# Experiment 4

## Frequency Modulation (5-1)

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**Course Title & Number:**

RF Communications (EET-2325C)

**Submitted to:**

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## Objective:

The purpose of this experiment is to demonstrate frequency modulation using a voltage-controlled oscillator (VCO). By applying a modulating signal to the VCO, we aim to observe how the frequency of the carrier wave varies in response to changes in the amplitude and frequency of the modulating signal. This experiment will help in understanding the principles of frequency modulation and its practical applications using the 2206 function generator IC.

## Materials:

- 2206 function generator circuit (previously constructed)
- Oscilloscope
- Frequency counter
- External function generator
- 10-µF capacitor
- 100-kΩ resistor
- Power supply (+12V)
- Connecting wires and breadboard
- 4.7-kΩ resistors (2 pieces)
- 47-kΩ resistor
- 150-Ω resistor
- 0.002-µF capacitor
- 1-µF capacitor

## Background:

Frequency modulation (FM) is a method of encoding information in a carrier wave by varying the instantaneous frequency of the wave. This contrasts with amplitude modulation (AM), where the amplitude of the carrier wave is varied while its frequency remains constant. In FM, the frequency of the carrier is altered according to the amplitude of the modulating signal, while the amplitude of the carrier remains constant.

The primary advantage of FM over AM is its resilience to signal amplitude variations caused by noise and interference. This makes FM a preferred choice for high-fidelity audio broadcasting and other applications requiring robust signal integrity.

The frequency deviation in FM is directly proportional to the amplitude of the modulating signal. The frequency deviation $f_d$ is given by:

$$f_d = k_f m(t)$$

where $k_f$ is the frequency sensitivity of the modulator and $m(t)$ is the amplitude of the modulating signal.

The modulation index $m_f$ is an important parameter in FM, defined as the ratio of the frequency deviation to the modulating frequency $f_m$:

$$m_f = \frac{f_d}{f_m}$$

In this experiment, a voltage-controlled oscillator (VCO) is used to generate the FM signal. The 2206 function generator IC, which includes a VCO, will be modulated by an external function generator. The 2206 IC is capable of generating frequency-modulated signals by applying a varying voltage to its control input, resulting in changes to its output frequency.

The objective of this experiment is to observe the effects of varying the amplitude and frequency of the modulating signal on the carrier wave's frequency deviation. By analyzing the output on an oscilloscope, the relationship between the modulating signal's properties and the frequency-modulated output can be understood and quantified.

## Procedure:

1. **Setup the Circuit:**
    - Construct the circuit as shown in Fig. 5-1 using the 2206 function generator. Note that you will add a 10-µF capacitor and a 100-kΩ resistor to pin 7 of the 2206. Connect an external function generator to serve as the modulating signal.

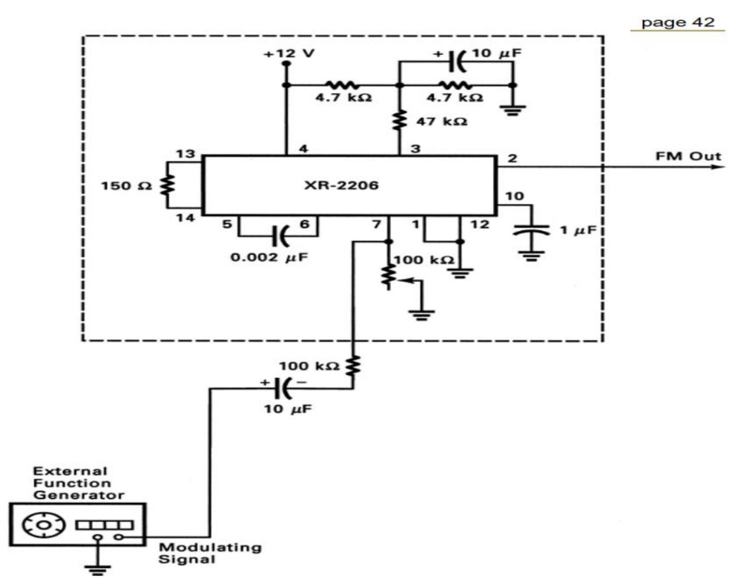


*Figure 1 - Fig 5-1 from Lab manual.*

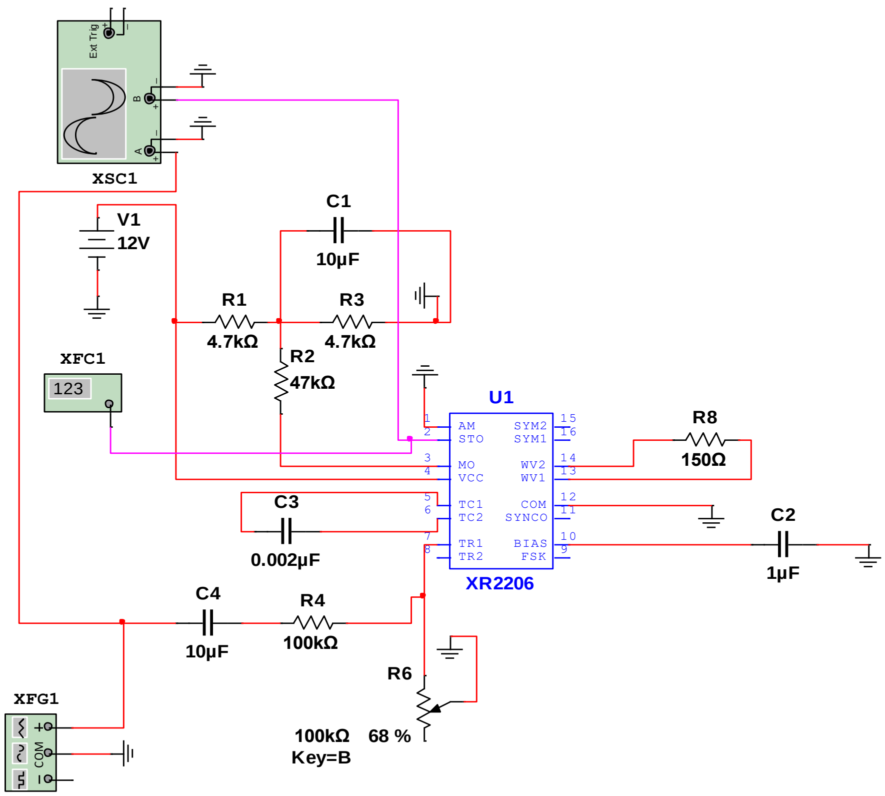


*Figure 2 - FM Circuit Multisim*

- Ensure all components are correctly placed and connections are secure on the breadboard.

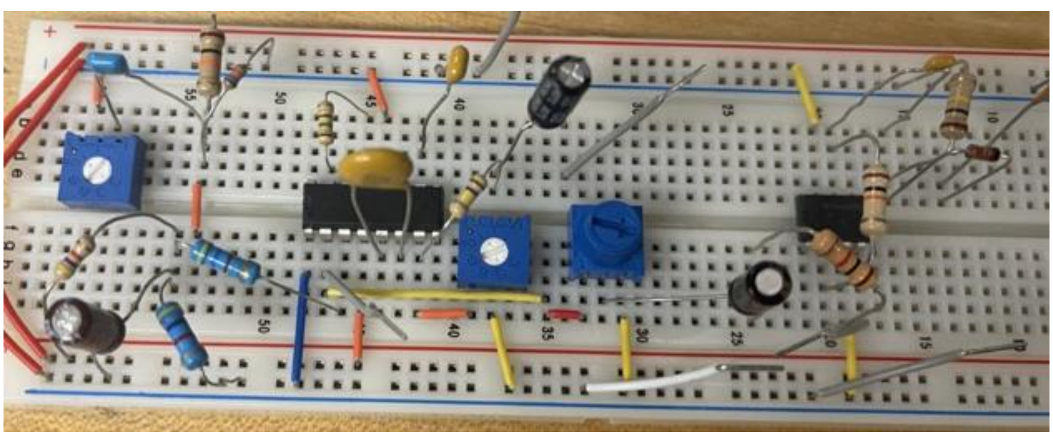

*Figure 3 - FM Circuit Bench*

2. **Power Up the Circuit:**

   - Apply power to the circuit using a +12V power supply.

3. **Initial Observations:**

- Reduce the modulating signal amplitude from the external function generator to zero.
- Observe the carrier output at pin 2 of the 2206 using an oscilloscope.
- Adjust the 100-kΩ potentiometer on the 2206 for a frequency of approximately 30 kHz.

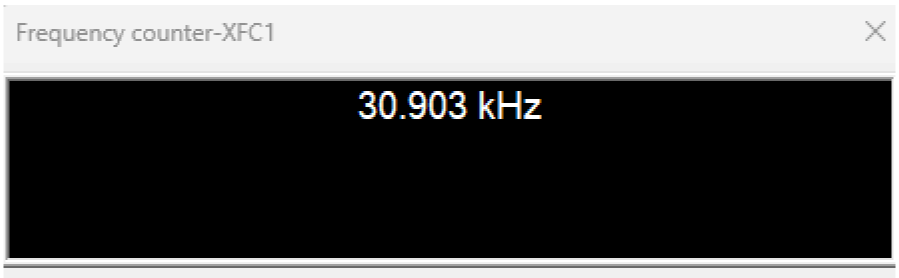


*Figure 4 - Frequency of the carrier wave in Multisim.*

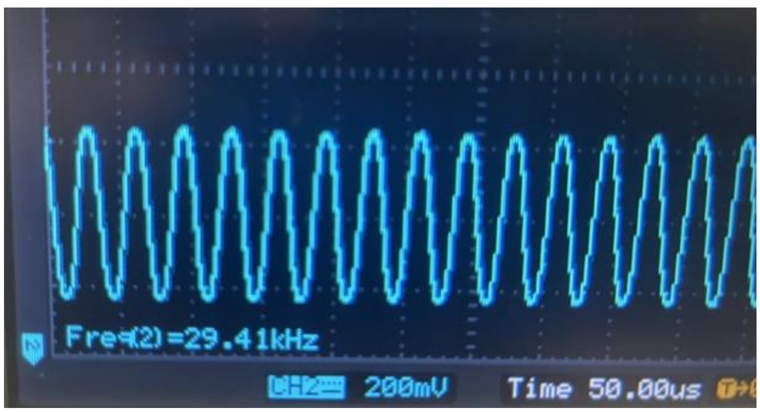


*Figure 5 - Setting the carrier Frequency to 30 kHz.*

- Set the horizontal sweep controls on the oscilloscope to display approximately three cycles of the carrier wave.

4. **Increase Modulating Signal:**

- Slowly increase the amplitude of the modulating signal from the external function generator. Set the frequency of the signal to approximately 200 Hz.
- As the amplitude of the modulating signal increases, observe the oscilloscope display. The carrier wave should begin to "vibrate," indicating a change in frequency due to the modulating signal.

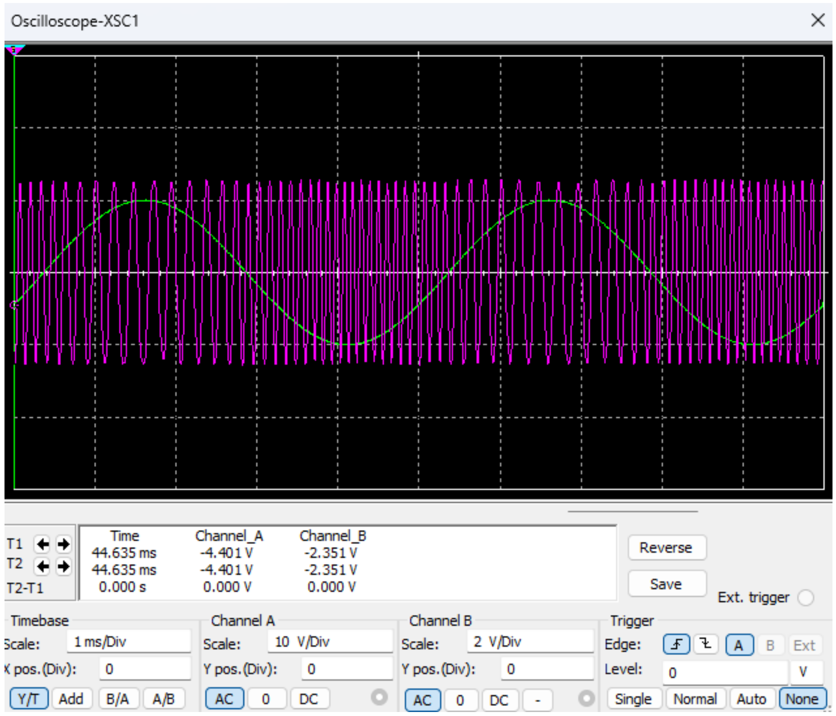


*Figure 6 - Multisim output FM waveform at 10 Vp for a noticeable Vibration.*

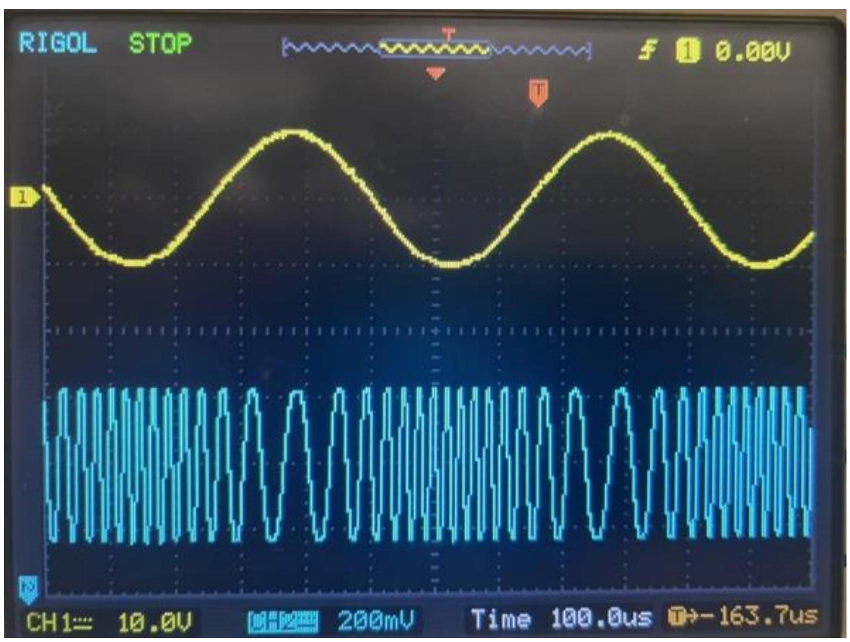


*Figure 7 – Bench output FM waveform at 10 Vp for a noticeable Vibration*

- Adjust the oscilloscope controls to obtain a stable display if needed.

5. **Observe FM Waveform:**

- Set the amplitude of the modulating signal at the 10-µF capacitor to 2 $V_{pp}$.

- Observe the carrier output on the oscilloscope. The waveform should resemble the one shown in Fig. 5-2, indicating frequency deviation.

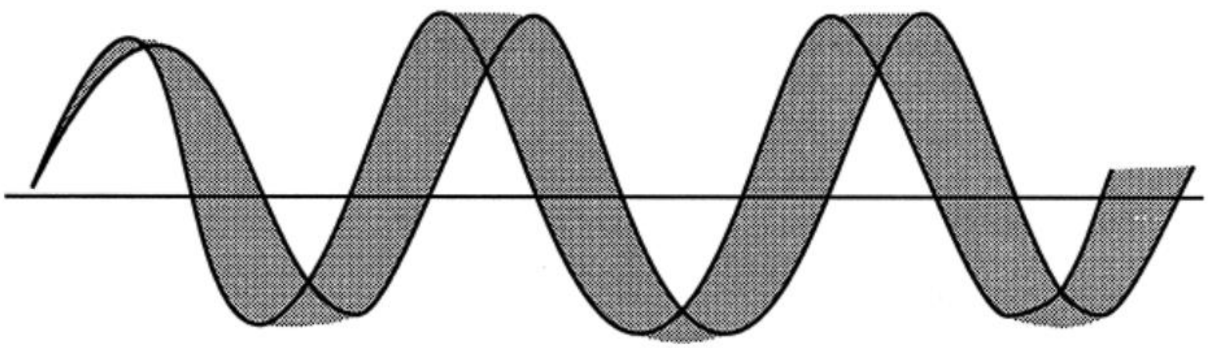

*Figure 8 - Fig 5-2 from the Lab Manual.*

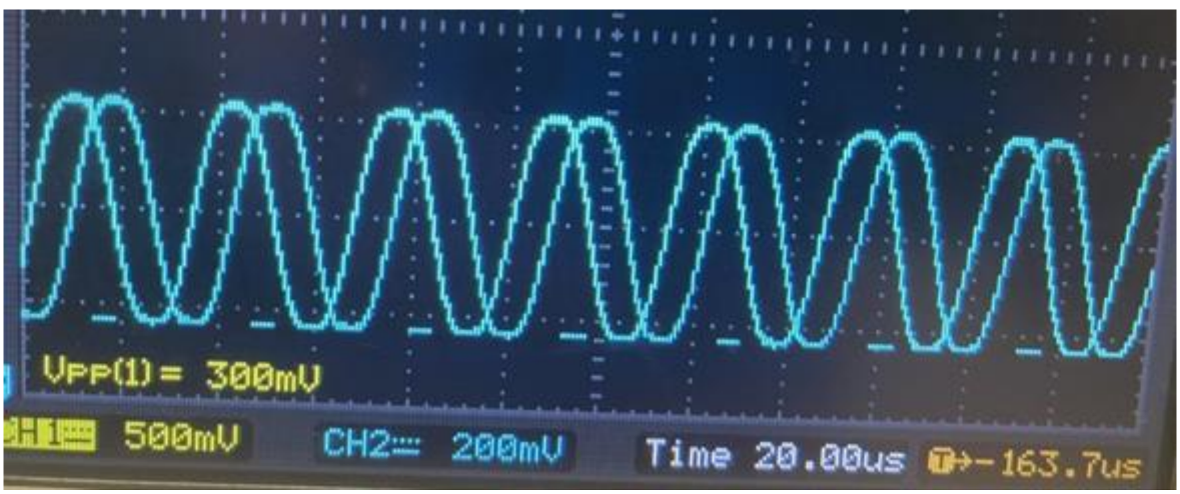


*Figure 9 - Bench Carrier Output.*

- While observing the waveform, vary the frequency of the modulating signal and note the effect on the waveform.

6. **Frequency Deviation and Modulating Signal Frequency:**
    - Determine the relationship between the frequency deviation and the modulating signal amplitude by varying the amplitude of the modulating signal and observing the resulting FM output.


*Figure 10 - Carrier waveform with a small amplitude (2 Vpp).*


*Figure 11 - Output carrier waveform with a larger Amplitude on the modulating wave (10 Vpp).*

## Data & Observations:

**Measured Data and Resulting Calculations:**

- Since this lab focused on observing the effects of varying the modulating signal on the frequency-modulated output, no quantitative data was collected. The observations were primarily qualitative, focusing on the changes in the waveform displayed on the oscilloscope.

**Observations:**

1. **Carrier Wave Observation:**
    - When the modulating signal amplitude was set to zero, the carrier output at pin 2 of the 2206 displayed a stable waveform with a frequency of approximately 30 kHz.
2. **Effect of Increasing Modulating Signal Amplitude:**
    - As the amplitude of the modulating signal was increased, the carrier wave on the oscilloscope began to "vibrate," indicating a change in frequency. This visual change confirmed the modulation effect.
    - With the modulating signal frequency set to approximately 200 Hz, the waveform on the oscilloscope showed clear frequency deviation, indicating successful frequency modulation.
3. **FM Waveform with 2 $V_{pp}$ Modulating Signal:**
    - Setting the modulating signal amplitude to 2 $V_{pp}$ resulted in a waveform similar to Fig. 5-2 in the manual. This waveform demonstrated the characteristic frequency deviation of FM signals.
    - Varying the frequency of the modulating signal further showed corresponding changes in the frequency deviation of the carrier wave, highlighting the direct relationship between the modulating signal's properties and the FM output.

**Presentation of Data through Tables and Graphs:**

- Since no quantitative data was collected, tables and graphs are not applicable for this lab report. The focus is on qualitative observations supported by visual evidence from oscilloscope screenshots and photos of the experimental setup.

**Discussion of Experimental Results:**

- The experiment successfully demonstrated the principles of frequency modulation using a voltage-controlled oscillator (VCO) in the 2206 function generator IC.

- The observed frequency deviation in response to varying the amplitude and frequency of the modulating signal confirmed the theoretical understanding of FM. The oscilloscope displayed characteristic FM waveforms, validating the modulation process.

**Sources of Error:**

- Potential sources of error include inaccuracies in setting the modulating signal amplitude and frequency on the external function generator. Ensuring precise control and calibration of the equipment is crucial for accurate observations.
- Electrical noise and interference could affect the oscilloscope readings, leading to potential misinterpretation of the waveform characteristics. Shielding the setup and ensuring proper grounding can minimize such issues.

**Accuracy of Measurements:**

- The qualitative nature of the observations limits the need for precise measurements. However, the clear visual representation of the FM waveforms on the oscilloscope provides sufficient evidence to support the experimental objectives.

## Answers to Lab Questions:

1. **Which of the following is the most correct statement with regard to the relationship between the carrier frequency deviation and the amplitude of the modulating signal?**
   - a. Decreasing the modulating signal amplitude increases the carrier deviation.
   - **b. Decreasing the modulating signal amplitude decreases carrier deviation.**
   - c. Carrier deviation is not affected by the amplitude of the modulating signal.
   - d. The frequency deviation varies in direct proportion to the modulating signal frequency.

The frequency deviation in FM is directly proportional to the amplitude of the modulating signal. As the amplitude increases, the deviation increases, and vice versa.

2. **Varying the frequency of the modulating signal causes the frequency deviation of the carrier to ________.**
   - a. Increase
   - b. Decrease
   - **c. Remain the same**

- d. Drop to zero

The frequency deviation is determined by the amplitude of the modulating signal, not its frequency. Thus, varying the modulating frequency does not affect the frequency deviation of the carrier.

3. **The type of modulation produced by the VCO in the 2206 IC is ________.**

    - **a. Frequency modulation**
    - b. Phase modulation
    - c. Indirect FM
    - d. FSK

The 2206 IC uses a voltage-controlled oscillator (VCO) to vary the frequency of the carrier signal based on the input voltage, which is the principle of frequency modulation (FM).

4. **What is the deviation ratio of an FM system in which the maximum permitted frequency deviation is 10 kHz and the maximum modulating frequency is 3 kHz?**

    - a. 0.3
    - b. 1
    - c. 3
    - **d. 3.33**

The deviation ratio ($m_f$) is calculated as the frequency deviation ($f_d$) divided by the modulating frequency ($f_m$). Therefore, $m_f = \frac{10\,kHz}{3\,kHz} = 3.33$.

5. **The number of sidebands produced by a sine-wave carrier being frequency-modulated by a single-frequency sine-wave tone is ________.**

    - a. 1
    - b. 2
    - c. 4
    - **d. Infinite**

In frequency modulation, the number of sidebands is theoretically infinite because the carrier can be modulated by harmonics of the modulating frequency, producing an infinite series of sidebands.

# Conclusion:

In this experiment, the principles of frequency modulation (FM) were demonstrated using the 2206 function generator IC with a voltage-controlled oscillator (VCO). By varying the amplitude and frequency of the modulating signal, the corresponding changes in the carrier wave's frequency deviation were observed and analyzed. The experiment successfully demonstrated the relationship between the modulating signal's amplitude and the carrier frequency deviation. As the amplitude of the modulating signal increased, the frequency deviation of the carrier wave also increased, as expected. The frequency of the modulating signal did not affect the magnitude of the frequency deviation but altered the rate at which the carrier frequency changed, confirming the theoretical understanding of FM.

The oscilloscope waveforms clearly showed the characteristic FM waveforms, validating the modulation process. The observed results aligned with the theoretical principles of FM, indicating that the experiment was conducted successfully. The experiment highlighted the direct proportionality between the modulating signal amplitude and the frequency deviation, and the independence of the deviation magnitude from the modulating frequency.

This experiment reinforced the understanding of frequency modulation and its practical implementation using a VCO. It illustrated how varying the properties of the modulating signal influences the FM output. For future work, it is recommended to explore the effects of different types of modulating signals, such as square waves or complex waveforms, on the FM output. Additionally, implementing digital methods for more precise control and measurement of the modulating signal could enhance the accuracy of the observations. Ensuring proper calibration of equipment and minimizing electrical noise through better shielding and grounding can further improve the reliability of the results. Overall, the experiment provided valuable insights into the behavior of frequency-modulated signals and confirmed the theoretical concepts underlying FM.