Objective: Students will gain understanding on the concept of modulation, and the visualization of modulation signals.

Equipment and Material
- Rohde & Schwarz FSH3 Spectrum analyzer
- 2-Function Generators
- Oscilloscope
- Power supply: +18v, -18v
- LF356 operational amplifier
- VCR2N JFET
- Diode 1N4148
- Capacitors and resistors
- Breadboard

Background
Before going to the lab carefully read the following section, and answer the pre-lab questions. Be sure that you understand all the material presented here. From the textbook read Chapter 6: sections 6.1 and 6.2.

1. - Modulation
Modulation is a process that causes a shift in the range of frequencies in a signal. Before discussing modulation, it is important to distinguish between communication that does not use modulation: “Baseband communication”, & communication that uses modulation: “Carrier communication”.

The term baseband is used to designate the band of frequencies of the signal delivered by the source. For example, in telephony the baseband is the audio band (voice signals): 0 to 3.5 KHz. In television, the baseband is the video band occupying 0 to 4.3 MHz.

In baseband communication, baseband signals are transmitted without modulation, that is, without any shift in the range of frequencies on the signal. Because power can not be transmitted over long distances, the baseband signals cannot be transmitted over a radio link but are suitable for transmission over a pair of wires, coaxial cables, or optical fibers.

By modulating several baseband signals and shifting their spectra to non-overlapping bands, one can use the vast spectrum of frequencies available.

Communication that uses modulation to shift the frequency spectrum of a signal in known as Carrier Communication. In this mode, one of the basic parameters: amplitude, frequency, or phase of a sinusoidal carrier of high frequency $\omega_c$ is varied in proportion to the baseband signal $m(t)$. This results in amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM), respectively.

2. Amplitude Modulation
Amplitude modulation (AM) is characterized by the fact that the amplitude of the carrier, $\cos(\omega_c t)$, is varied in proportion to the baseband signal (message) $m(t)$, the modulating signal. The frequency $\omega_c$ is constant.
In AM signals, the amplitude of a carrier is modulated by a signal $m(t)$, and the information content of $m(t)$ is in the amplitude variations of the carrier. If the carrier amplitude is made directly proportional to the modulating signal $m(t)$, the modulated signal is:

$$A m(t) \cos(\omega_c t).$$

Then the AM modulation shifts the spectrum of $m(t)$ to the carrier frequency, as represented in the following expressions:

<table>
<thead>
<tr>
<th>Time domain</th>
<th>Frequency domain</th>
</tr>
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<tbody>
<tr>
<td>$m(t)$</td>
<td>$M(\omega)$</td>
</tr>
<tr>
<td>$A m(t) \cos(\omega_c t)$</td>
<td>$A/2 \left[ M(\omega + \omega_c) + M(\omega - \omega_c) \right]$</td>
</tr>
</tbody>
</table>

The term $M(\omega - \omega_c)$ means that $M(\omega)$ has been shifted to the right by $\omega_c$, and in the term $M(\omega + \omega_c)$ the spectrum $M(\omega)$ has been shifted to the left by $\omega_c$. Then the process of modulation shifts the spectrum of the modulating signal to the left and to the right by $\omega_c$. Also if the bandwidth of $m(t)$ is $B$ Hz, then, as seen in Fig. 1, the bandwidth of the modulated signal is $2B$ Hz. Also in Fig. 1 it is shown that the modulated signal spectrum centered at $\omega_c$ is composed of two parts: a portion that lies above $\omega_c$, known as the upper sideband (USB), and a portion that lies below $\omega_c$ known as the lower sideband (LSB). This is called a modulation scheme with double sidebands.

![Diagram of AM modulation](image-url)

**Fig. 1. Amplitude Modulation: Double Sideband**
The relationship of $B$ to $\omega_c$ is very important. Fig. 1 shows that $\omega_c$ has to be greater than $(2\pi B)$ in order to avoid the overlap of the spectra centered at $\omega_c$ and $-\omega_c$. If $\omega_c$ is less than $(2\pi B)$, then these spectra overlap and the information of $m(t)$ is lost in the process of modulation.

3. Demodulation of AM Signals.

The simplest method to demodulate an AM signal is using an **Envolop Detector**. In an envelop detector, the output of the detector follows the envelop of the modulated signal.

The circuit shown in Fig. 3 functions as an envelop detector. On the positive cycle of the input signal, the diode conducts and the capacitor $C$ charges up to the peak voltage of the input signal. As the input signal falls below this peak value, the diode is cut off. The capacitor now discharges through the resistor $R$ at a slow rate, with a time constant $RC$. During the next positive cycle, the same action happens. During each positive cycle when the input signal becomes greater that the capacitor voltage, the diode conducts again. The capacitor again charges to the peak value of this new cycle. The capacitor discharges slowly during the cutoff period, thus changing the capacitor voltage very slightly.

![Fig. 3. Envelop Detector Circuit](image)

During each positive cycle, the capacitor charges up to the peak voltage of the input signal and then decays slowly until the next positive cycle as shown in Fig. 4. The output voltage $v_c(t)$ closely follows the envelop of the input. The discharge of the capacitor between positive peaks causes a ripple signal of frequency $\omega_c$ in the output. This ripple can be reduced by increasing the time constant $RC$ so that the capacitor discharges very little between the positive peaks ($RC >> 1 / \omega_c$).
However, making $RC$ too large, would make it impossible for the capacitor voltage to follow the envelop. Then $RC$ should be large compared to $1/\omega_c$, but should be small compared to $1/2\pi B$, where $B$ is the highest frequency in the message $m(t)$. This requires that $\omega_c \gg 2\pi B$, a condition that is necessary for a well-defined envelope. The output of the envelop detector is $v_e(t) = A + m(t)$ with a ripple of frequency $\omega_c$. The DC term $A$ can be blocked out by a capacitor or a simple $RC$ high-pass filter. The ripple may be reduced further by another low-pass $RC$ filter.

### PRE LAB

Before going to the lab answer the following questions.

**AM Modulation**

1.- Consider the message $m(t)$ given by a triangular wave with frequency **500Hz**, and amplitude $A$. Assume that you modulate this message using the carrier: $\cos(\omega_c t)$, where $\omega_c = 2\pi(15\text{ kHz})$

   a) Sketch the modulated signal in the time domain
   b) Sketch the modulated signal in the frequency domain

2.- Consider the message $m(t)$ given by a square wave with frequency **500Hz**, and amplitude $A$. Assume that you modulate this message using the carrier: $\cos(\omega_c t)$, where $\omega_c = 2\pi(15\text{ kHz})$

   a). Sketch the modulated signal in time domain
   b). Sketch the modulated signal in frequency domain

3.- Consider the message $m(t)$ given by a sinusoidal wave with frequency **500Hz**, and amplitude $A$. Assume that you modulate this message using the carrier: $\cos(\omega_c t)$, where $\omega_c = 2\pi(15\text{ kHz})$

   a). Sketch the modulated signal in time domain
   b). Sketch the modulated signal in frequency domain
LAB PROCEDURE

General Instructions
- To avoid damage to the electronic components, keep the power supply off during the assembling of the circuits.
- After each part of the experiment is done, make sure that you show to your TA or instructor the performance of your circuit to verify that your results are correct. This also serves to monitor your progress and performance.

1. A simple AM modulator
The circuit diagram of a simple AM modulator is shown in Fig. 5. This circuit implements a two-quadrant multiplier using a n-channel junction FET, the VCR2N, that works as a voltage-controlled resistor (VCR), and an operational amplifier, the LF356.

1.1. Prepare circuit of Fig. 5:
Keeping the power supply off, assemble the circuit of Fig. 5. To generate the carrier and the message you will need two signal generators. For the carrier use a sine wave, 100mVpp, 15 kHz, no DC component. For the message you will use three types of waveforms: sine, square and triangular. Each signal having amplitude of 5Vpp, and a frequency of 500Hz.

- **Carrier** = 100mVpp, 15 kHz, sine wave, no DC component
- **Messages:**
  - i) $m_1(t) = 5Vpp, 500Hz, \text{sine wave}, -2.5V \text{ DC component}$
  - ii) $m_2(t) = 5Vpp, 500Hz, \text{square wave}, -2.5V \text{ DC component}$
  - iii) $m_3(t) = 5Vpp, 500Hz, \text{triangular wave}, -2.5V \text{ DC component}$

You will report the results of the modulation, in the time domain, and in the frequency domain, for each message.

Time Domain (oscilloscope):
Sketch and measure: Carrier (t), m(t), and Output (t)

Frequency Domain (spectrum analyzer):
Sketch and measure: Carrier (f), M(f), and Output (f) up to 50kHz

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![Fig.5. AM modulator](image-url)
2. Envelop Detector

2.1. Prepare circuit of Fig. 6:

Fig. 6 shows an envelop detector circuit. The design equation for this circuit is: \( f_{co} = \frac{1}{2\pi R_1 C_1} \)
where \( f_{co} \) is the cut-off frequency of the low-pass filter \( R_1 C_1 \). The capacitor \( C_2 \) is a coupling capacitor, chosen such as \( C_2 > C_1 \)

Connect this envelop detector to the output of your modulator (circuit in Fig. 5). The signal at \( V_0(t) \) should be your recovered message.

Report the results of the envelop detector circuit, in the time domain, and in the frequency domain.

- **Time Domain (oscilloscope):**
  Sketch and measure: \( AM \) signal(t), and \( V_0(t) \)

- **Frequency Domain (spectrum analyzer):**
  Sketch and measure: \( AM \) signal(f), and \( V_0(f) \) up to 50kHz

**POST LAB**

For each case compare the theoretical plots with the experimental plots and discuss the differences.

**Post Experiment (Report) Requirements:**

1- Every student must have his own individual lab report.

2- The report should include the following:
   a) Results with detailed explanations are needed.
   b) Answer the questions if there are any.
   c) Conclusion - what did you learn in this experiment? Please write only a few lines.

3- All reports should be word processed and should also have the assigned cover page.