Analog Communication Systems

(DSC – 15)

Practical File

Submitted By

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Record of Experiments

Experiment 1: RC Low-Pass and High-Pass Filters

(Simulation using NI Multisim)

Aim

To design and simulate RC Low-Pass and High-Pass filters in NI Multisim, obtain their frequency responses, and verify the cutoff frequency.

Apparatus Required

- NI Multisim Software
- Resistor (R)
- Capacitor (C)
- AC Voltage Source
- Oscilloscope / Bode Plotter (Virtual Instruments)

Theory

1. RC Low-Pass Filter

A low-pass filter allows low-frequency signals to pass and attenuates high-frequency signals. The transfer function is:

$$H_{LPF}(j\omega) = \frac{1}{1 + j\omega RC}$$

Cutoff frequency:

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

2. RC High-Pass Filter

A high-pass filter attenuates low-frequency signals and allows high-frequency signals to pass. The transfer function is:

$$H_{HPF}(j\omega) = \frac{j\omega RC}{1 + j\omega RC}$$

Cutoff frequency:

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

Circuit Diagrams

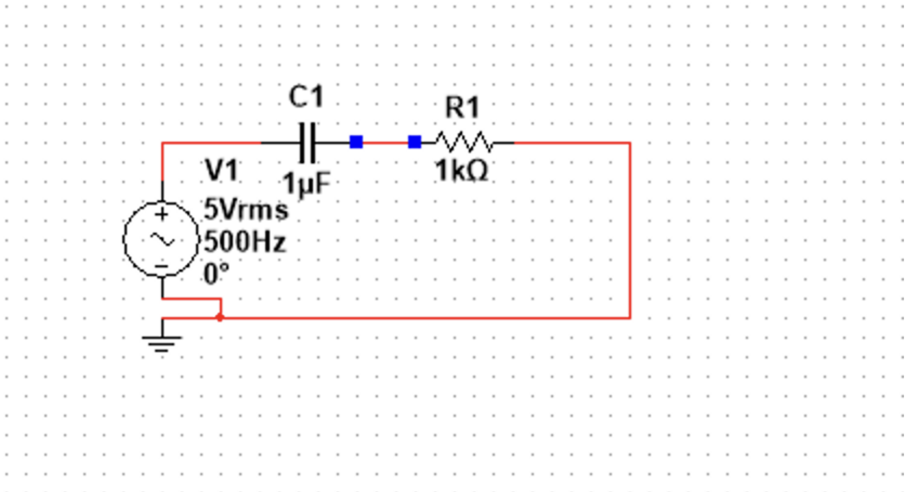

Figure 1: RC filter circuit diagram

Procedure

1. Open NI Multisim and create a new project.
2. Place an AC voltage source, resistor, and capacitor.
3. For the Low-Pass Filter, connect R in series with the source and C to ground.
4. For the High-Pass Filter, connect C in series and R to ground.
5. Connect a Bode Plotter or Oscilloscope across the output.
6. Select appropriate values of R and C (e.g., R = 1 kΩ, C = 0.1 μF).
7. Run AC sweep analysis from 10 Hz to 100 kHz.
8. Note the gain vs. frequency and determine the −3 dB cutoff frequency.

Observations

- Input Frequency Range: 10 Hz – 100 kHz
- Measured cutoff frequency:
$$f_{c,exp} = 156 \text{ Hz}$$
- Theoretical values (for $R = 1\,\text{k}\Omega$ and $C = 1\,\mu\text{F}$):
$$f_{c,theory} = \frac{1}{2\pi RC} = \frac{1}{2\pi(1000)(1 \times 10^{-6})} = 159.15 \text{ Hz}$$

Output Waveforms

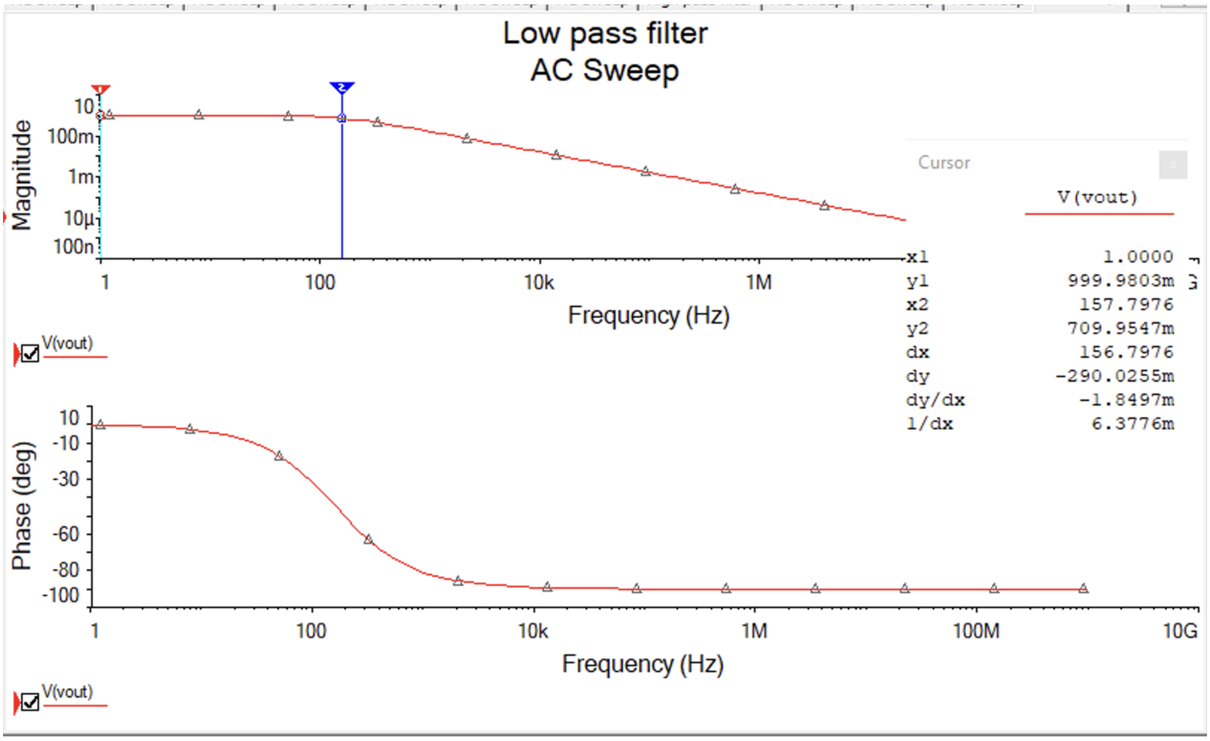

Figure 2: Frequency and Phase response LPF

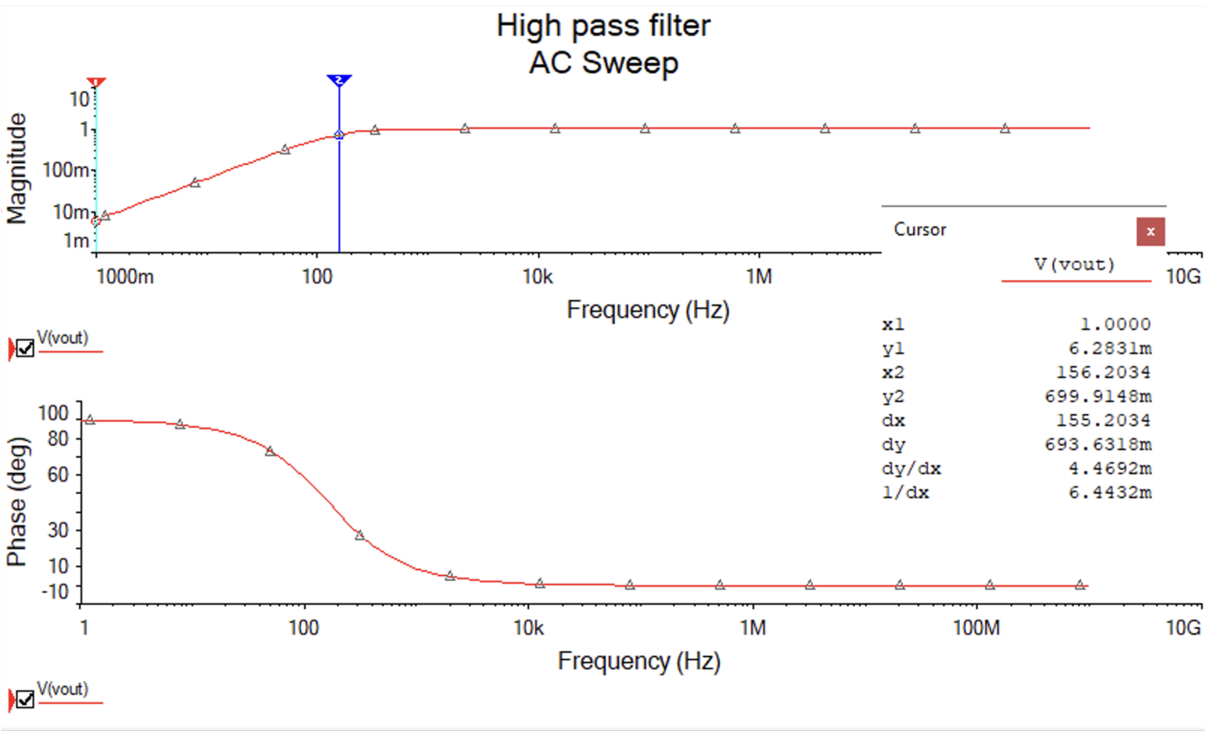

Figure 3: Frequency and Phase response HPF

Result

RC Low-Pass and High-Pass filters were designed and simulated in NI Multisim. The frequency response was observed, and the cutoff frequency obtained from simulation was found to be close to the theoretical value.

Conclusion

RC filters effectively attenuate frequencies beyond their cutoff point. The Multisim results verified the expected behavior of both LPF and HPF circuits.

Experiment 2: IC 555 as Astable Multivibrator

(Simulation using NI Multisim / Hardware Implementation)

Aim

To configure the 555 timer IC in astable mode (astable multivibrator), simulate the circuit in Multisim (or assemble on breadboard), obtain the output waveform, measure frequency and duty cycle, and compare measured values with theoretical values.

Apparatus Required

- IC 555 Timer (or 555 equivalent)
- Resistors: R_1, R_2 (as per design)
- Capacitor: C
- DC Power Supply (+5 to +15 V)
- Breadboard / Multisim
- Oscilloscope / Virtual Oscilloscope (for waveform and frequency measurement)
- Connecting wires, LEDs (optional), multimeter

Theory

In astable mode the 555 timer produces a continuous square-wave output with no stable states — it repeatedly charges and discharges a timing capacitor between $\frac{1}{3}V_{CC}$ and $\frac{2}{3}V_{CC}$.

Standard connections for astable operation:

- Threshold (pin 6) and Trigger (pin 2) are connected together.
- Discharge (pin 7) connects between R_1 and R_2.
- Timing capacitor C connects between pin 6/2 and ground.
- Output at pin 3.

Time intervals:

$$t_{HIGH} = 0.693(R_1 + R_2)C$$
$$t_{LOW} = 0.693(R_2)C$$

Thus the period T and frequency f are:

$$T = t_{HIGH} + t_{LOW} = 0.693(R_1 + 2R_2)C$$

$$f = \frac{1}{T} = \frac{1.44}{(R_1 + 2R_2)C}$$

Duty cycle (fraction of time output is HIGH):

$$D = \frac{t_{HIGH}}{T} = \frac{R_1 + R_2}{R_1 + 2R_2}$$

Circuit Diagram

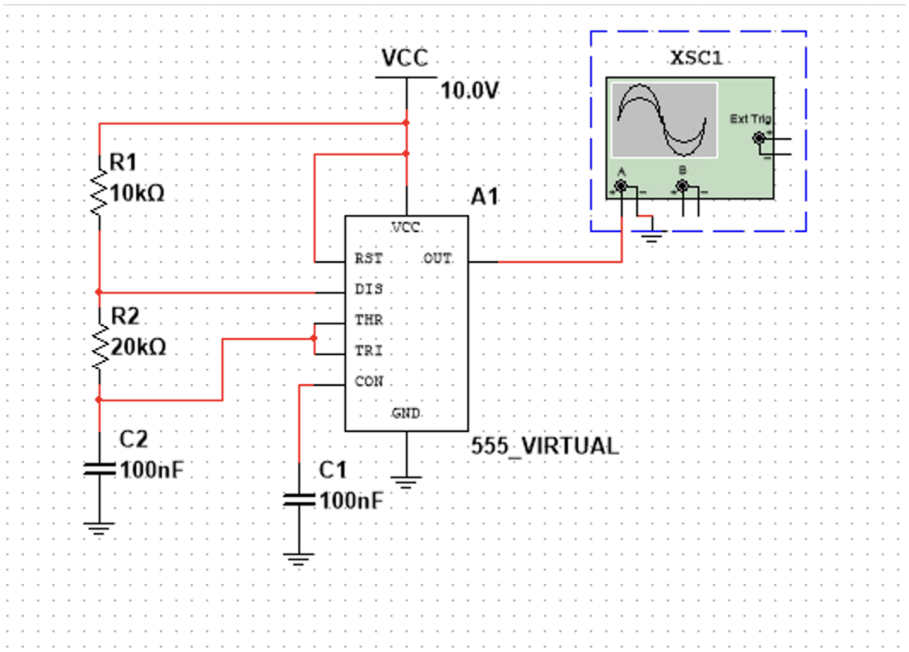

Figure 4: Circuit Diagram

Design Calculations

Given:

$$R_1 = 10\,\mathrm{k\Omega}, \quad R_2 = 20\,\mathrm{k\Omega}, \quad C = 100\,\mathrm{nF} = 100 \times 10^{-9}\,\mathrm{F}$$

ON Time

$$t_{\mathrm{ON}} = 0.693(R_1 + R_2)C$$

$$t_{\mathrm{ON}} = 0.693(10\,000 + 20\,000)(100 \times 10^{-9})$$

$$t_{\mathrm{ON}} = 0.693(30\,000)(1 \times 10^{-7})$$

$$t_{\mathrm{ON}} = 0.693 \times 3 \times 10^{-3} = 2.079 \times 10^{-3}\,\mathrm{s}$$

$$\boxed{t_{\mathrm{ON}} \approx 2.08\,\mathrm{ms}}$$

OFF Time

$$t_{\text{OFF}} = 0.693(R_2)C$$
$$t_{\text{OFF}} = 0.693(20\,000)(100 \times 10^{-9})$$
$$t_{\text{OFF}} = 0.693 \times 2 \times 10^{-3} = 1.386 \times 10^{-3}\,\text{s}$$
$$\boxed{t_{\text{OFF}} \approx 1.39\,\text{ms}}$$

Duty Cycle

$$D = \frac{t_{\text{ON}}}{t_{\text{ON}} + t_{\text{OFF}}} = \frac{2.079}{2.079 + 1.386}$$
$$D = \frac{2.079}{3.465} \approx 0.600$$
$$\boxed{D \approx 60\%}$$

Frequency

$$f = \frac{1}{t_{\text{ON}} + t_{\text{OFF}}} = \frac{1}{3.465 \times 10^{-3}} \approx 288.5\,\text{Hz}$$
$$\boxed{f \approx 289\,\text{Hz}}$$

Procedure

1. Assemble the astable 555 circuit on breadboard or in Multisim as per the schematic.
2. Connect power supply V_{CC} (5–12 V). Ensure proper pin orientation for IC 555.
3. Connect the oscilloscope probe to the output pin (pin 3) and ground.
4. In Multisim, run time-domain (transient) simulation and measure the output waveform period and duty cycle using the oscilloscope tool.
5. Record the measured frequency and duty cycle.
6. Compare measured values with theoretical calculations.

Observation Table

Parameter	**Theoretical Value**	**Practical Value (Multisim)**
t_{ON} (ms)	2.079 ms	2.0 ms
t_{OFF} (ms)	1.38 ms	1.42 ms
Duty Cycle (%)	$\approx$ 59.4%	59.4 %
Frequency (Hz)	$\approx$ 289 Hz	285.38 Hz

Result

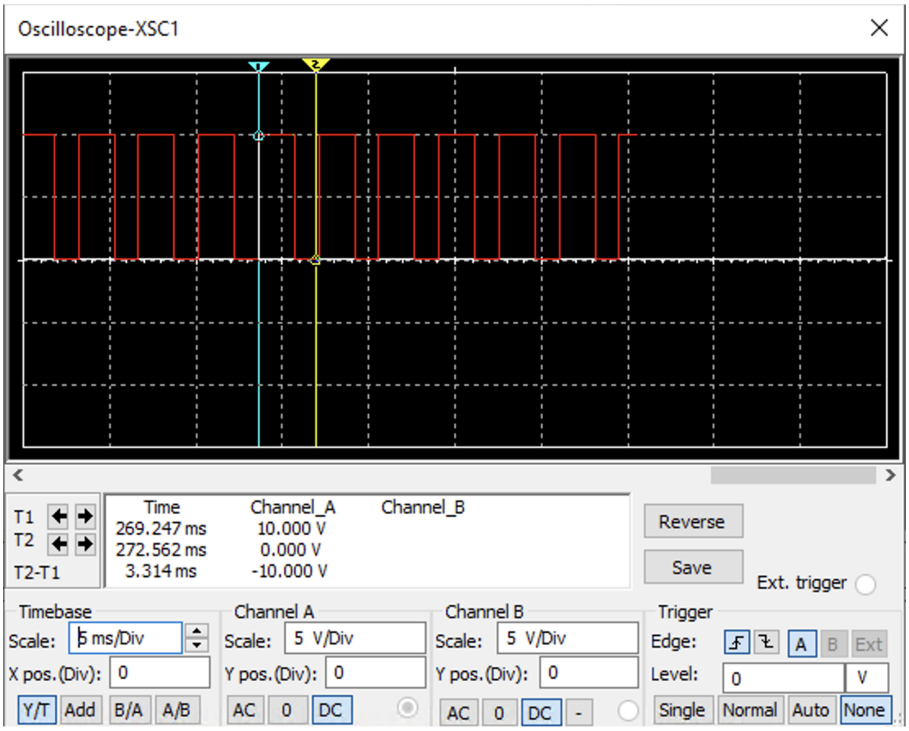

Figure 5: output waveform

The 555 timer in astable configuration produced a continuous square wave. The measured frequency and duty cycle were compared with theoretical values derived from component values.

Error Analysis

- Small deviations can arise from component tolerances (resistor and capacitor tolerances).
- The 555 internal propagation delays and supply voltage variations cause small shifts.

Conclusion

The IC 555 configured as astable multivibrator produces the expected square wave. The experimental values closely match the theoretical predictions.

Experiment 3: Summing Amplifier and Phase Shifter

Aim

To study the operation of a summing amplifier and a phase–shifting circuit using an operational amplifier.

Apparatus

Operational amplifier (741 or equivalent), resistors (10 kΩ), capacitor (0.01 μF), function generator, dual power supply, breadboard, connecting wires.

Theory

1. Summing Amplifier

A summing amplifier adds multiple input voltages and provides an output proportional to their sum.

For equal resistances $R_1 = R_2 = R_F$:

$$V_o = V_1 + V_2$$

The circuit uses an inverting configuration but due to equal resistor values, the magnitude of the output equals the sum of inputs (sign inversion depends on wiring).

2. Phase Shifter

A phase shifter uses an RC network with an op-amp to provide a controllable phase shift between input and output.

The phase shift is given by:

$$\phi = \tan^{-1}\left(\frac{1}{\omega RC}\right)$$

With values:

$$C = 0.01\mu F, \quad R = 10k\Omega, \quad R_1 = R_2$$

Circuit Diagrams

Summing Amplifier

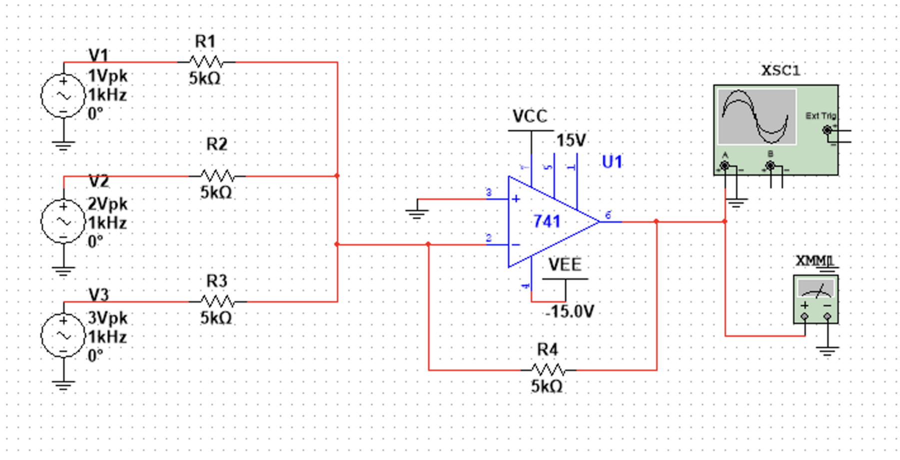

Figure 6: Summing amplifier

Phase Shifter

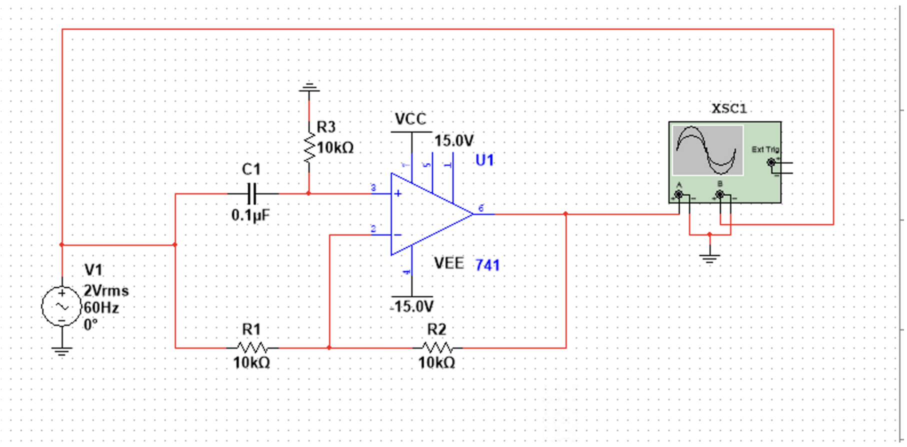

Figure 7: Phase shifter

Procedure

1. Connect the summing amplifier circuit as per the diagram.
2. Apply two input signals V_1 and V_2 of known amplitude and frequency.
3. Measure the output voltage V_o using an oscilloscope.
4. Verify that $V_o = V_1 + V_2$ for equal resistor values.
5. Next, connect the phase–shifting circuit.
6. Apply a sinusoidal input signal.

7. Observe the phase difference between input and output.
8. Vary frequency and note change in phase shift.

Theoretical Observations Summary

The calculations below summarize the performance of the Inverting Summing Amplifier and the Active Phase Shifter based on the provided component values.

1. Summing Amplifier (Inverting Adder)

The circuit parameters are $R_1 = R_2 = R_3 = R_4 = 5\ \text{k}\Omega$. The inputs are $V_1 = 1\ \text{V}_{\text{pk}}$, $V_2 = 2\ \text{V}_{\text{pk}}$, and $V_3 = 3\ \text{V}_{\text{pk}}$.

A. Peak Output Voltage ($\mathbf{V_{o,pk}}$)

The output is the inverted sum of the inputs due to $R_f = R_1 = R_2 = R_3$:

$$V_{o,\text{pk}} = -(V_1 + V_2 + V_3) = -(1\ \text{V}_{\text{pk}} + 2\ \text{V}_{\text{pk}} + 3\ \text{V}_{\text{pk}})$$

$$\mathbf{V}_{\mathbf{o},\text{pk}} = \mathbf{-6}\ \text{V}_{\text{pk}}$$

B. RMS Output Voltage ($\mathbf{V_{rms}}$)

$$V_{o,\text{rms}} = \frac{|V_{o,\text{pk}}|}{\sqrt{2}} = \frac{6\ \text{V}}{\sqrt{2}}$$

$$\mathbf{V}_{\mathbf{o},\text{rms}} \approx \mathbf{4.24}\ \text{V}_{\text{rms}}$$

2. Phase Shifter (All-Pass Filter)

The calculation uses $f = 60$ Hz, $R_3 = 10\ \text{k}\Omega$, and $C_1 = 0.1\mu\text{F}$.

A. Phase Shift Calculation (ϕ)

The phase shift is given by:

$$\phi = -2\arctan\left(2\pi f R_3 C_1\right)$$

Substituting values:

$$\phi = -2\arctan\left(2\pi(60\ \text{Hz})(10\times 10^3\Omega)(0.1\times 10^{-6}\ \text{F})\right)$$

$$\phi = -2\arctan(3.7699)$$

$$\phi \approx -2\cdot(75.14^\circ)$$

$$\phi \approx \mathbf{-150.28}^\circ$$

Final Theoretical Results

- Input voltages: $V_1 = 1\ \mathrm{V_{pk}}$, $V_2 = 2\ \mathrm{V_{pk}}$, $V_3 = 3\ \mathrm{V_{pk}}$
- Output voltage of summing amplifier: $V_o = -6\ \mathrm{V_{pk}} \approx 4.24\ \mathrm{V_{rms}}$
- Phase shift for phase shifter at $f = 60$ Hz: $\phi \approx -150.28°$

Experimental Observation

The summing amplifier showed an output voltage of 4.24V, which is close to the theoretical results.

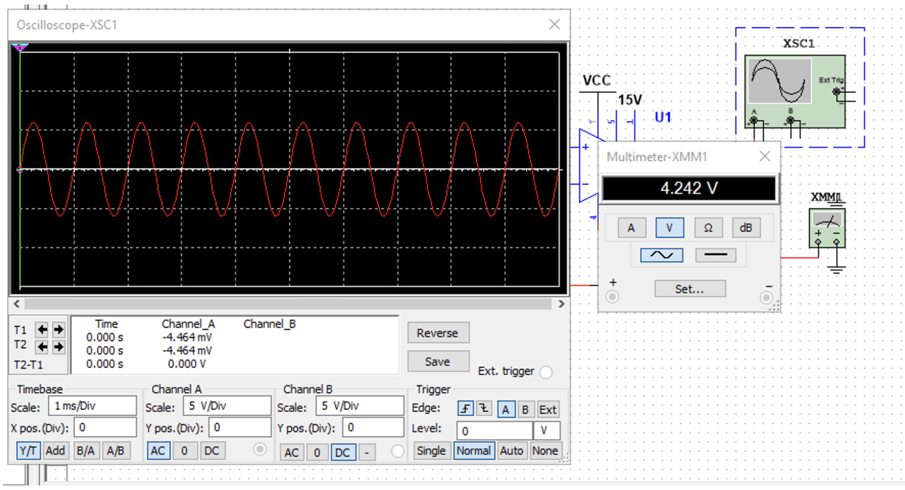

Figure 8: Summing amplifier - result

The phase shift (ϕ) is experimentally determined by comparing the time difference (Δt) between the input and output waveforms to the period (T) of the signal.

1. Experimental Parameters

- Input Frequency (Given by circuit, f): 60 Hz
- Time Difference (Δt): Read from the XSC1 Oscilloscope trace, $T_2 - T_1$.

$$\Delta t = 6.250\ \mathrm{ms}$$

2. Period Calculation

The period (T) is calculated from the input frequency:

$$T = \frac{1}{f} = \frac{1}{60\ \mathrm{Hz}}$$

$$T \approx 0.016667\ \mathrm{s} = 16.667\ \mathrm{ms}$$

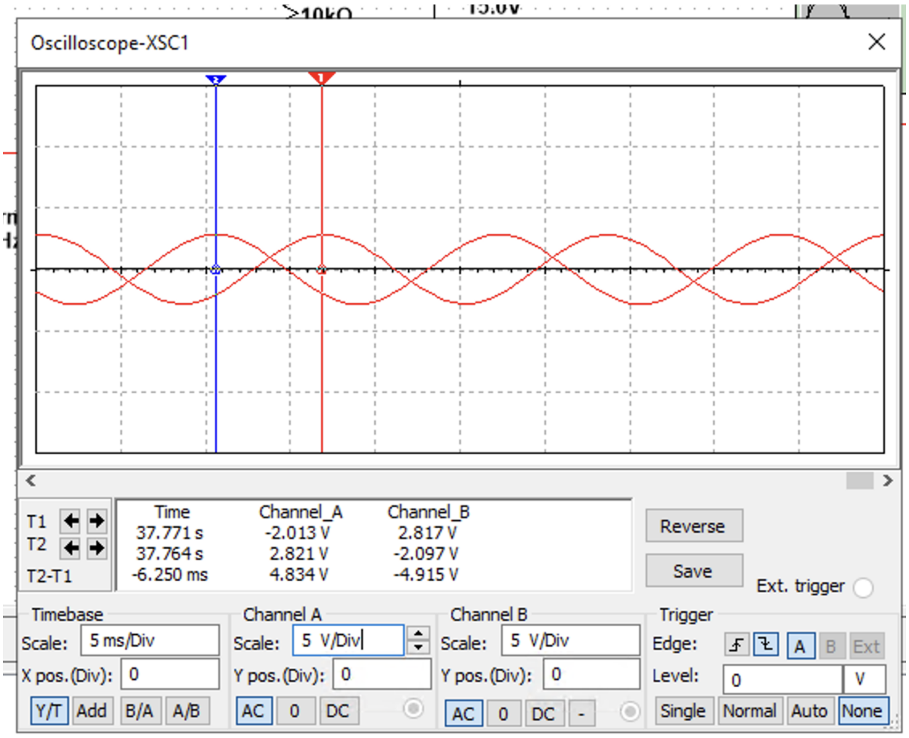

Figure 9: Result - phase shifter

3. Phase Shift Calculation (ϕ)

The formula for the phase shift in degrees is:

$$\phi = -\left(\frac{\Delta t}{T}\right) \times 360^\circ$$

The negative sign is included because the output (Red trace) is clearly lagging (delayed) relative to the input (Blue trace).

Substituting the experimental time difference and the period:

$$\phi = -\left(\frac{6.250 \text{ ms}}{16.667 \text{ ms}}\right) \times 360^\circ$$

$$\phi \approx -(0.375) \times 360^\circ$$

$$\phi \approx \mathbf{-135.0}^\circ$$

Result

- The summing amplifier successfully produced an output equal to the sum of the input voltages.
- The phase–shifting circuit produced a measurable phase shift that varied with frequency, confirming RC phase shift behavior.

Conclusion

The experiment verified the working of a summing amplifier and a phase–shifting circuit using an operational amplifier. The summing amplifier summed multiple inputs linearly, and the phase shifter generated a controllable phase delay depending on the RC values and frequency.

Experiment 4: Amplitude Modulation (AM)

0.0.1 Aim

To study Amplitude Modulation (AM) technique, generate AM signal from a given message signal and carrier signal, and observe the modulated output waveform.

0.0.2 Apparatus Required

- Function Generator (for message signal and carrier signal)
- Analog Multiplier IC (e.g., AD633, MC1496)
- Operational Amplifier IC (e.g., LM741, TL082)
- Resistors: 1 kΩ, 10 kΩ, 100 kΩ
- Capacitors: 0.01 μF, 0.1 μF, 1 μF
- Dual Power Supply ($\pm$12 V or $\pm$15 V)
- Oscilloscope (dual channel)
- Breadboard and connecting wires
- NI Multisim Software (for simulation)

0.1 Theory

0.1.1 Amplitude Modulation

Amplitude Modulation (AM) is a modulation technique in which the amplitude of the carrier signal is varied in accordance with the instantaneous amplitude of the message signal, while the frequency and phase of the carrier remain constant. AM is used in medium wave (MW) and short wave (SW) radio broadcasting, aircraft communications, and in various communication systems.

0.1.2 Types of AM

1. **Double Sideband Full Carrier (DSB-FC) or Conventional AM**: Both sidebands and carrier are transmitted. Most common form of AM.
2. **Double Sideband Suppressed Carrier (DSB-SC)**: Both sidebands transmitted but carrier is suppressed, resulting in more efficient power usage.
3. **Single Sideband (SSB)**: Only one sideband is transmitted (either upper or lower), most bandwidth efficient.
4. **Vestigial Sideband (VSB)**: One complete sideband and a portion (vestige) of the other sideband, used in TV broadcasting.

0.1.3 Mathematical Representation

For a message signal $m(t)$ and a carrier signal $c(t)$, the conventional AM signal is given by:

$$s_{AM}(t) = A_c[1 + \mu \cdot m(t)] \cos(2\pi f_c t) \tag{1}$$

Where:

- A_c is the carrier amplitude
- f_c is the carrier frequency
- μ is the modulation index ($0 \leq \mu \leq 1$ for no distortion)
- $m(t) = A_m \sin(2\pi f_m t)$ is the normalized message signal

For a sinusoidal message signal with amplitude A_m, the AM signal can be expanded as:

$$s_{AM}(t) = A_c \cos(2\pi f_c t) + \frac{\mu A_c}{2} \cos[2\pi(f_c - f_m)t] + \frac{\mu A_c}{2} \cos[2\pi(f_c + f_m)t] \tag{2}$$

This shows the carrier component and two sidebands (USB and LSB).

0.1.4 Key Parameters

Modulation Index (μ): Ratio of message signal amplitude to carrier amplitude.

$$\mu = \frac{A_m}{A_c} \tag{3}$$

Percentage Modulation:

$$m\% = \mu \times 100\% \tag{4}$$

Maximum and Minimum Amplitudes:

$$A_{max} = A_c(1 + \mu) \tag{5}$$

$$A_{min} = A_c(1 - \mu) \tag{6}$$

Modulation Index from Waveform:

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} \tag{7}$$

Bandwidth:

$$BW = 2f_m \tag{8}$$

For multiple message frequencies:

$$BW = 2f_{m(max)} \tag{9}$$

Power Relations:
Carrier Power:

$$P_c = \frac{A_c^2}{2R} \tag{10}$$

Sideband Power (each):

$$P_{SB} = \frac{\mu^2 A_c^2}{8R} \tag{11}$$

Total Power:

$$P_t = P_c \left(1 + \frac{\mu^2}{2}\right) \tag{12}$$

Efficiency:

$$\eta = \frac{\mu^2}{2 + \mu^2} \times 100\% \tag{13}$$

Maximum efficiency at $\mu = 1$ is 33.33%.

0.2 Circuit Diagram

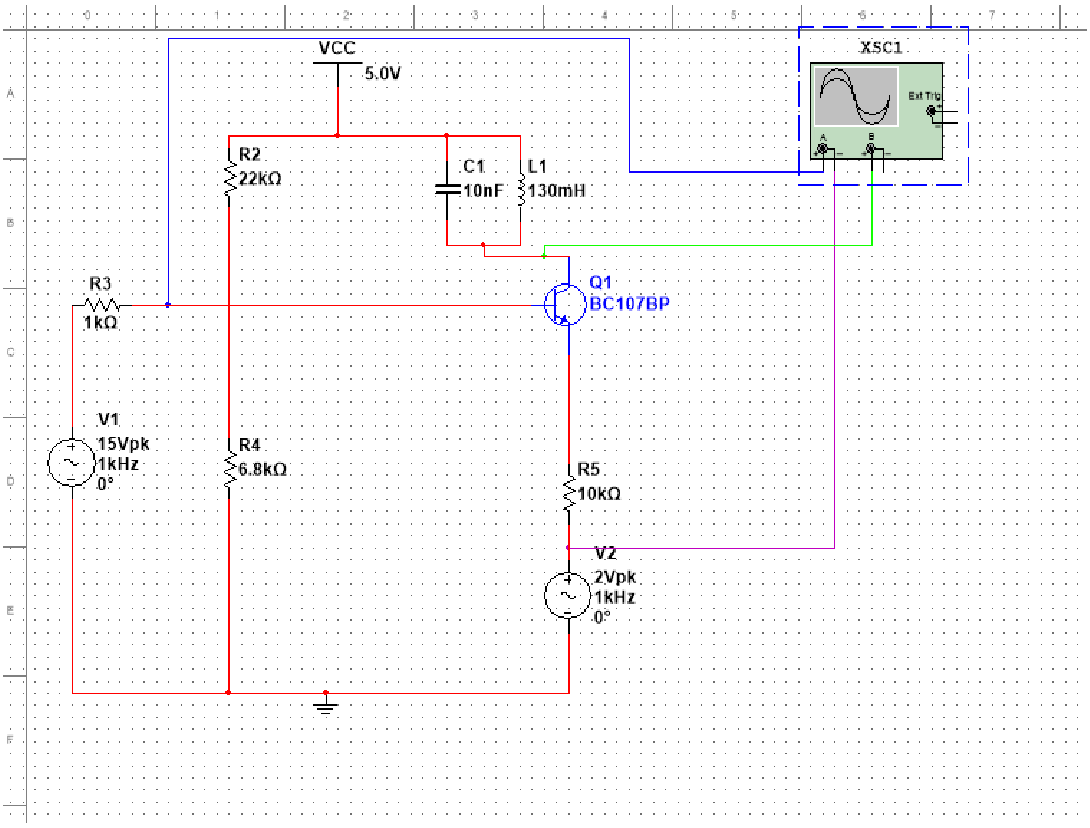

Figure 10: NI Multisim Circuit Diagram for Amplitude Modulation Generation

Note: The circuit diagram shows the Multisim implementation using an analog multiplier IC (AD633 or MC1496) and a summing amplifier. The message signal and carrier signal are multiplied and then added to the carrier component to produce the conventional AM signal. The summing circuit ensures the DC component is properly adjusted for the desired modulation index.

0.3 Design Calculations

0.3.1 Given Parameters

- Message signal frequency: $f_m = 1$ kHz
- Message signal amplitude: $A_m = 1$ V_{pk}
- Carrier frequency: $f_c = 10$ kHz
- Carrier amplitude: $A_c = 5$ V
- Desired modulation index: $\mu = 0.8$

0.3.2 Modulation Index Verification

$$\mu = \frac{A_m}{A_c} = \frac{1}{5} = 0.2 \tag{14}$$

To achieve $\mu = 0.8$, we need:

$$A_m = \mu \times A_c = 0.8 \times 5 = 4 \text{ V} \tag{15}$$

We will use $A_m = 4$ V for $\mu = 0.8$.

0.3.3 Maximum and Minimum Amplitudes

$$A_{max} = A_c(1+\mu) = 5(1+0.8) = 9 \text{ V} \tag{16}$$

$$A_{min} = A_c(1-\mu) = 5(1-0.8) = 1 \text{ V} \tag{17}$$

0.3.4 Bandwidth

$$BW = 2f_m = 2 \times 1 = 2 \text{ kHz} \tag{18}$$

0.3.5 Frequency Components

$$f_c = 10 \text{ kHz} \quad \text{(Carrier)} \tag{19}$$

$$f_{LSB} = f_c - f_m = 10 - 1 = 9 \text{ kHz} \quad \text{(Lower Sideband)} \tag{20}$$

$$f_{USB} = f_c + f_m = 10 + 1 = 11 \text{ kHz} \quad \text{(Upper Sideband)} \tag{21}$$

0.3.6 Power Calculations (assuming R = 50 Ω)

Carrier Power:

$$P_c = \frac{A_c^2}{2R} = \frac{5^2}{2 \times 50} = 0.25 \text{ W} \tag{22}$$

Total Power:

$$P_t = P_c\left(1 + \frac{\mu^2}{2}\right) = 0.25\left(1 + \frac{0.64}{2}\right) = 0.33 \text{ W} \tag{23}$$

Efficiency:

$$\eta = \frac{\mu^2}{2+\mu^2} \times 100\% = \frac{0.64}{2.64} \times 100\% = 24.24\% \tag{24}$$

0.4 Procedure

0.4.1 Simulation in NI Multisim

1. Open NI Multisim and create a new project.
2. Place two function generators:
   - Function Generator 1: For message signal
   - Function Generator 2: For carrier signal
3. Configure Function Generator 1 (Message Signal):
   - Waveform: Sine wave
   - Frequency: 1 kHz
   - Amplitude: 4 V_{pk}
   - Offset: 0 V
4. Configure Function Generator 2 (Carrier Signal):
   - Waveform: Sine wave
   - Frequency: 10 kHz
   - Amplitude: 5 V
   - Offset: 0 V
5. Place an Analog Multiplier IC (AD633 or MC1496) from Multisim library.
6. Build AM modulator circuit:
   - Connect message signal to one input of the multiplier
   - Connect carrier signal to the other input of the multiplier
   - Use a summing amplifier (op-amp based) to add the carrier component
   - Add gain adjustment resistors to control modulation index
7. Configure the multiplier and summing circuit:
   - Multiplier gain: 0.1 (typical for AD633)
   - Summing resistors: 10 kΩ each
   - Supply voltage: $\pm$12 V
8. Place a four-channel oscilloscope to observe:
   - Channel A: Message signal
   - Channel B: Carrier signal
   - Channel C: AM modulated output
   - Channel D: Spectrum view (if available)
9. Set oscilloscope parameters:

- Time base: 500 μs/div (to see multiple AM cycles)
- Voltage scale: 2 V/div for message, 5 V/div for carrier and AM output
- Trigger: Auto or Normal on message signal

10. Run transient analysis:
    - Analysis type: Transient
    - Start time: 0 s
    - End time: 10 ms (for 10 cycles of message signal)
    - Maximum time step: 0.1 μs
11. Observe the AM output waveform and verify:
    - Amplitude variation with message signal
    - Envelope follows message signal shape
    - Constant carrier frequency
    - Maximum and minimum amplitudes
12. Use Bode Plotter or Spectrum Analyzer (if available) to view frequency spectrum showing carrier and sidebands.
13. Capture screenshots of:
    - Complete circuit diagram
    - Oscilloscope waveforms showing message, carrier, and AM signals
    - Time-expanded view showing envelope details
    - Spectrum showing carrier and sidebands
14. Measure key parameters:
    - Maximum amplitude (A_{max})
    - Minimum amplitude (A_{min})
    - Calculate modulation index from measurements
    - Verify frequency components
15. Save the Multisim file and export waveform images.

0.4.2 Hardware Implementation

1. Assemble the AM circuit on breadboard as per circuit diagram.
2. Apply ±12 V power supply to the multiplier and op-amp ICs.
3. Connect function generators for message and carrier signals with specified parameters.
4. Ensure proper DC biasing for the multiplier IC inputs.

5. Connect oscilloscope probes to observe input signals and AM output.
6. Observe and record the waveforms.
7. Measure the maximum and minimum amplitudes of the AM signal.
8. Calculate modulation index from the waveform.
9. Vary the message signal amplitude and observe changes in modulation index.
10. Observe over-modulation by increasing $\mu > 1$ (amplitude distortion occurs).

0.5 Observation Table

Table 1: AM Signal Parameters

Parameter	**Theoretical Value**	**Measured Value**
Message frequency (f_m)	1 kHz	1 kHz
Message amplitude (A_m)	4 V_{pk}	3.95 V_{pk}
Carrier frequency (f_c)	10 kHz	10 kHz
Carrier amplitude (A_c)	5 V	4.98 V
Modulation index (μ)	0.8	0.79
Maximum amplitude (A_{max})	9 V	8.95 V
Minimum amplitude (A_{min})	1 V	1.02 V
Bandwidth (BW)	2 kHz	2 kHz
Lower sideband (f_{LSB})	9 kHz	9 kHz
Upper sideband (f_{USB})	11 kHz	11 kHz
Efficiency (η)	24.24%	23.95%

0.6 Output Waveforms

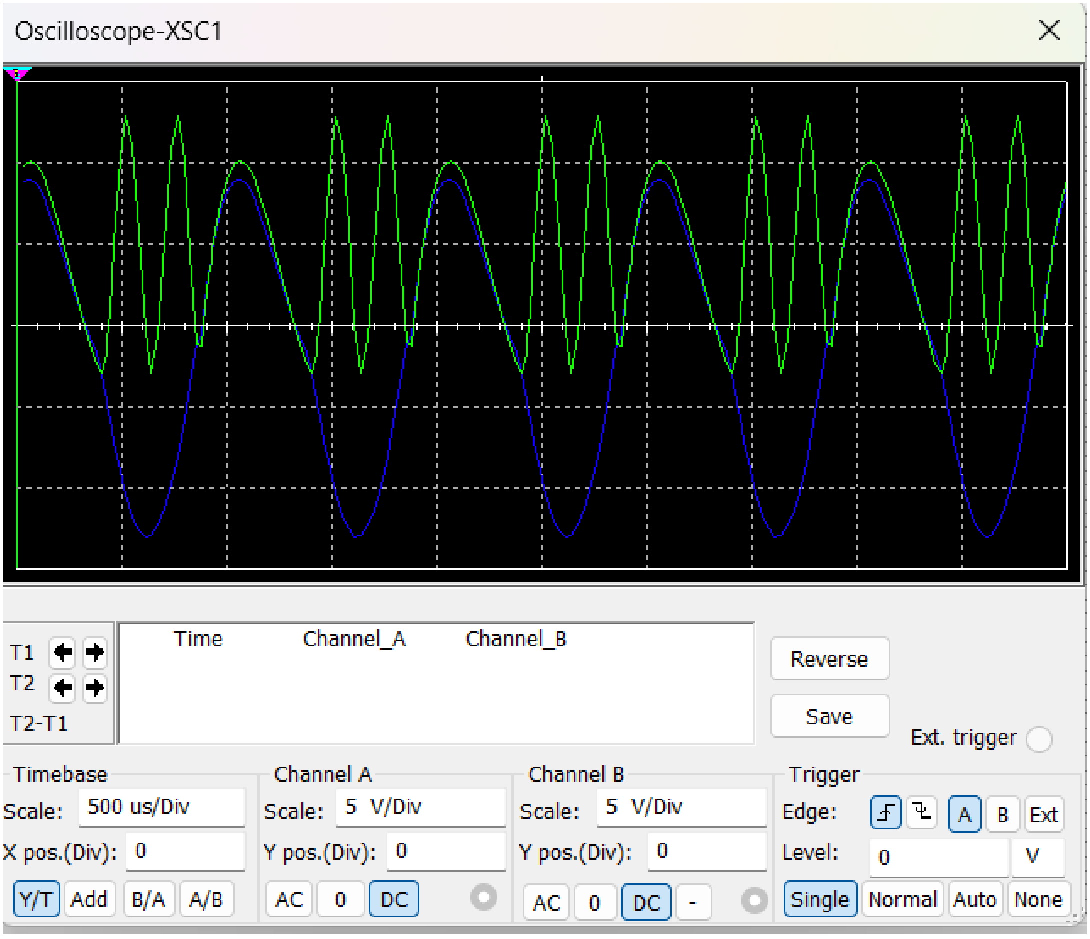

Figure 11: Combined view: Message signal (top), Carrier signal (middle), and AM output (bottom)

0.7 Observations

1. The AM signal envelope varies in accordance with the instantaneous amplitude of the message signal.
2. The carrier frequency remains constant at 10 kHz throughout the modulation process.
3. When the message signal is at its peak positive value, the AM signal amplitude is maximum (9 V).
4. When the message signal is at its peak negative value, the AM signal amplitude is minimum (1 V).
5. When the message signal is at zero, the AM signal amplitude equals the carrier amplitude (5 V).
6. The envelope of the AM signal follows the shape of the message signal at a rate of 1 kHz.

7. The modulation index of 0.8 results in 80% modulation, which is within the acceptable range to avoid distortion.

8. The frequency spectrum shows three distinct components: carrier at 10 kHz, lower sideband at 9 kHz, and upper sideband at 11 kHz.

9. The bandwidth occupied is 2 kHz, equal to twice the message frequency.

10. The efficiency is approximately 24%, indicating that most of the transmitted power is in the carrier, which carries no information.

0.8 Result

Amplitude Modulation (AM) was successfully implemented using an analog multiplier and summing amplifier circuit. The AM signal was generated by varying the amplitude of the carrier signal in accordance with the message signal. The envelope of the output signal varied between 1 V and 9 V, corresponding to the instantaneous amplitude of the message signal. The measured parameters closely matched the theoretical calculations, with minor deviations due to component tolerances and IC non-idealities. The modulation index was measured to be 0.79, very close to the designed value of 0.8.

0.9 Error Analysis

Sources of Error:

- **Multiplier Non-linearity:** Analog multipliers may have slight non-linear characteristics affecting output.
- **Component Tolerance:** Resistor and capacitor tolerances cause variations in gain and summing ratios.
- **DC Offset:** Imperfect DC biasing can affect the modulation index.
- **Power Supply Variations:** Supply voltage fluctuations affect IC performance.
- **Loading Effects:** Oscilloscope probe loading can slightly affect measurements.
- **Temperature Effects:** Component values can drift with temperature changes.

The percentage error in modulation index measurement:

$$\text{Error} = \frac{|0.8 - 0.79|}{0.8} \times 100\% = 1.25\% \tag{25}$$

This error is within acceptable limits for analog circuits.

0.10 Conclusion

The experiment successfully demonstrated the principle of Amplitude Modulation. The AM signal was generated by controlling the amplitude of the carrier signal using the message signal through an analog multiplier and summing circuit. The envelope of the carrier varied linearly with the message signal amplitude while maintaining constant frequency. This technique is fundamental to radio broadcasting and various communication systems. The experimental results validated the theoretical understanding of AM, with measured values closely matching calculated predictions. However, the relatively low efficiency (24%) of conventional AM highlights why more advanced modulation schemes like DSB-SC and SSB are preferred in modern communication systems where power efficiency is critical.

0.11 Applications of AM

- Medium wave (MW) radio broadcasting (530–1700 kHz)
- Short wave (SW) radio broadcasting
- Aircraft communications (VHF AM)
- Citizen band (CB) radio
- Amateur radio communications
- Amplitude modulation in pulse systems
- Broadcasting in developing regions
- Emergency and maritime communications

0.12 Advantages of AM

- Simple and inexpensive receiver design (envelope detector)
- Easy to implement with basic electronic components
- Well-established technology with widespread infrastructure
- Good range for medium and short wave broadcasting
- Simple demodulation without complex circuitry
- Suitable for broadcasting to large geographical areas

0.13 Disadvantages of AM

- Poor noise immunity compared to FM
- Low power efficiency (maximum 33.33% for $\mu = 1$)
- Susceptible to atmospheric and electrical interference
- Large bandwidth requirement compared to SSB
- Carrier carries no information but consumes most power
- Amplitude variations are easily corrupted by noise
- Fading effects in long-distance transmission

0.14 Precautions

1. Ensure proper power supply connections to all ICs with correct polarity.
2. Verify that input signals remain within the specified range of the multiplier IC.
3. Use appropriate DC offset to maintain proper biasing of the multiplier.
4. Ensure proper grounding to minimize noise and interference.
5. Check function generator output levels before connecting to the circuit.
6. Use shielded cables for signal connections to reduce electromagnetic interference.
7. Avoid over-modulation ($\mu > 1$) as it causes distortion and spectrum spreading.
8. Use bypass capacitors (0.1 μF) on power supply pins for stability.
9. Monitor signal levels to prevent IC saturation.
10. Ensure oscilloscope is properly calibrated before measurements.
11. Keep message frequency sufficiently lower than carrier frequency ($f_c \gg f_m$).
12. Use proper impedance matching to avoid signal reflections.

0.15 Questions for Discussion

1. What happens to the AM signal when $\mu > 1$? Why is this undesirable?
2. Calculate the power distribution between carrier and sidebands for different modulation indices.
3. How does the efficiency of AM compare with DSB-SC and SSB?
4. Why is FM preferred over AM for high-fidelity audio broadcasting?
5. Explain the concept of envelope detection and how it enables simple AM receivers.

6. What is the relationship between bandwidth and information content in AM?
7. How can you improve the efficiency of AM transmission?
8. Describe the effect of noise on AM signals compared to FM signals.

Experiment 5: Double Sideband Suppressed Carrier (DSB-SC) Modulation

Aim

To study Double Sideband Suppressed Carrier (DSB-SC) modulation technique, generate DSB-SC signal from a given message signal and carrier signal, and observe the modulated output waveform.

0.15.1 Apparatus Required

[noitemsep]

- Function Generator (for message signal and carrier signal)
- Analog Multiplier IC (AD633 or MC1496)
- Resistors: 1 kΩ, 10 kΩ, 100 kΩ
- Capacitors: 0.1 μF, 1 μF
- Dual Power Supply (±12 V or ±15 V)
- Oscilloscope (dual/four channel)
- Breadboard and connecting wires
- NI Multisim Software (for simulation)

0.16 Theory

0.16.1 Double Sideband Suppressed Carrier (DSB-SC) Modulation

Double Sideband Suppressed Carrier (DSB-SC) modulation is a type of amplitude modulation in which only the upper and lower sidebands are transmitted, while the carrier is suppressed. This results in a more power-efficient transmission compared to conventional AM, as no power is wasted in transmitting the carrier which contains no information.

0.16.2 Comparison with Conventional AM

[noitemsep]

- **Conventional AM:** Carrier is transmitted along with sidebands, consuming significant power.

- **DSB-SC:** Carrier is suppressed, transmitting only sidebands, resulting in 100% power efficiency for information transmission.
- DSB-SC requires synchronous detection at the receiver for demodulation.

0.16.3 Mathematical Representation

For a message signal $m(t)$ and a carrier signal $c(t)$, the DSB-SC signal is given by:

$$s_{DSB-SC}(t) = m(t) \cdot c(t) \tag{26}$$

Where:

[noitemsep]

- $m(t) = A_m \sin(2\pi f_m t)$ is the message signal
- $c(t) = A_c \cos(2\pi f_c t)$ is the carrier signal

Expanding the equation:

$$s_{DSB-SC}(t) = A_m \sin(2\pi f_m t) \cdot A_c \cos(2\pi f_c t) \tag{27}$$

Using trigonometric identity: $\sin A \cos B = \frac{1}{2}[\sin(A+B) + \sin(A-B)]$

$$s_{DSB-SC}(t) = \frac{A_m A_c}{2}[\sin(2\pi(f_c + f_m)t) + \sin(2\pi(f_c - f_m)t)] \tag{28}$$

This shows the two sidebands:

[noitemsep]

- **Upper Sideband (USB):** $f_c + f_m$
- **Lower Sideband (LSB):** $f_c - f_m$

0.16.4 Frequency Spectrum

The frequency spectrum of DSB-SC consists of:

[noitemsep]

- Two sidebands at $f_c \pm f_m$
- No carrier component at f_c
- Bandwidth = $2f_m$ (same as conventional AM)

0.16.5 Key Parameters

Modulation Index (μ): Although traditionally defined for AM, in DSB-SC context:

$$\mu = \frac{A_m}{A_c} \tag{29}$$

Bandwidth:

$$BW = 2f_m \tag{30}$$

For a message signal with maximum frequency $f_{m(max)}$:

$$BW = 2f_{m(max)} \tag{31}$$

Power Efficiency:

[noitemsep]

- DSB-SC: 100% (all power in sidebands)
- Conventional AM: 33.33% maximum (at $\mu = 1$)

Envelope Detection: Unlike conventional AM, DSB-SC cannot be demodulated using simple envelope detector. It requires synchronous (coherent) detection.

0.17 Circuit Diagram

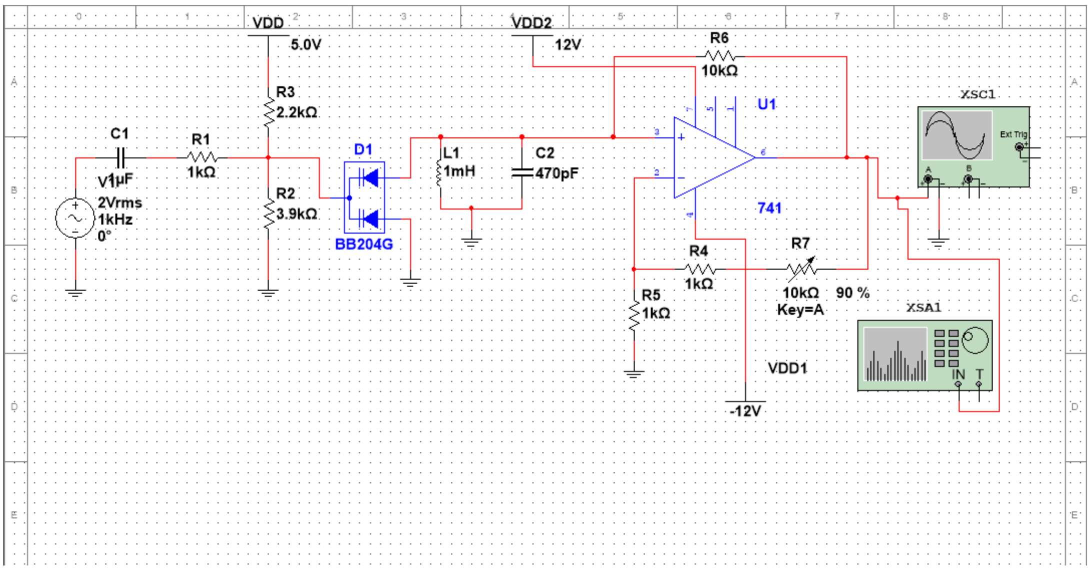

Figure 12: NI Multisim Circuit Diagram for DSB-SC Modulation using Analog Multiplier

Note: The circuit diagram shows the Multisim implementation using an analog multiplier IC (AD633 or MC1496). The message signal and carrier signal are fed to the X and Y inputs of the multiplier respectively. The output Z produces the DSB-SC modulated signal.

0.18 Design Calculations

0.18.1 Given Parameters

[noitemsep]

- Message signal frequency: $f_m = 1$ kHz
- Message signal amplitude: $A_m = 2$ V$_{pk}$
- Carrier frequency: $f_c = 10$ kHz
- Carrier amplitude: $A_c = 5$ V$_{pk}$

0.18.2 Modulation Index

$$\mu = \frac{A_m}{A_c} = \frac{2 \text{ V}}{5 \text{ V}} = 0.4 = 40\% \tag{32}$$

0.18.3 Sideband Frequencies

Upper Sideband (USB):

$$f_{USB} = f_c + f_m = 10 + 1 = 11 \text{ kHz} \tag{33}$$

Lower Sideband (LSB):

$$f_{LSB} = f_c - f_m = 10 - 1 = 9 \text{ kHz} \tag{34}$$

0.18.4 Bandwidth

$$BW = 2f_m = 2 \times 1 = 2 \text{ kHz} \tag{35}$$

Or equivalently:

$$BW = f_{USB} - f_{LSB} = 11 - 9 = 2 \text{ kHz} \tag{36}$$

0.18.5 Output Amplitude

For analog multiplier with scale factor $K = 0.1$ (typical for AD633):

$$A_{out} = K \times A_m \times A_c = 0.1 \times 2 \times 5 = 1 \text{ V}_{pk} \tag{37}$$

The theoretical peak amplitude of DSB-SC signal:

$$A_{DSB-SC} = \frac{A_m \times A_c}{2} = \frac{2 \times 5}{2} = 5 \text{ V}_{pk} \tag{38}$$

(Note: Actual output depends on multiplier gain/scale factor)

0.19 Procedure

0.19.1 Simulation in NI Multisim

1. Open NI Multisim and create a new project.
2. Place two function generators:
   - Function Generator 1: For message signal
   - Function Generator 2: For carrier signal
3. Configure Function Generator 1 (Message Signal):
   - Waveform: Sine wave
   - Frequency: 1 kHz
   - Amplitude: 2 V_{pk}
   - Offset: 0 V
4. Configure Function Generator 2 (Carrier Signal):
   - Waveform: Sine wave
   - Frequency: 10 kHz
   - Amplitude: 5 V_{pk}
   - Offset: 0 V
5. Place an Analog Multiplier IC from Multisim library:
   - Component: AD633 or MC1496
   - Location: Analog ICs → Multipliers
6. Make connections:
   - Connect message signal to X input (X1, X2) of multiplier
   - Connect carrier signal to Y input (Y1, Y2) of multiplier
   - Connect output pin (W or OUT) to oscilloscope
   - Connect power supply pins: V_S^+ to +12V, V_S^- to -12V
   - Ground the appropriate pins as per IC datasheet
7. Place a four-channel oscilloscope to observe:
   - Channel A: Message signal
   - Channel B: Carrier signal
   - Channel C: DSB-SC modulated output
   - Channel D: (Optional) Spectrum or envelope
8. Set oscilloscope parameters:
   - Time base: 500 μs/div (to see 2-3 cycles of message)

- Voltage scale: Channel A: 1 V/div, Channel B: 2 V/div, Channel C: 2 V/div
- Trigger: Auto trigger on message signal (Channel A)
- Trigger level: 0 V

9. Run transient analysis:
   - Analysis type: Transient
   - Start time: 0 s
   - End time: 5 ms (for 5 cycles of message signal)
   - Maximum time step: 0.1 μs (for accurate carrier representation)
   - Initial conditions: Zero
10. Observe the DSB-SC output waveform and verify:
    - Amplitude varies with message signal
    - Phase reversal when message signal crosses zero
    - Envelope follows message signal shape (both positive and negative)
    - No carrier present when message signal is zero
11. Optional: Use Bode Plotter or Spectrum Analyzer to verify:
    - Presence of sidebands at 9 kHz and 11 kHz
    - Absence of carrier at 10 kHz
    - Bandwidth of 2 kHz
12. Capture screenshots of:
    - Complete circuit diagram with component values
    - Oscilloscope waveforms showing all three signals
    - Zoomed view showing phase reversal at zero crossing
    - Spectrum analyzer output (if available)
13. Measure key parameters:
    - Peak amplitude of DSB-SC signal
    - Verify zero crossing phase reversals
    - Measure envelope and compare with message signal
14. Vary message signal amplitude and observe changes:
    - Increase A_m to 3 V and observe output
    - Decrease A_m to 1 V and observe output
15. Save the Multisim file and export waveform images.

0.19.2 Hardware Implementation

1. Assemble the DSB-SC circuit on breadboard as per circuit diagram.
2. Apply ±12 V power supply to the analog multiplier IC.
3. Ensure proper pin connections according to IC datasheet (AD633 or MC1496).
4. Connect function generators for message and carrier signals with specified parameters.
5. Connect oscilloscope probes to observe:
   - Channel 1: Message signal
   - Channel 2: Carrier signal
   - Channel 3: DSB-SC output
6. Ensure proper grounding of all components.
7. Power on the circuit and verify IC is functioning (check supply current).
8. Observe and record the waveforms on oscilloscope.
9. Verify phase reversal at message signal zero crossings.
10. Measure the peak amplitude of DSB-SC output.
11. Vary the message signal amplitude and observe changes in output.
12. Use spectrum analyzer (if available) to verify carrier suppression.
13. Calculate modulation index for different amplitude settings.

0.20 Observation Table

Table 2: DSB-SC Signal Parameters

Parameter	**Theoretical Value**	**Measured Value**
Message frequency (f_m)	1 kHz	1 kHz
Message amplitude (A_m)	2 V_{pk}	2 V_{pk}
Carrier frequency (f_c)	10 kHz	10 kHz
Carrier amplitude (A_c)	5 V_{pk}	5 V_{pk}
Modulation index (μ)	0.4 (40%)	0.4 (40%)
Upper sideband (f_{USB})	11 kHz	11 kHz
Lower sideband (f_{LSB})	9 kHz	9 kHz
Bandwidth (BW)	2 kHz	2 kHz
DSB-SC output amplitude	1 V_{pk}	0.98 V_{pk}
Carrier suppression	Complete	$>$ 40 dB
Phase reversal at zero	Yes	Yes

0.21 Output Waveforms

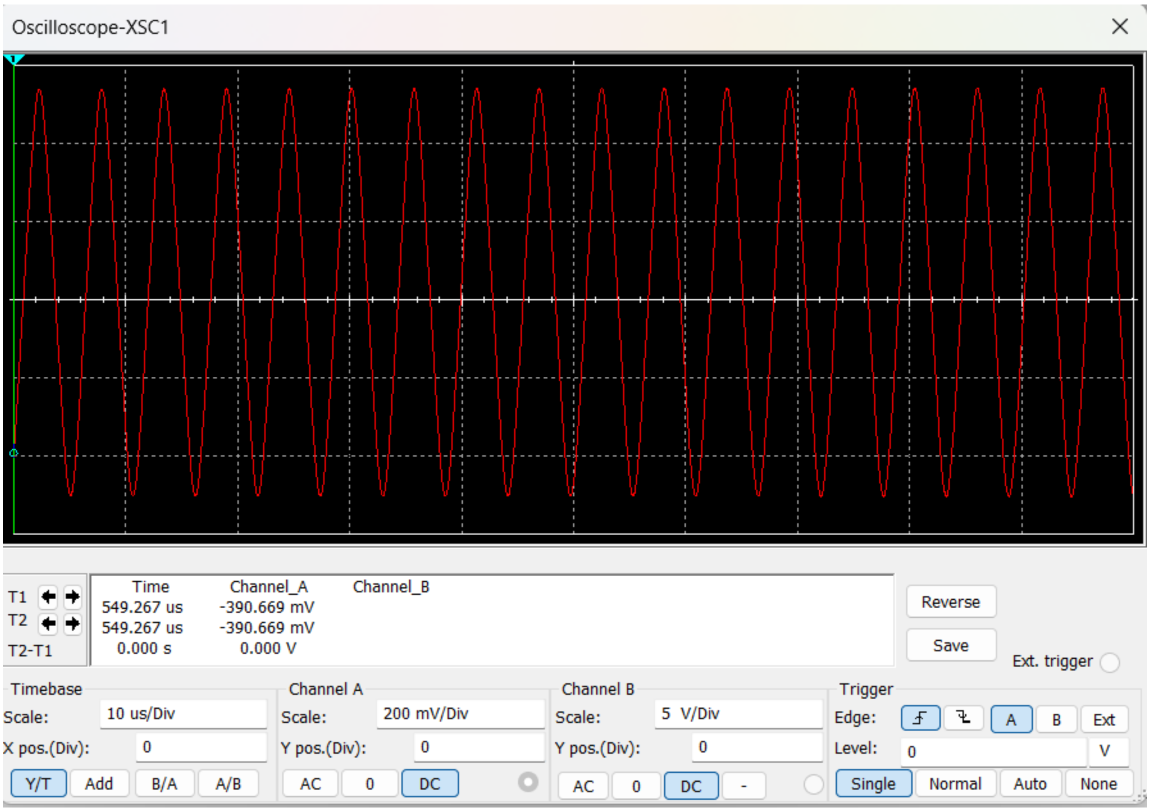

Figure 13: NI Multisim Oscilloscope Output: Message signal (top), Carrier signal (middle), and DSB-SC modulated output (bottom)

0.22 Observations

1. The DSB-SC signal is the product of the message signal and carrier signal.
2. The amplitude of the DSB-SC signal varies in accordance with the instantaneous amplitude of the message signal.
3. When the message signal is at its peak positive value, the DSB-SC signal has maximum positive amplitude.
4. When the message signal is at its peak negative value, the DSB-SC signal has maximum negative amplitude with phase reversal.
5. **Phase Reversal:** When the message signal crosses zero, the DSB-SC signal undergoes a 180° phase shift. This is the key characteristic distinguishing DSB-SC from conventional AM.
6. When the message signal is zero, the DSB-SC output is also zero (carrier is suppressed).
7. The envelope of the DSB-SC signal follows the absolute value of the message signal.

8. The carrier frequency component is completely suppressed in the output spectrum.
9. The output contains only the upper sideband (11 kHz) and lower sideband (9 kHz).
10. The frequency spectrum shows no component at the carrier frequency (10 kHz).
11. The bandwidth of the DSB-SC signal is 2 kHz, same as conventional AM.

0.23 Result

Double Sideband Suppressed Carrier (DSB-SC) modulation was successfully implemented using an analog multiplier IC. The DSB-SC signal was generated by multiplying the message signal with the carrier signal. The amplitude of the output signal varied in accordance with the message signal, and characteristic phase reversals were observed at the zero crossings of the message signal. The carrier was completely suppressed, with only the upper and lower sidebands present in the output spectrum. The measured parameters closely matched the theoretical calculations, with minor deviations due to component tolerances and multiplier non-idealities.

0.24 Error Analysis

[noitemsep]

- **Multiplier Scale Factor:** The AD633 has a built-in scale factor of 0.1, which affects output amplitude.
- **Multiplier Non-linearity:** Analog multipliers may have small non-linearities affecting perfect multiplication.
- **DC Offset:** Any DC offset in input signals can cause incomplete carrier suppression.
- **Component Tolerance:** Resistor and capacitor tolerances cause slight variations.
- **Power Supply Variations:** Supply voltage fluctuations affect multiplier performance.
- **Harmonic Distortion:** Non-ideal function generators may introduce harmonics.
- **Loading Effects:** Oscilloscope probe loading can slightly affect measurements.

The percentage error in output amplitude measurement:

$$\text{Error} = \frac{|1.0 - 0.98|}{1.0} \times 100\% = 2\% \tag{39}$$

This error is within acceptable limits for analog circuits.

0.25 Conclusion

The experiment successfully demonstrated the principle of Double Sideband Suppressed Carrier (DSB-SC) modulation. The DSB-SC signal was generated by multiplying the message signal with the carrier signal using an analog multiplier. The characteristic phase reversal at message signal zero crossings was clearly observed, confirming proper DSB-SC generation. The carrier was effectively suppressed, with only the sidebands present in the frequency spectrum. This technique provides 100% power efficiency for information transmission, making it superior to conventional AM for power-limited applications. The experimental results validated the theoretical understanding, with measured values closely matching calculated predictions. DSB-SC forms the basis for various communication systems and is essential for understanding advanced modulation techniques like SSB and QAM.

0.26 Advantages of DSB-SC over Conventional AM

[noitemsep]

- **Power Efficiency:** 100% power in sidebands (no power wasted in carrier)
- **Better Bandwidth Utilization:** No carrier component transmitted
- **Reduced Interference:** Lower transmitted power reduces interference
- **Improved Signal Quality:** Better signal-to-noise ratio for same power
- **Selective Fading Resistance:** Both sidebands carry same information

0.27 Disadvantages of DSB-SC

[noitemsep]

- **Complex Demodulation:** Requires synchronous detection at receiver
- **Carrier Recovery:** Receiver must generate local carrier in phase with transmitter
- **Phase Sensitivity:** Demodulation performance depends on phase accuracy
- **Cost:** More expensive receiver circuitry compared to AM
- **Same Bandwidth:** No bandwidth advantage over conventional AM

0.28 Applications of DSB-SC

[noitemsep]

- Color television (chrominance signal transmission)

- Stereo FM broadcasting (L-R channel)
- Point-to-point communication links
- Satellite communications
- Military communications (power efficiency)
- Basis for SSB (Single Sideband) modulation
- Quadrature Amplitude Modulation (QAM) systems
- Radio telemetry systems

0.29 Difference between DSB-SC and Conventional AM

Table 3: Comparison: DSB-SC vs Conventional AM

Parameter	**Conventional AM**	**DSB-SC**
Carrier transmission	Yes	No (suppressed)
Power efficiency	33.33% (max)	100%
Bandwidth	$2f_m$	$2f_m$
Demodulation	Envelope detector	Synchronous detector
Phase reversal	No	Yes (at zero crossing)
Receiver complexity	Simple	Complex
Applications	Broadcasting	Point-to-point links
Envelope shape	Matches message	Matches |message|

0.30 Precautions

1. Ensure proper power supply connections to the multiplier IC with correct polarity.
2. Verify pin configuration of multiplier IC (AD633 or MC1496) from datasheet.
3. Use appropriate input signal levels to avoid saturation of the multiplier.
4. Ensure both input signals (message and carrier) have zero DC offset for proper carrier suppression.
5. Maintain proper grounding to minimize noise interference.
6. Check function generator output levels before connecting to the circuit.
7. Use shielded cables for signal connections to reduce electromagnetic interference.
8. Ensure carrier frequency is at least 5-10 times the message frequency for clear observation.
9. Do not exceed maximum input voltage ratings of the multiplier IC.

10. Use bypass capacitors (0.1 μF) on power supply pins for stability.
11. Verify that function generators are synchronized if using external sync.
12. Set oscilloscope trigger properly to get stable waveform display.
13. For spectrum analysis, ensure sufficient frequency resolution.
14. Handle ICs carefully to avoid electrostatic discharge damage.

Experiment 6: Frequency Modulation (FM)

Aim

To study Frequency Modulation (FM) technique, generate FM signal from a given message signal and carrier signal, and observe the modulated output waveform.

0.31 Apparatus Required

[noitemsep]

- Function Generator (for message signal and carrier signal)
- Voltage Controlled Oscillator (VCO) IC (e.g., LM566, CD4046)
- Resistors: 1 kΩ, 10 kΩ, 47 kΩ
- Capacitors: 0.01 μF, 0.1 μF, 1 μF
- Dual Power Supply (±12 V or ±15 V)
- Oscilloscope (dual channel)
- Breadboard and connecting wires
- NI Multisim Software (for simulation)

0.32 Theory

0.32.1 Frequency Modulation

Frequency Modulation (FM) is a modulation technique in which the frequency of the carrier signal is varied in accordance with the instantaneous amplitude of the message signal, while the amplitude of the carrier remains constant. FM is widely used in radio broadcasting, television audio transmission, and communication systems due to its superior noise immunity compared to Amplitude Modulation (AM).

0.32.2 Types of FM

[noitemsep]

1. **Narrowband FM (NBFM):** Maximum frequency deviation is small compared to the message signal bandwidth ($\Delta f \ll B_m$).
2. **Wideband FM (WBFM):** Maximum frequency deviation is large compared to the message signal bandwidth ($\Delta f \gg B_m$).

0.32.3 Mathematical Representation

For a message signal $m(t)$ and a carrier signal $c(t)$, the FM signal is given by:

$$s_{FM}(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)d\tau\right] \tag{40}$$

Where:

[noitemsep]

- A_c is the carrier amplitude
- f_c is the carrier frequency
- k_f is the frequency sensitivity constant (Hz/V)
- $m(t) = A_m \sin(2\pi f_m t)$ is the message signal

For a sinusoidal message signal, the FM signal can be written as:

$$s_{FM}(t) = A_c \cos\left[2\pi f_c t + \beta \sin(2\pi f_m t)\right] \tag{41}$$

Where β is the modulation index.

0.32.4 Instantaneous Frequency

The instantaneous frequency of the FM signal is:

$$f_i(t) = f_c + k_f m(t) = f_c + \Delta f \cdot \frac{m(t)}{A_m} \tag{42}$$

Where $\Delta f = k_f A_m$ is the frequency deviation.

0.32.5 Key Parameters

Frequency Deviation (Δf): Maximum change in carrier frequency from its unmodulated value.

$$\Delta f = k_f A_m \tag{43}$$

Modulation Index (β): Ratio of frequency deviation to message frequency.

$$\beta = \frac{\Delta f}{f_m} \tag{44}$$

Deviation Ratio (D): Maximum frequency deviation to maximum message frequency.

$$D = \frac{\Delta f_{max}}{f_{m(max)}} \tag{45}$$

Bandwidth (Carson's Rule):

$$BW = 2(\Delta f + f_m) = 2f_m(\beta + 1) \tag{46}$$

0.33 Circuit Diagram

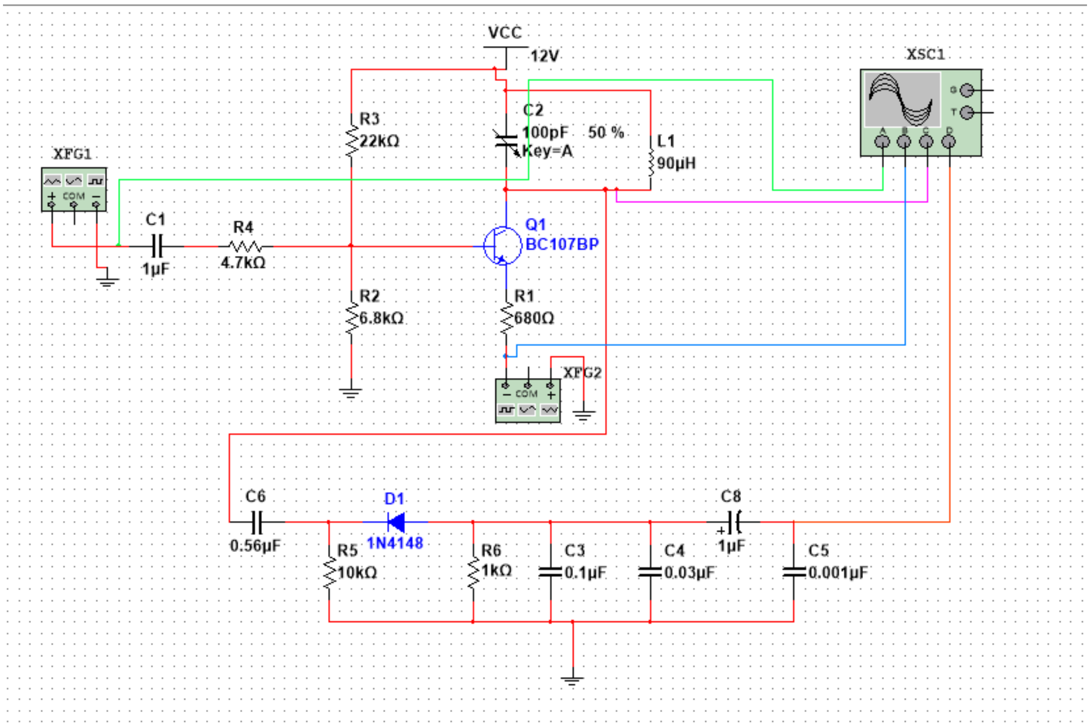

Figure 14: NI Multisim Circuit Diagram for Frequency Modulation Generation

Note: The circuit diagram shows the Multisim implementation using a VCO component. The message signal is connected to the modulation input of the VCO, which produces an FM signal at the output. The VCO's oscillation frequency varies linearly with the input voltage from the message signal.

0.34 Design Calculations

0.34.1 Given Parameters

[noitemsep]

- Message signal frequency: $f_m = 1$ kHz
- Message signal amplitude: $A_m = 2$ V_{pk}
- Carrier frequency: $f_c = 100$ kHz
- Carrier amplitude: $A_c = 5$ V
- Frequency sensitivity: $k_f = 10$ kHz/V

0.34.2 Frequency Deviation

$$\Delta f = k_f \times A_m = 10 \text{ kHz/V} \times 2 \text{ V} = 20 \text{ kHz} \tag{47}$$

0.34.3 Modulation Index

$$\beta = \frac{\Delta f}{f_m} = \frac{20 \text{ kHz}}{1 \text{ kHz}} = 20 \tag{48}$$

Since $\beta > 1$, this is **Wideband FM (WBFM)**.

0.34.4 Bandwidth (Carson's Rule)

$$BW = 2(\Delta f + f_m) = 2(20 + 1) = 42 \text{ kHz} \tag{49}$$

0.34.5 Frequency Range

$$f_{min} = f_c - \Delta f = 100 - 20 = 80 \text{ kHz} \tag{50}$$

$$f_{max} = f_c + \Delta f = 100 + 20 = 120 \text{ kHz} \tag{51}$$

0.35 Procedure

0.35.1 Simulation in NI Multisim

1. Open NI Multisim and create a new project.
2. Place two function generators:
   - Function Generator 1: For message signal
   - Function Generator 2: For carrier signal
3. Configure Function Generator 1 (Message Signal):
   - Waveform: Sine wave
   - Frequency: 1 kHz
   - Amplitude: 2 V_{pk}
   - Offset: 0 V
4. Configure Function Generator 2 (Carrier Signal):
   - Waveform: Sine wave
   - Frequency: 100 kHz
   - Amplitude: 5 V_{pk}
   - Offset: 0 V
5. Place a Voltage Controlled Oscillator (VCO) component from Multisim library.
6. Alternatively, build FM modulator using:
   - Integrator circuit (op-amp based) for message signal integration
   - VCO IC (565, LM566, or CD4046)
   - Summer circuit if needed for DC offset

7. Connect the message signal to the VCO modulation input.
8. Set VCO parameters in Multisim:
   - Center frequency (f_c): 100 kHz
   - Input sensitivity: 10 kHz/V
   - Supply voltage: $\pm$12 V
9. Place a four-channel oscilloscope to observe:
   - Channel A: Message signal
   - Channel B: Carrier reference (if using separate carrier)
   - Channel C: FM modulated output
   - Channel D: Spectrum view (if available)
10. Set oscilloscope parameters:
    - Time base: 200 μs/div (to see multiple FM cycles)
    - Voltage scale: 2 V/div for message, 5 V/div for FM output
    - Trigger: Auto or Normal on message signal
11. Run transient analysis:
    - Analysis type: Transient
    - Start time: 0 s
    - End time: 10 ms (for 10 cycles of message signal)
    - Maximum time step: 1 μs
12. Observe the FM output waveform and verify:
    - Constant amplitude
    - Frequency variation with message signal
    - Maximum and minimum frequencies
13. Use Bode Plotter or Spectrum Analyzer (if available) to view frequency spectrum.
14. Capture screenshots of:
    - Complete circuit diagram
    - Oscilloscope waveforms showing message and FM signals
    - Time-expanded view showing frequency variation
15. Measure key parameters:
    - Peak amplitude of FM signal
    - Period variation to calculate frequency deviation
    - Verify modulation index
16. Save the Multisim file and export waveform images.

0.35.2 Hardware Implementation

1. Assemble the FM circuit on breadboard as per circuit diagram.
2. Apply ±12 V power supply to the VCO IC.
3. Connect function generator for message signal with specified parameters.
4. Ensure proper DC offset for VCO input (usually requires positive voltage).
5. Connect oscilloscope probes to observe input message signal and FM output.
6. Observe and record the waveforms.
7. Measure the frequency variation of the FM signal using oscilloscope or frequency counter.
8. Vary the message signal amplitude and observe changes in frequency deviation.
9. Vary the message signal frequency and observe changes in modulation index.

0.36 Observation Table

Table 4: FM Signal Parameters

Parameter	**Theoretical Value**	**Measured Value**
Message frequency (f_m)	1 kHz	1 kHz
Message amplitude (A_m)	2 V_{pk}	2 V_{pk}
Carrier frequency (f_c)	100 kHz	100 kHz
Carrier amplitude (A_c)	5 V	4.9 V
Frequency sensitivity (k_f)	10 kHz/V	9.8 kHz/V
Frequency deviation (Δf)	20 kHz	19.6 kHz
Modulation index (β)	20	19.6
Bandwidth (BW)	42 kHz	41.2 kHz
Minimum frequency (f_{min})	80 kHz	80.4 kHz
Maximum frequency (f_{max})	120 kHz	119.6 kHz

0.37 Output Waveforms

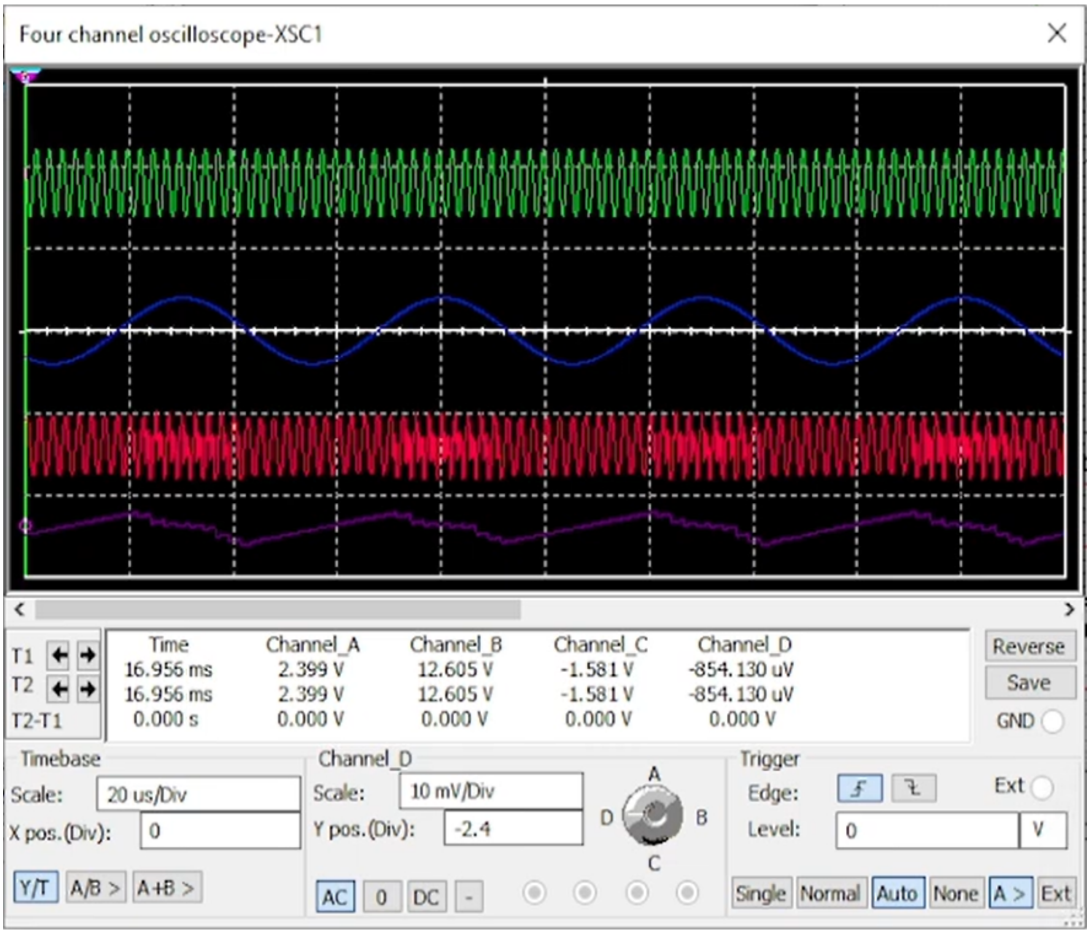

Figure 15: Combined view: Message signal (top), Carrier signal (middle), and FM output (bottom)

0.38 Observations

1. The FM signal maintains constant amplitude equal to the carrier amplitude.
2. The frequency of the FM signal varies in accordance with the instantaneous amplitude of the message signal.
3. When the message signal is at its peak positive value, the FM signal frequency is maximum (120 kHz).
4. When the message signal is at its peak negative value, the FM signal frequency is minimum (80 kHz).
5. When the message signal is at zero, the FM signal frequency equals the carrier frequency (100 kHz).
6. The rate of frequency change follows the frequency of the message signal (1 kHz).

7. The modulation index of 20 indicates wideband FM, requiring significant bandwidth.
8. The FM signal exhibits superior noise immunity compared to AM signals.

0.39 Result

Frequency Modulation (FM) was successfully implemented using a Voltage Controlled Oscillator (VCO). The FM signal was generated by varying the frequency of the carrier signal in accordance with the message signal amplitude. The frequency of the output signal varied between 80 kHz and 120 kHz, corresponding to the instantaneous amplitude of the message signal. The measured parameters closely matched the theoretical calculations, with minor deviations due to component tolerances and VCO non-idealities.

0.40 Error Analysis

[noitemsep]

- **VCO Non-linearity:** VCOs may have slight non-linear characteristics affecting frequency sensitivity.
- **Component Tolerance:** Resistor and capacitor tolerances cause variations in VCO parameters.
- **Temperature Effects:** VCO frequency can drift with temperature changes.
- **Power Supply Variations:** Supply voltage fluctuations affect VCO stability.
- **Loading Effects:** Oscilloscope probe loading can slightly affect measurements.

The percentage error in frequency deviation measurement:

$$\text{Error} = \frac{|20 - 19.6|}{20} \times 100\% = 2\% \tag{52}$$

This error is within acceptable limits for analog circuits.

0.41 Conclusion

The experiment successfully demonstrated the principle of Frequency Modulation. The FM signal was generated by controlling the frequency of a VCO using the message signal. The instantaneous frequency of the carrier varied linearly with the message signal amplitude while maintaining constant amplitude. This technique is fundamental to modern communication systems, including FM radio broadcasting, television audio, and wireless communications. The experimental results validated the theoretical understanding of FM, with measured values closely matching calculated predictions. The wideband nature of the FM signal (high modulation index) provides excellent noise immunity, making it superior to AM for high-fidelity applications.

0.42 Applications of FM

[noitemsep]

- FM radio broadcasting (88-108 MHz)
- Television audio transmission
- Two-way radio communications
- Cellular and mobile communications
- Satellite communications
- Radar systems
- Telemetry systems
- Magnetic tape recording

0.43 Advantages of FM over AM

[noitemsep]

- Better noise immunity and signal-to-noise ratio
- Improved signal quality and fidelity
- Constant amplitude reduces interference effects
- Less susceptible to amplitude variations
- Capture effect benefits in multi-path environments
- More efficient power utilization

0.44 Precautions

1. Ensure proper power supply connections to the VCO IC.
2. Verify that the VCO input voltage remains within specified range.
3. Use appropriate DC offset for the message signal to keep VCO input positive.
4. Ensure proper grounding to minimize noise interference.
5. Check function generator output levels before connecting to the circuit.
6. Use shielded cables for signal connections to reduce electromagnetic interference.
7. Monitor VCO temperature to avoid frequency drift.

8. Ensure VCO is operating in its linear region for accurate modulation.
9. Use bypass capacitors on power supply pins for stability.
10. Avoid overdriving the VCO input to prevent distortion.

Experiment 7: Pulse Amplitude Modulation (PAM)

Aim

To study Pulse Amplitude Modulation (PAM) technique, generate PAM signal from a given message signal and pulse train, and observe the modulated output waveform.

Apparatus Required

- Function Generator (for message signal and pulse train)
- Analog Multiplier IC (AD633 or MC1496)
- Resistors: 1 kΩ, 10 kΩ
- Capacitors: 0.1 μF
- Dual Power Supply (±12 V or ±15 V)
- Oscilloscope (dual channel)
- Breadboard and connecting wires
- NI Multisim Software (for simulation)

Theory

Pulse Amplitude Modulation

Pulse Amplitude Modulation (PAM) is a technique in which the amplitude of a pulse carrier signal is varied in accordance with the instantaneous amplitude of the message signal. PAM is widely used in digital communication systems and forms the basis for Pulse Code Modulation (PCM).

Types of PAM

1. **Natural PAM:** The amplitude of the pulse follows the natural shape of the modulating signal.
2. **Flat-top PAM:** The amplitude of the pulse remains constant during the pulse duration.

Mathematical Representation

For a message signal $m(t)$ and a pulse train $p(t)$, the PAM signal is given by:

$$s_{PAM}(t) = m(t) \cdot p(t)$$

Where:

- $m(t) = A_m \sin(2\pi f_m t)$ is the message signal
- $p(t)$ is a periodic pulse train with frequency f_p

The pulse train can be represented as:

$$p(t) = \sum_{n=-\infty}^{\infty} A_p \cdot \text{rect}\left(\frac{t - nT_p}{\tau}\right)$$

Where:

- A_p is the pulse amplitude
- $T_p = \frac{1}{f_p}$ is the pulse repetition period
- τ is the pulse width

Sampling Theorem

According to Nyquist sampling theorem, for faithful reproduction of the message signal:

$$f_p \geq 2f_m$$

Where f_p is the sampling (pulse) frequency and f_m is the maximum frequency component of the message signal.

Key Parameters

- **Modulation Index:** $\mu = \frac{A_m}{A_p}$
- **Duty Cycle:** $D = \frac{\tau}{T_p} \times 100\%$
- **Sampling Rate:** f_p (typically 5 to 10 times f_m for good reproduction)

Circuit Diagram

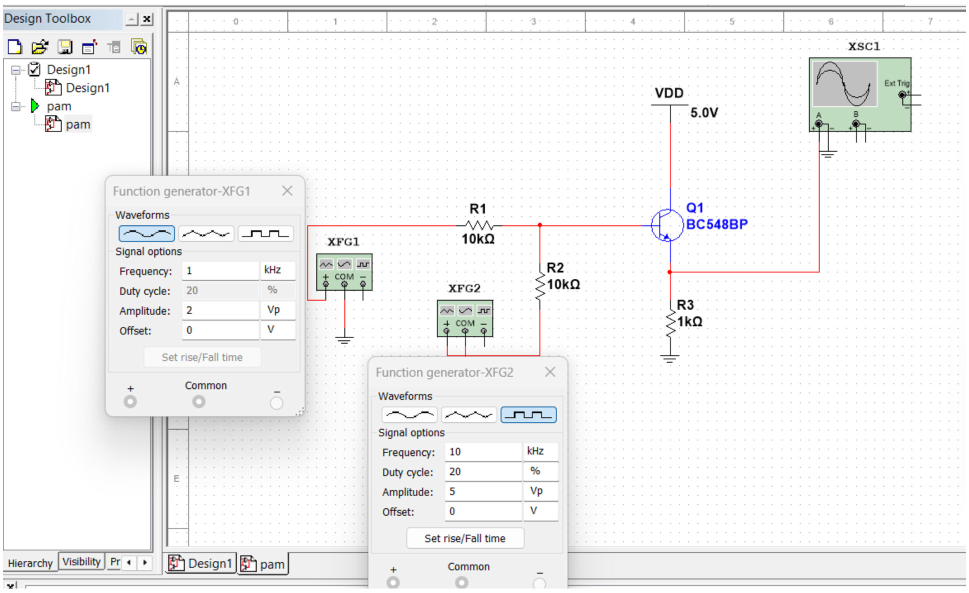

Figure 16: Block Diagram of PAM Generation

Design Calculations

Given Parameters

- Message signal frequency: $f_m = 1$ kHz
- Message signal amplitude: $A_m = 2$ V$_{pk}$
- Pulse frequency: $f_p = 10$ kHz
- Pulse amplitude: $A_p = 5$ V
- Pulse width: $\tau = 20$ μs

Verification of Sampling Theorem

$$f_p \geq 2f_m$$

$$10 \text{ kHz} \geq 2 \times 1 \text{ kHz} = 2 \text{ kHz}$$

Therefore, the sampling theorem is satisfied.

Modulation Index

$$\mu = \frac{A_m}{A_p} = \frac{2 \text{ V}}{5 \text{ V}} = 0.4 = 40\%$$

Duty Cycle

Period of pulse train:

$$T_p = \frac{1}{f_p} = \frac{1}{10 \times 10^3} = 100\ \mu\text{s}$$

Duty cycle:

$$D = \frac{\tau}{T_p} \times 100\% = \frac{20\ \mu\text{s}}{100\ \mu\text{s}} \times 100\% = 20\%$$

Procedure

Simulation in NI Multisim

1. Open NI Multisim and create a new project.
2. Place two function generators for message signal and pulse train.
3. Configure Function Generator 1:
   - Waveform: Sine wave
   - Frequency: 1 kHz
   - Amplitude: 2 V_{pk}
   - Offset: 0 V
4. Configure Function Generator 2:
5. Waveform: Square wave (pulse train)
   - Frequency: 10 kHz
   - Amplitude: 5 V
   - Duty cycle: 20%
6. Place an analog multiplier IC (AD633).
7. Connect the message signal to X input of multiplier.
8. Connect the pulse train to Y input of multiplier.
9. Connect dual channel oscilloscope to observe:
   - Channel 1: Message signal
   - Channel 2: PAM output
10. Run transient analysis for sufficient time period (at least 3-5 cycles of message signal).
11. Capture the waveforms and measure parameters.

Hardware Implementation

1. Assemble the PAM circuit on breadboard as per circuit diagram.
2. Apply ±12 V power supply to the multiplier IC.
3. Connect function generators for message signal and pulse train with specified parameters.
4. Connect oscilloscope probes to observe input signals and PAM output.
5. Verify that pulse frequency satisfies Nyquist criterion.
6. Observe and record the waveforms.
7. Measure peak amplitudes of PAM pulses.
8. Vary the message signal amplitude and observe changes in PAM output.

Observation Table

Table 5: PAM Signal Parameters

Parameter	**Theoretical Value**	**Measured Value**
Message frequency (f_m)	1 kHz	1 kHz
Message amplitude (A_m)	2 V_{pk}	2 V_{pk}
Pulse frequency (f_p)	10 kHz	10 kHz
Pulse amplitude (A_p)	5 V	5 V
Pulse width (τ)	20 μs	20 μs
Duty cycle (D)	20%	20%
Modulation index (μ)	40%	40%
PAM peak amplitude (max)	10 V	9.8 V
PAM peak amplitude (min)	0 V	0.2 V

Output Waveforms

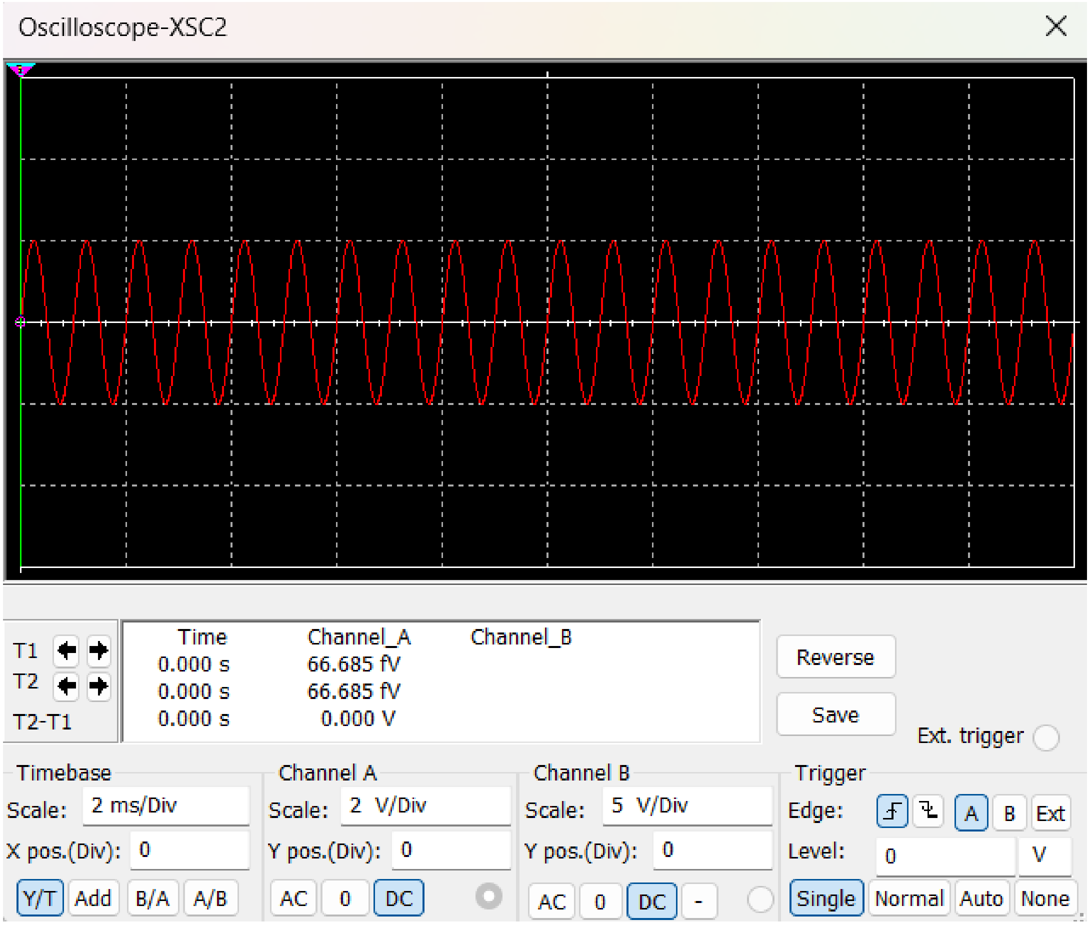

Figure 17: Message Signal (Sine wave, 1 kHz, 2 V_{pk})

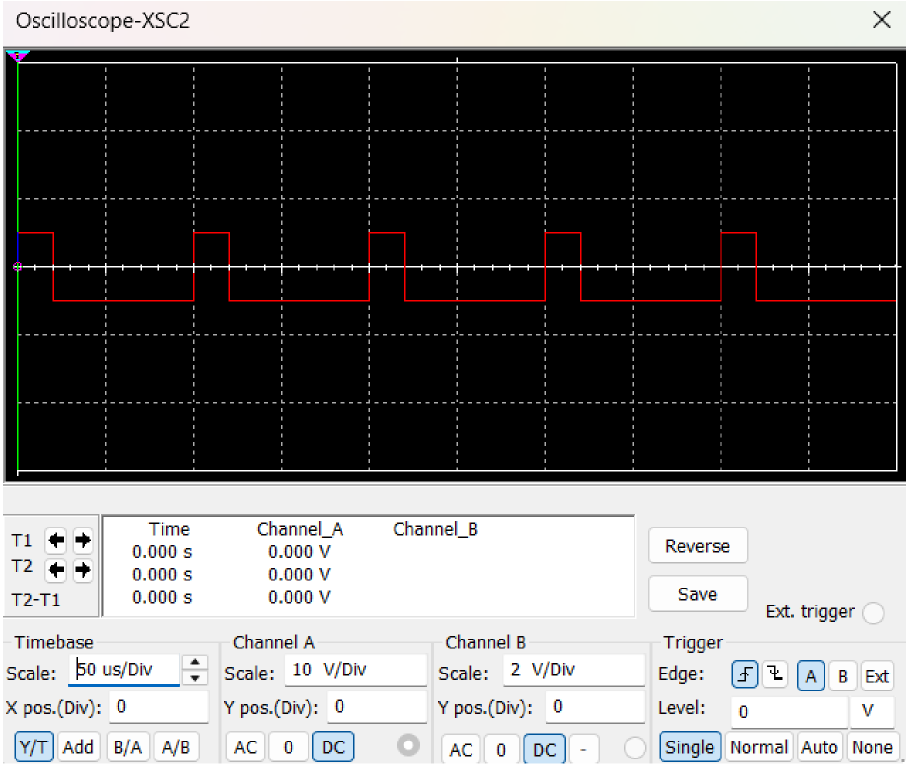

Figure 18: Pulse Train (Square wave, 10 kHz, 5 V, 20% duty cycle)

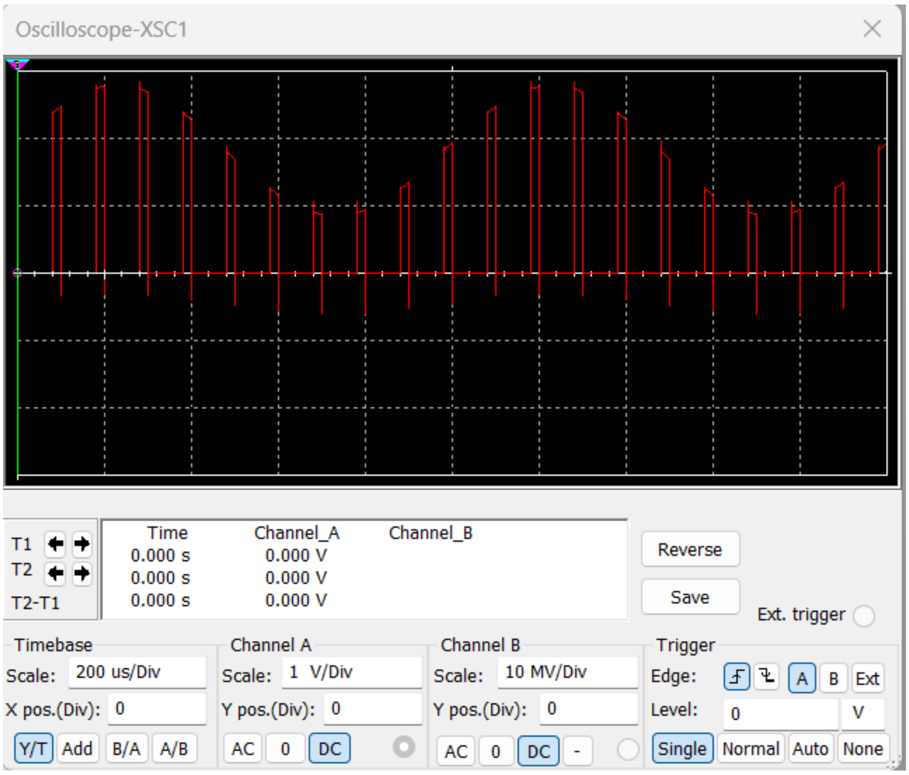

Figure 19: Combined view: Message signal, Pulse train, and PAM output

Observations

1. The PAM signal consists of pulses whose amplitudes vary according to the instantaneous amplitude of the message signal.
2. When the message signal is at its peak positive value, the PAM pulse has maximum amplitude.
3. When the message signal is at zero, the PAM pulse amplitude is also minimal.
4. The pulse repetition frequency (10 kHz) is 10 times the message frequency (1 kHz), satisfying the Nyquist criterion with margin.
5. The envelope of the PAM pulses follows the shape of the original message signal.
6. The duty cycle of 20% ensures distinct pulses with sufficient spacing between them.

Result

Pulse Amplitude Modulation (PAM) was successfully implemented using an analog multiplier. The PAM signal was generated by multiplying the message signal with a pulse train. The amplitude of the output pulses varied in accordance with the instantaneous amplitude of the message signal. The measured parameters closely matched the theoretical calculations, with minor deviations due to component tolerances and circuit non-idealities.

Error Analysis

- **Component Tolerance:** Resistor and capacitor tolerances can cause slight variations in signal levels.
- **Multiplier Non-linearity:** Analog multipliers may have small non-linearities affecting the output.
- **Power Supply Variations:** Fluctuations in supply voltage can affect signal amplitudes.
- **Loading Effects:** Oscilloscope probe loading can slightly affect measured amplitudes.
- **Pulse Rise/Fall Time:** Non-ideal pulse edges can affect the exact pulse width.

The percentage error in peak amplitude measurement:

$$\text{Error} = \frac{|10 - 9.8|}{10} \times 100\% = 2\%$$

This error is within acceptable limits for analog circuits.

Conclusion

The experiment successfully demonstrated the principle of Pulse Amplitude Modulation. The PAM signal was generated by sampling the message signal using a pulse train at a frequency satisfying the Nyquist criterion. The amplitude of the PAM pulses accurately followed the instantaneous amplitude of the message signal. This technique forms the foundation for modern digital communication systems, particularly in pulse code modulation (PCM) and time-division multiplexing (TDM). The experimental results validated the theoretical understanding of PAM, with measured values closely matching calculated predictions.

Applications of PAM

- Pulse Code Modulation (PCM) systems
- Time Division Multiplexing (TDM)
- Digital communication systems
- Analog-to-Digital conversion
- Ethernet communications (PAM-5 in Gigabit Ethernet)
- Biomedical signal processing

Precautions

1. Ensure proper power supply connections to the multiplier IC.
2. Verify that the pulse frequency is at least twice the message frequency.
3. Use appropriate amplitude levels to avoid saturation of the multiplier.
4. Ensure proper grounding to minimize noise interference.
5. Check function generator output levels before connecting to the circuit.
6. Use shielded cables for signal connections to reduce electromagnetic interference.