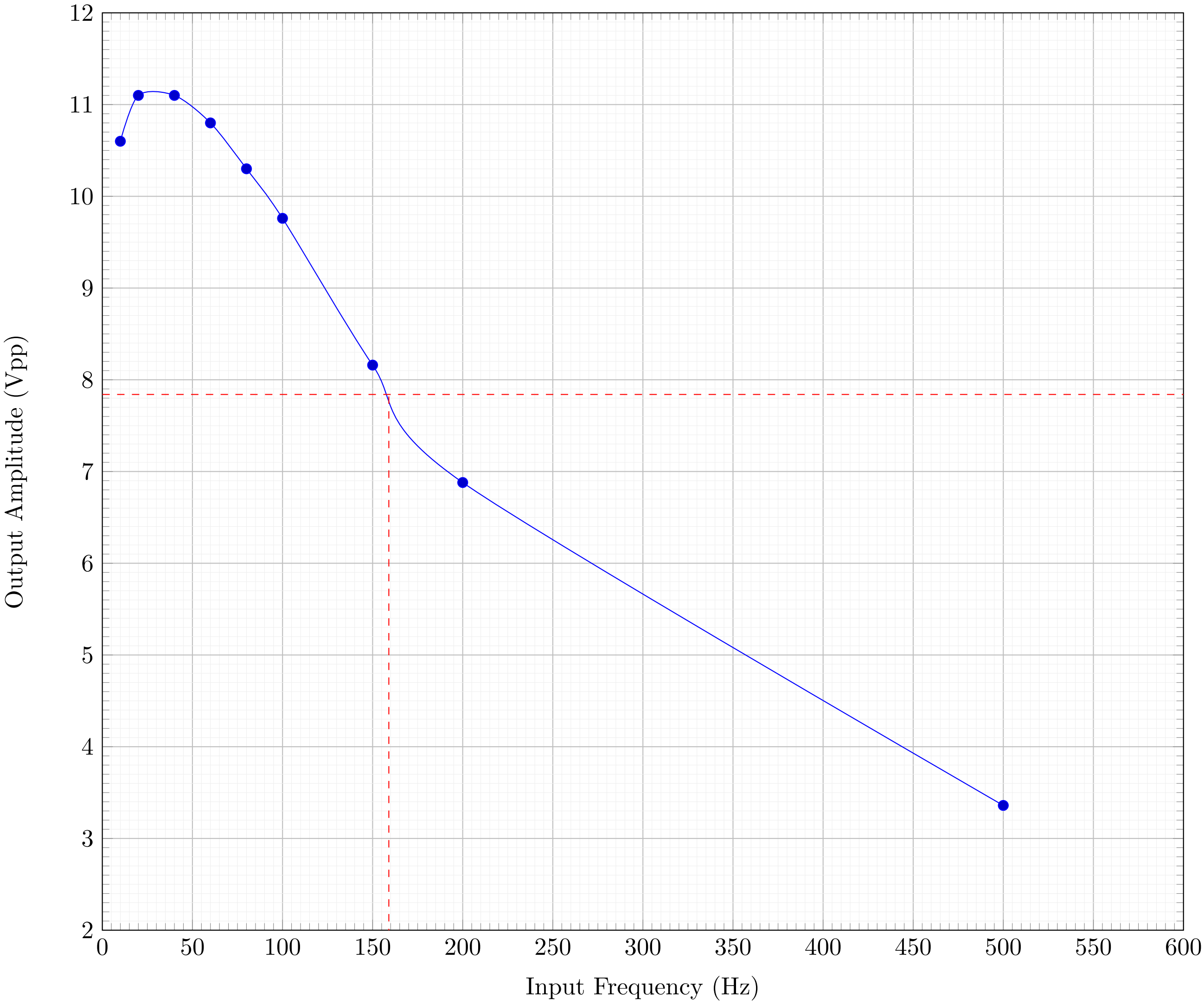


Figure 1: Input frequency vs. output amplitude (A15.4)

$$f_c = 159Hz$$

1.7 Turn switch S22 “ON”

- Now measure the cut-off frequency of the filter again.

Input Frequency (Hz)	Output Amplitude (Vpp)
10	8.24
20	5.88
40	3.36
60	2.35
80	1.72
100	1.49
150	0.87
200	0.64
500	0.18

Table 2: Input frequency and output amplitude measurements.

$$f_c = ?$$

$$power = 0.707 \cdot 8.24 = 5.82$$

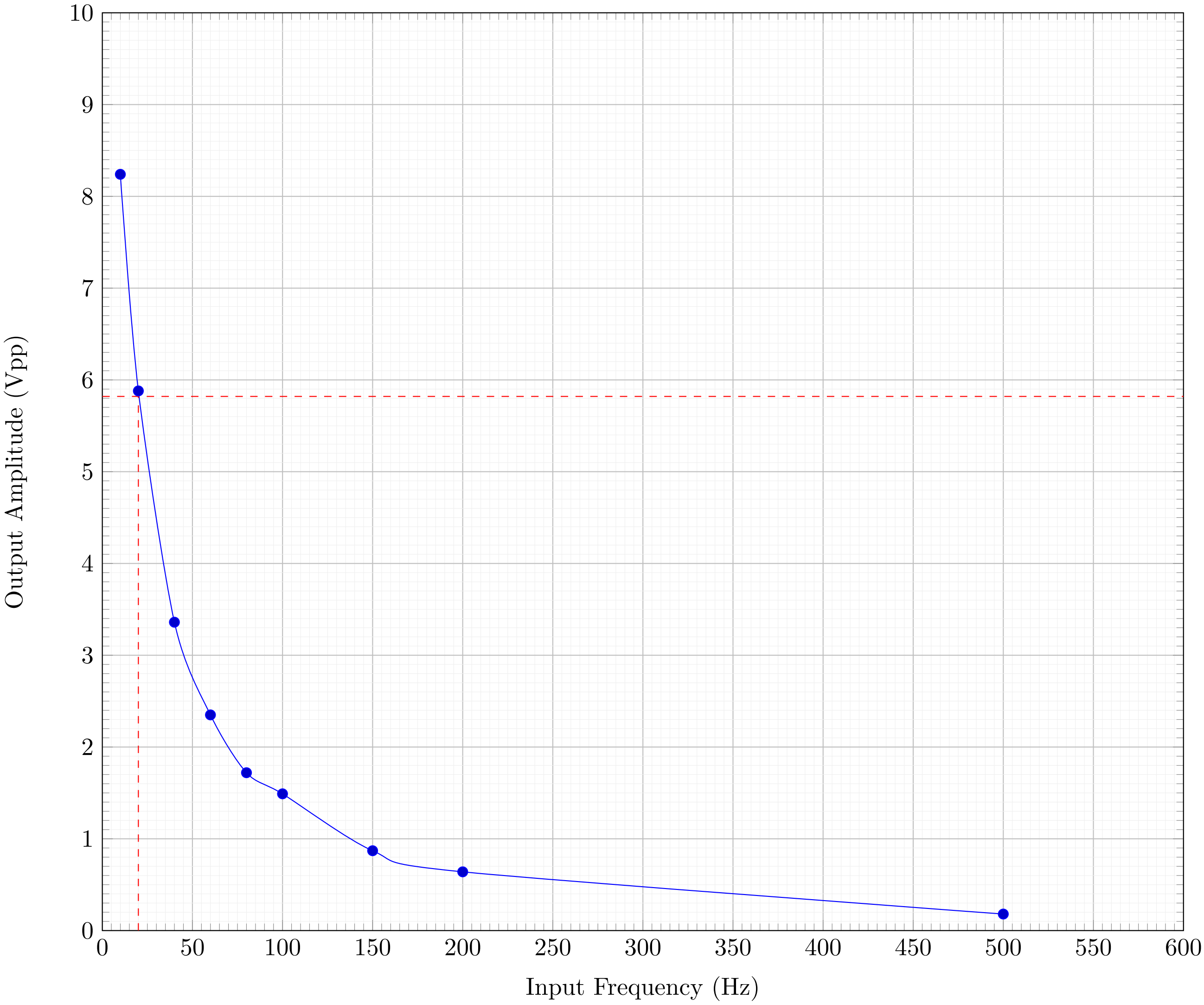


Figure 2: Input frequency vs. output amplitude (A15.4)

$$f_c = 20Hz$$

1.7.1 Q3: What do you notice?

The cut-off frequency is decreased while switch 2 was turned on.

1.7.2 Q4: What is the cause of this?

The capacitance C10 has decreased.

1.8 Conclusion

The low-pass filter experiment was successfully performed, and the cut-off frequency was determined to be 159 Hz. The cut-off frequency was then determined again after turning on switch S22, and it was found to be 20 Hz. This shows that the cut-off frequency can be adjusted by changing the capacitance of the filter circuit.

2 Experiment 2: Superposition of A.C and D.C. Voltages in linear and Non-linear Circuits

2.1 Objective

To demonstrate the effect of applying ac and dc voltages to the same circuit simultaneously.

2.2 Instruments

- Oscilloscope
- Low voltage DC power supply
- 12V center tapped transformer
- 1kΩ resistor
- Diode

2.3 Linear circuits - Demonstration of Superposition

2.3.1 Theory

The superposition theorem states that the response in any branch of a linear circuit with multiple independent sources is the algebraic sum of the responses caused by each independent source acting alone, while all other independent sources are turned off. The superposition theorem is used to solve circuits by hand by breaking the circuit into smaller parts and analyzing each part individually. The superposition theorem is also used in circuit simulation software such as SPICE for the same purpose. The superposition theorem is a fundamental principle in linear circuit analysis that simplifies the analysis of complex circuits. It states that in a linear circuit containing multiple independent sources, the response (voltage or current) at any element is equal to the algebraic sum of the responses caused by each independent source acting alone, with all other sources turned off.

2.3.2 Statement of the Superposition Theorem

Consider a linear circuit with multiple independent sources. Let $S_1, S_2, \ldots, S_n$ be the independent sources, and R be the response (voltage or current) at a specific element in the circuit. The total response R_{total} at the element is given by the sum of the responses caused by each source individually:

$$R_{\text{total}} = R_{S_1} + R_{S_2} + \ldots + R_{S_n}$$

where R_{S_i} is the response due to the i-th source acting alone, with all other sources turned off.

2.3.3 Applicability

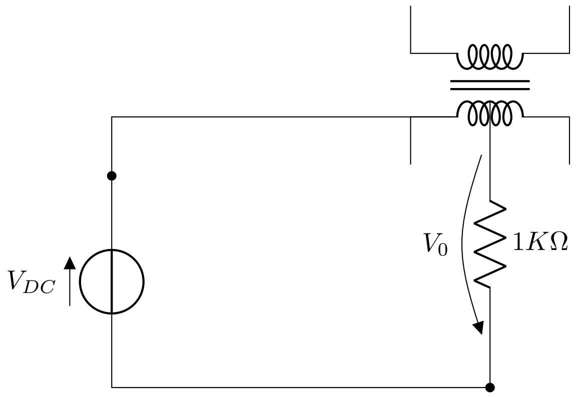
The superposition theorem is applicable only to linear circuits, where the circuit elements exhibit linear relationships between voltage and current. It is particularly useful in simplifying the analysis of circuits with multiple sources, allowing engineers to focus on individual sources and their effects.

2.3.4 Significance

The superposition theorem provides a powerful tool for simplifying circuit analysis, especially in circuits with multiple sources. By breaking down a complex circuit into simpler sub-circuits, engineers can better understand and design electronic systems with improved accuracy.

2.3.5 Procedure

Construct the circuit in figure 1



4.1.2 Conect the primary of the transformer to the 50Hz, 240V mains. Do not turn the dc voltage on yet but connect the supply into the circuit

NOTE: The dc supply must be well bypassed with capacitors. However if a regulated supply is used, the bypass capacitors are not necessary.

4.1.3 Measure and record the ac voltage V on the VTVM and observe the voltage V, accross the 1kΩ resistor on the scope. Sketch the waveform observed. You are advised to calibrate the vertical scale of the oscilloscope at 5 volts per division. Record and measure the peak to peak ac voltage accross R.

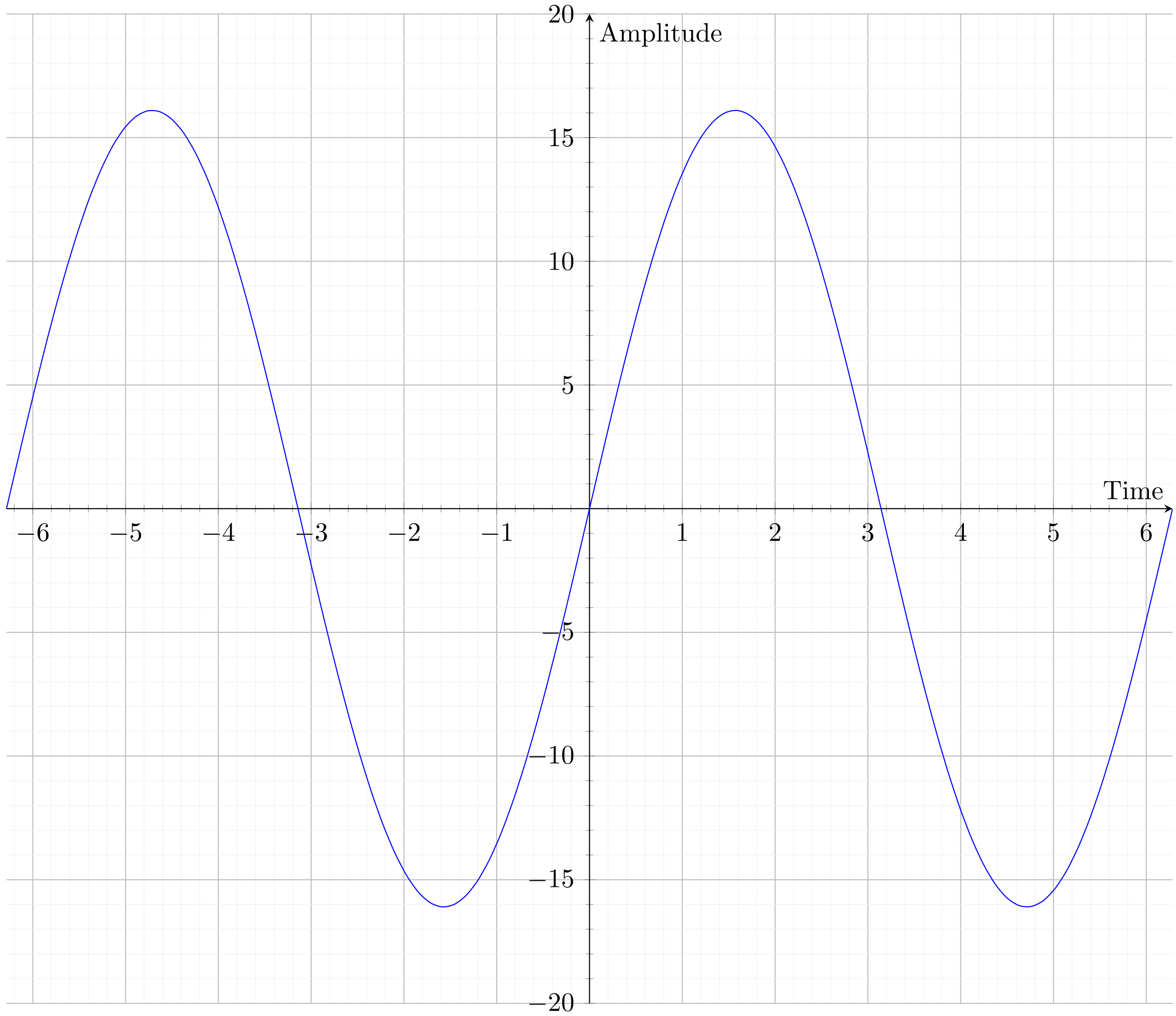


Figure 3: Voltage accross R

VPP=32.2V

4.1.4 Turn off the ac power supply leaving the transformer secondary connected. Apply 12V dc to terminals X-Y. Measure and record the dc voltage accross R.
Vdc = 11.86V
4.1.5 Now with the 12V dc still applied to the circuit, apply 240V ac to the transformer primary again. Measure the dc voltage accross R, observe the waveform of the voltage accross R on the scope sketch the waaveform observed What is the peak to peak voltage across R measured

NB: In sketching the waveform for Vo make sure to include both ac and dc components.

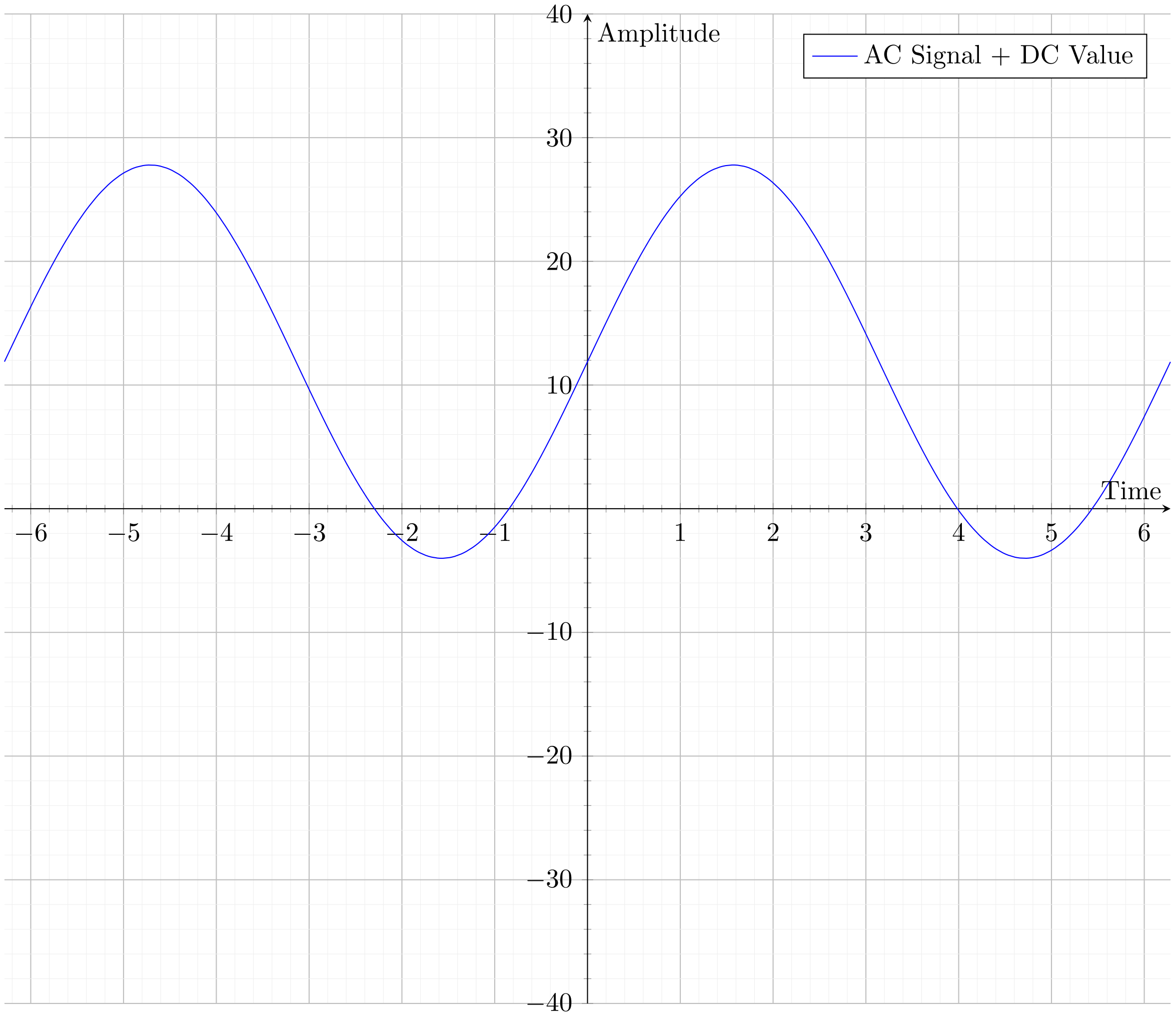


Figure 4: AC Signal Superposed with DC Value of 12V

$$Vdc = 11.89$$

$$Vac = 31.8Vpp$$

4.1.6 Now with both ac and dc applied, readjust the dc voltage to 5 volts and measure Vdc and Vac Sketch the waveform for Vo observed on the scope use the same

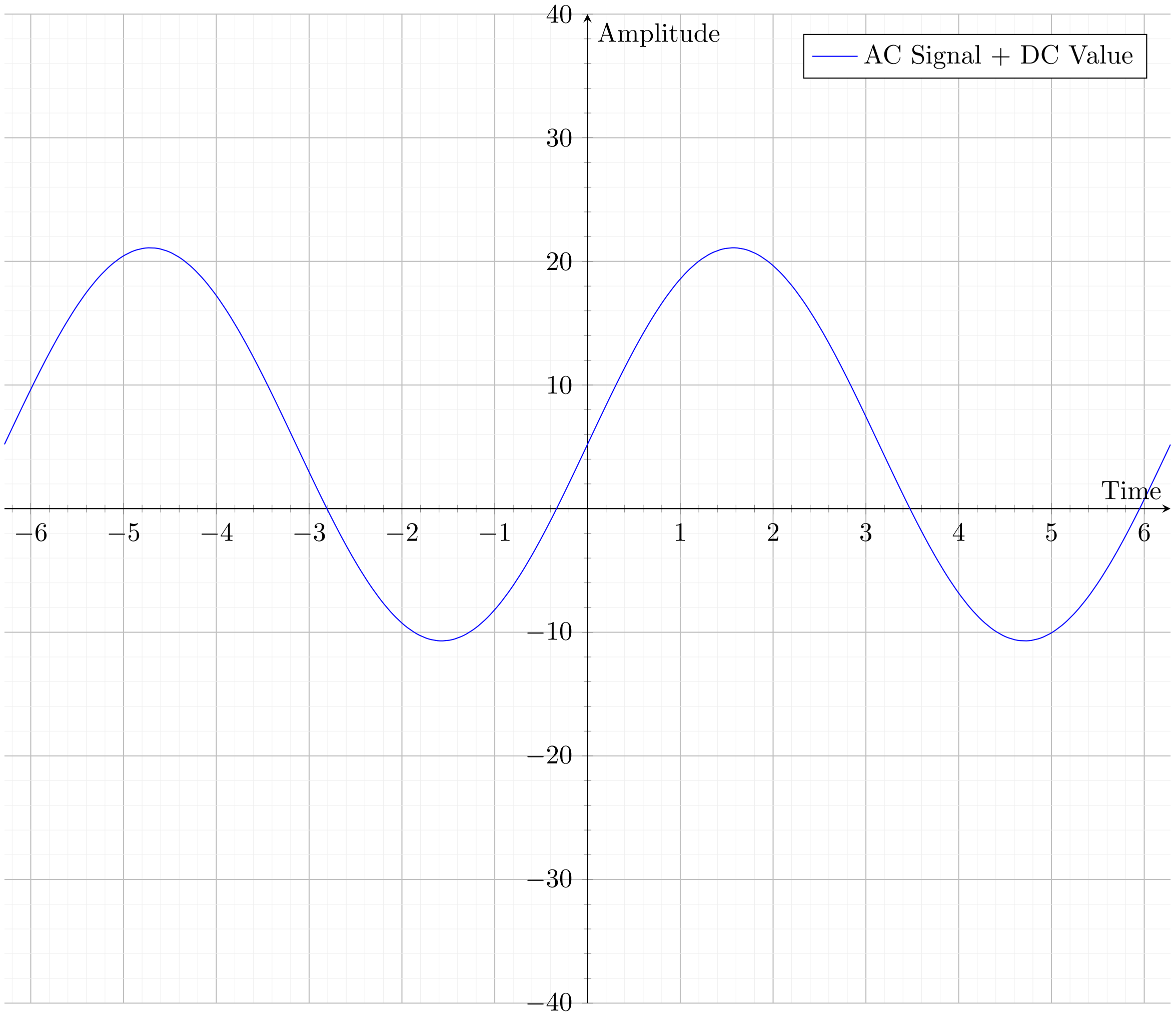


Figure 5: AC Signal Superposed with DC Value of 5V

$$Vdc = 5.20$$

$$Vac = 31.8Vpp$$

2.3.6 Discussion

2.4 Analysis Questions

2.4.1 1. State whether the DC level has any significant effect on the part of the value of the AC voltage.

The DC level does not have a significant effect on the amplitude of the AC voltage. According to the principle of superposition, in a linear circuit, the DC and AC components can be analyzed separately. The DC level sets the bias point, while the AC signal fluctuates around this bias. The amplitude of the AC signal is determined by the AC source, and the DC level does not impact it.

2.4.2 2. What happens to the DC level when the AC voltage is turned off?

When the AC voltage is turned off, the DC level remains unaffected. The DC component is a steady-state value that represents the average voltage or bias in the circuit. Turning off the AC source only removes the fluctuating AC signal, leaving the DC level unchanged.

2.4.3 3. What basic property of linear circuits is demonstrated by this experiment?

This experiment demonstrates the linearity of the circuit. Linearity implies that the circuit follows the principle of superposition, allowing separate analysis of the DC and AC components. The behavior of the circuit is consistent and predictable when subjected to varying input signals.

2.4.4 4. State this principle and briefly explain what it means.

The principle of superposition states that in a linear circuit, the response (voltage or current) at any point is the algebraic sum of the individual responses caused by each independent source acting alone, with all other sources turned off. This means that the effects of individual sources can be analyzed independently and then combined to determine the overall response of the circuit.

2.5 Non-linear circuits

2.5.1 Theory

The superposition theorem is a fundamental concept in linear circuit analysis, allowing for the simplification of complex circuits with multiple independent sources. However, it is crucial to understand that superposition is valid only for linear circuits, where the relationship between voltage and current is linear. In nonlinear circuits, components exhibit non-linear behavior, and applying superposition directly may lead to inaccuracies.

2.5.2 Nonlinear Components

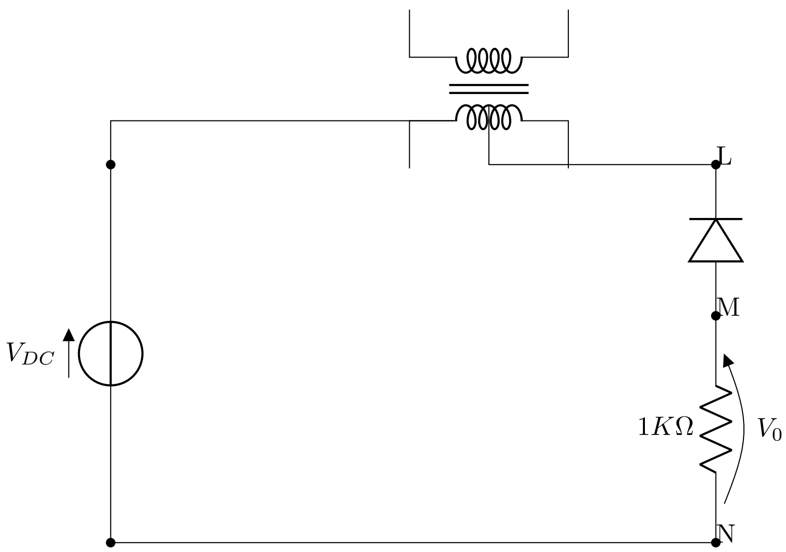
Nonlinear components, such as diodes and transistors, introduce non-linear relationships between voltage and current. Unlike resistors, these components do not follow Ohm's law, making the application of superposition challenging. To investigate the limitations of the superposition theorem in nonlinear circuits, consider a circuit with a nonlinear element, such as a diode. Design the circuit to include multiple independent sources and resistors along with the nonlinear component.

2.5.3 Significance

This experiment aims to highlight the limitations of applying superposition to nonlinear circuits. By comparing the superposition-based predictions with actual measurements, you can illustrate the impact of non-linear elements on the accuracy of the superposition theorem.

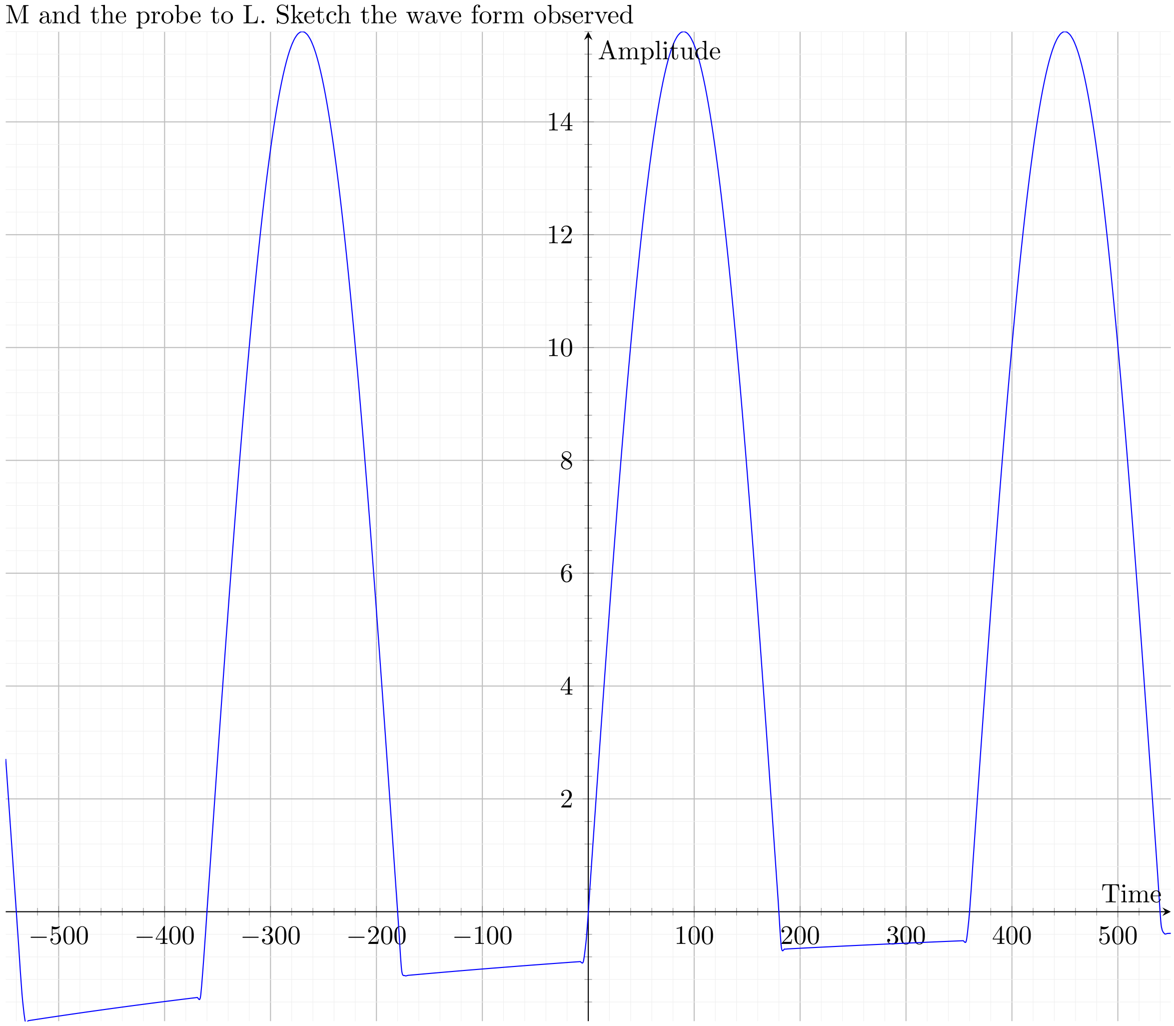
2.5.4 Procedure

5.1.1 Construct the circuit in figure 2.



5.1.2 Connect the primary of the transformer to the 50Hz, 240V mains. Do not turn the dc voltage on yet but connect the supply into the circuit.
5.1.3 With the vertical input of thr oscilloscope calibvrated to 5V per division, connect thew scope common to

M and the probe to L. Sketch the wave form observed



$$Vac = 15.6Vpp$$

5.1.4 with the scope common still at N, connect the probe to M. Sketch the waveform observed

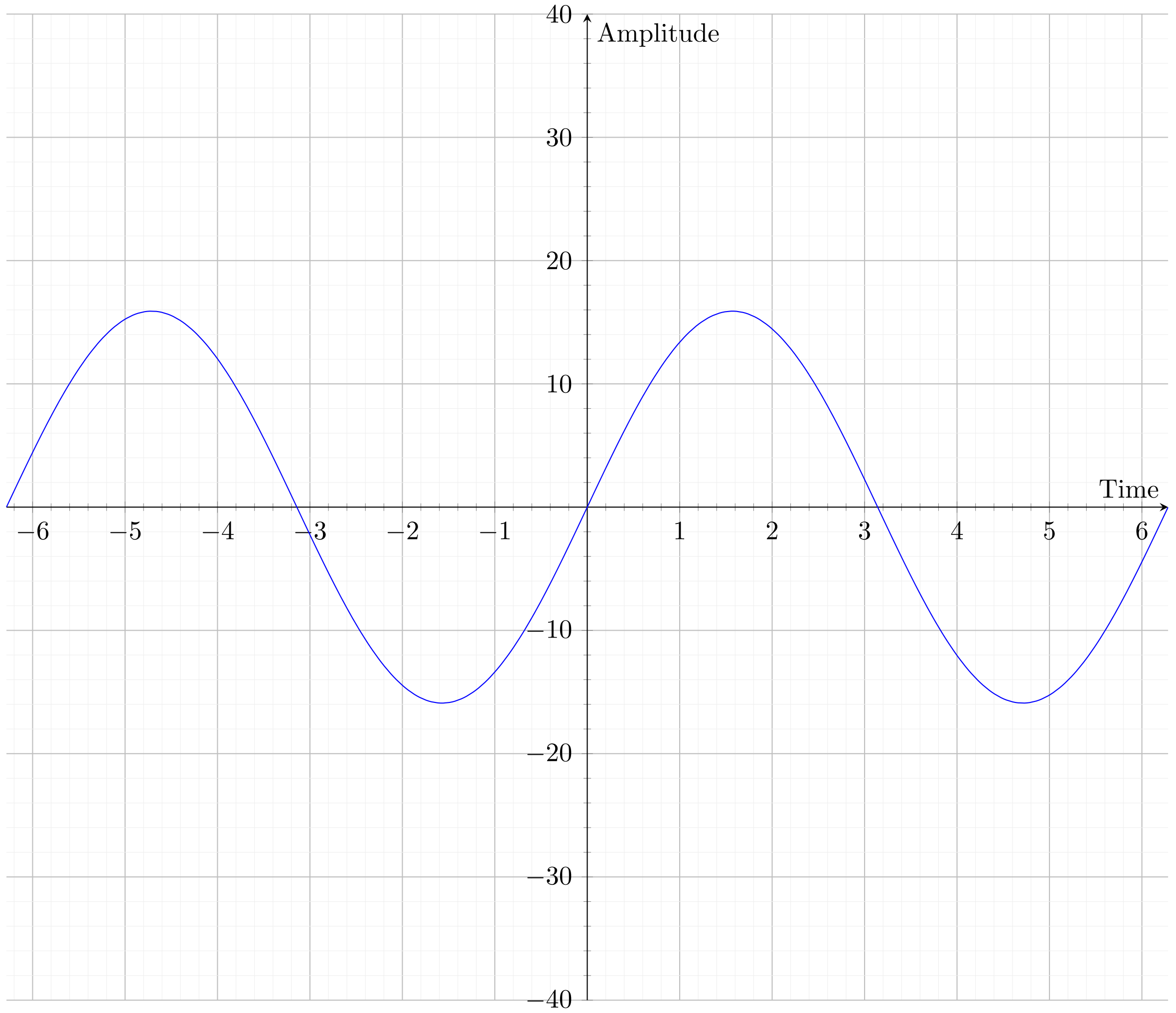
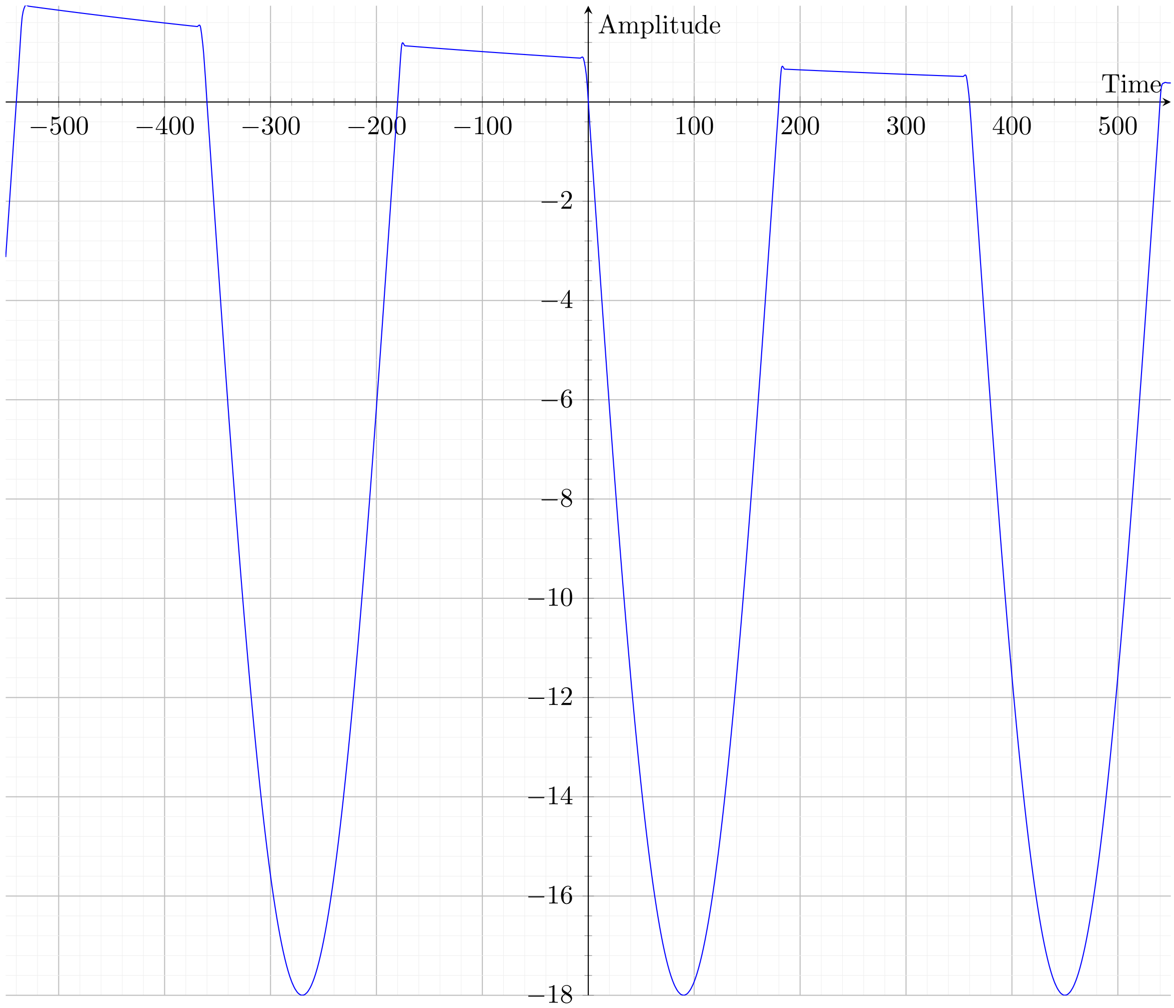


Figure 6: AC Signal Superposed with DC Value of 5V

$$Vdc = 5.20$$

$$Vac = 31.8Vpp$$

5.1.5 Next move the scope common to M and connect the probe to L. Sketch the waveform observed



$Vac = 18.0Vpp$

5.1.6 Now with the ac still applied to the circuit, apply 5V dc accross the terminals L-N.

5.1.7 With the scope common still at N, connect the probe to L. Sketch the waveform observed.

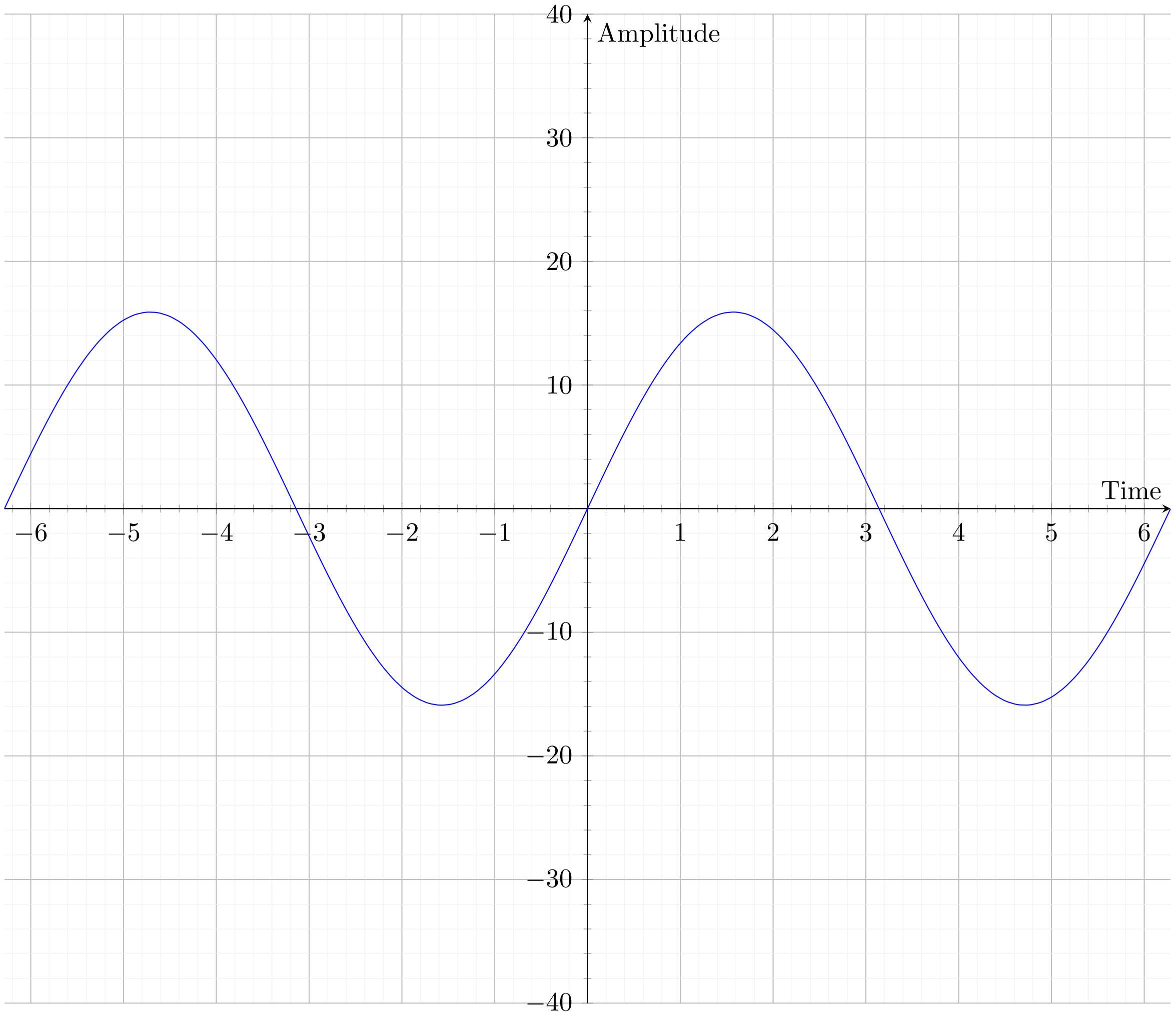
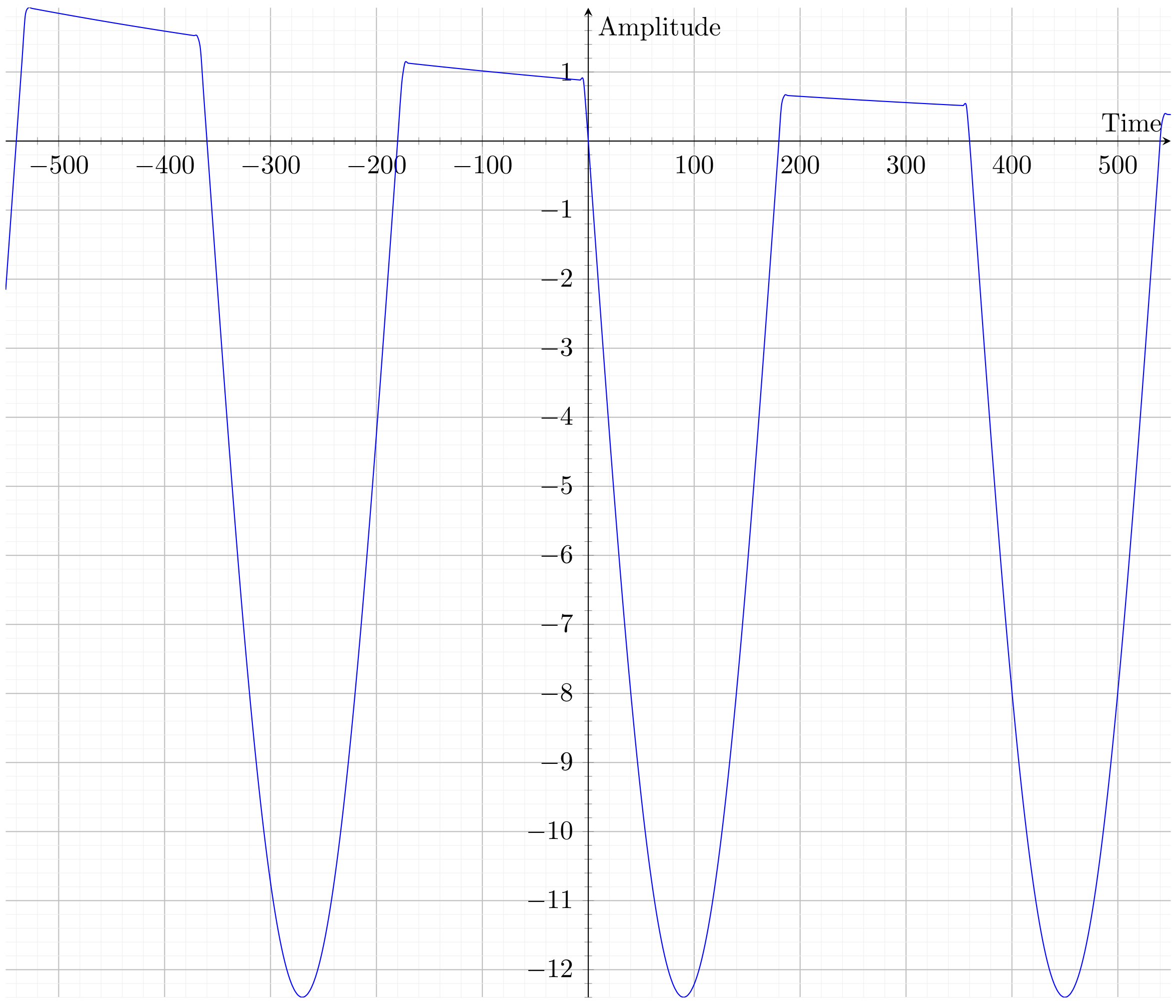


Figure 7: AC Signal

$$Vdc = 5.20$$

$$Vac = 31.8Vpp$$

5.1.8 Next move the scope common to M and connect the probe to L. Sketch the waveform observed.



$Vac = 12.4Vpp$

2.6 Conclusion

While the superposition theorem is a powerful tool in linear circuit analysis, its direct application to nonlinear circuits can lead to errors. Understanding these limitations is crucial for accurate analysis and design of circuits containing nonlinear components.