Amplitude Modulation

Amplitude Modulation Concepts (TechnologyUK, 2023)

Modulation is the process of converting raw message data into digital signals or waves over a modulator to optimize transmission. This process increases the strength of the signal to have maximum reach.

In *Figure 1*, the **carrier signal** is the steady waveform in terms of amplitude (height) and frequency, the **modulating signal** is the message that must be transmitted, and the **modulated signal** is the output signal after the process.

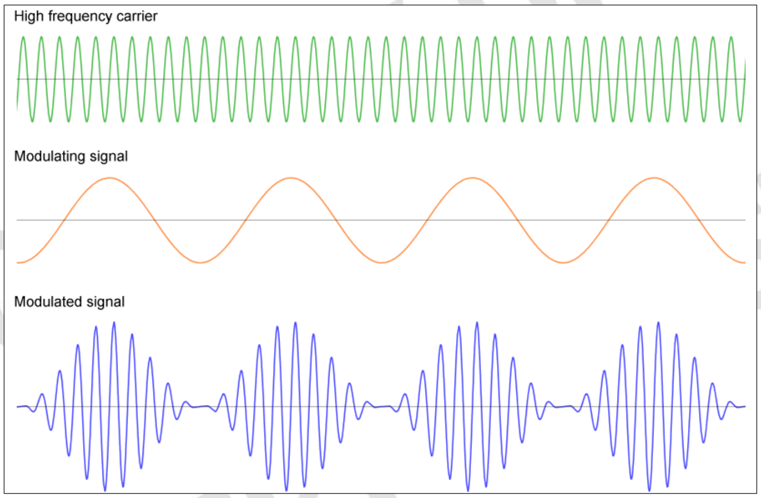

Figure 1. Modulation. Retrieved from https://www.technologyuk.net/

Modulation is done to improve signals often unsuitable for the transmission device. Just like a broadcast radio that plays news, music, and weather forecasts, the frequency people hear is in the audio spectrum only ranging from $20\ Hz – 20k\ Hz$. This makes sending audio signals wirelessly using radio frequency harder. One way to get a high-frequency signal to carry a low-frequency signal is by **amplitude modulation.**

The instantaneous amplitude of a radio frequency carrier wave is varied in direct proportion to that of the modulating signal to obtain an amplitude-modulated signal.

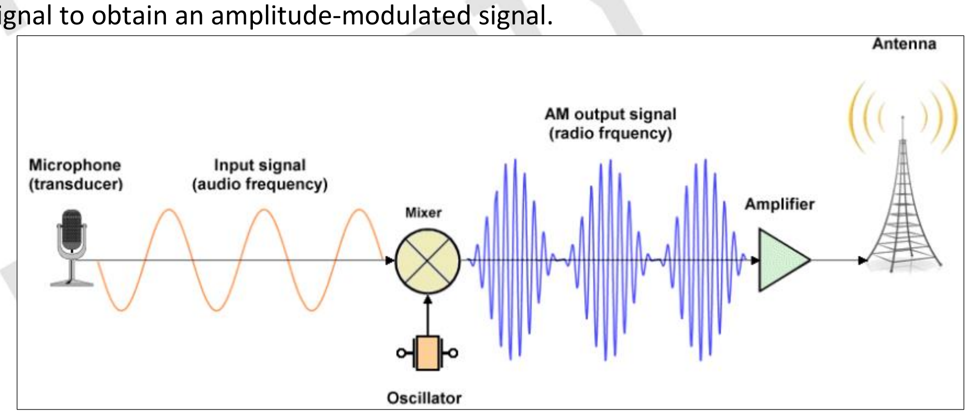

Figure 2. Amplitude modulation. Retrieved from https://www.technologyuk.net/

In Figure 2, a microphone acts as a transducer that receives the input signal in the form of audio frequency. This input signal will serve as the carrier. It is only modulated by adding the input signal in a mixer, turning it into a radio frequency acceptable for the transmission device.

Amplitude Modulation (AM)

It is a modulation process focused on modulating or changing the signal's amplitude. A device or a circuit can convert data into an electrical signal in an AM communications system. This signal, either the message or modulating signal, is then used to modify the amplitude of another signal.

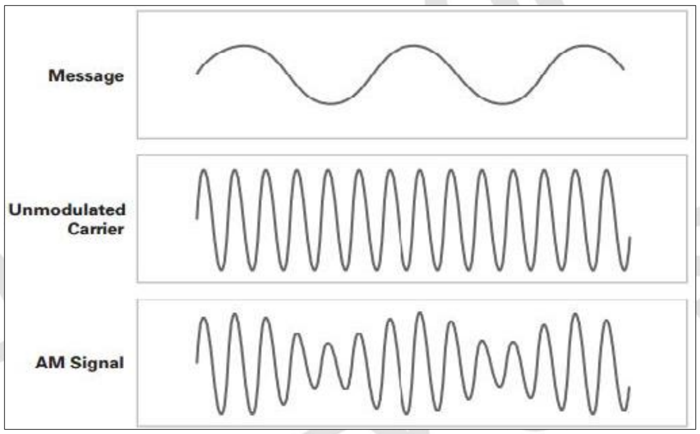

Figure 3. Amplitude modulation theory. Retrieved from https://digilent.com/reference/test-and-measurement/guides/complementary-labs/lab5/start

Figure 3 shows how the message modulates the carrier signal to produce the AM signal. Observe as the AM's signal increases or decreases based on the waveform of the message signal. In detail, see *Figure 4.*

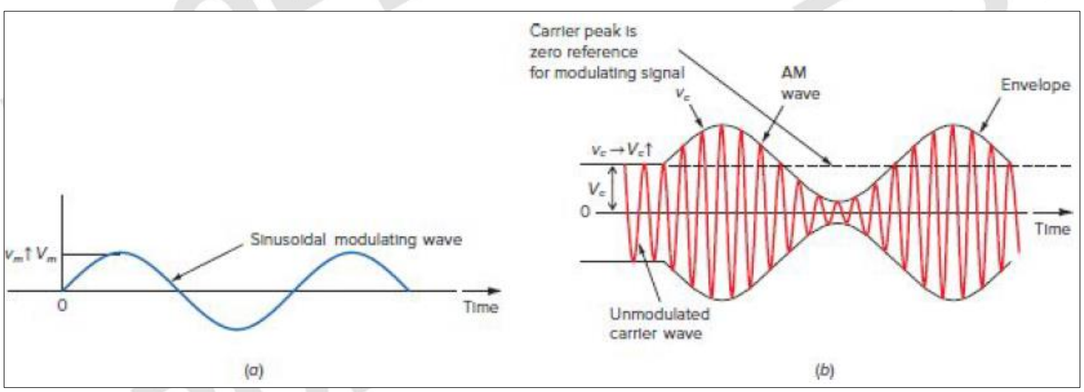

Figure 4. Retrieved from Frenzel, L. (2022). Principles of electronic communication systems: Fifth edition. McGraw Hill.

In *Figure 4*, (a) is the modulating signal, and (b) is the modulated carrier.

Here are the characteristics observed in applying amplitude modulation (b):

- The carrier frequency stays constant during the modulation process, but its amplitude (height) changes based on the modulating signal.
- An increase in the amplitude of the modulating signal increases the amplitude of the carrier.

- Changes in the positive and negative peaks of the carrier wave depend on the modulating signal.
- An imaginary line connects the positive and negative peaks of the carrier waveform. This imaginary line is called an "*envelope,*" which is the dashed line on (b).
- An increase/decrease in the amplitude of the modulating signal causes an increase/decrease in the positive and negative peaks of the carrier amplitude.

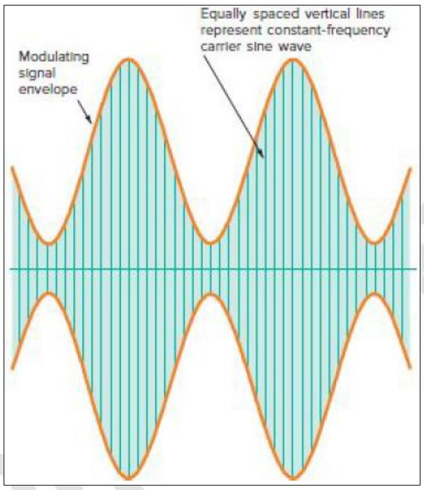

Figure 5. Retrieved from Frenzel, L. (2022). Principles of electronic communication systems: Fifth edition. McGraw Hill.

Figure 5 is the simplified waveform that uses equally spaced vertical lines to represent high-frequency carrier waves. The amplitude of these vertical lines also varies based on the modulating signal.

These illustrations show the variation of carrier amplitude concerning time and are to be in the time domain. **Time domain signals** are voltage or current variations that occur over time and are displayed on an oscilloscope screen.

Sidebands

During the modulation of a carrier wave by a modulating signal, new signals are generated at different frequencies as part of the process. These frequencies are called **sidebands**, or *side frequencies* found in the frequency spectrum above and below the carrier frequency. It is preferred to show the AM signal in the frequency domain rather than in the time domain if signals of more than one (1) frequency create a waveform.

Sidebands are the sum and difference of the carrier and modulating frequencies, such as:

$$f_{USB} = f_c + f_m$$
$$f_{LSB} = f_c - f_m$$

Wherein:

f_{USB} = Upper sideband
f_{LSB} = Lower sideband
f_c = Carrier Frequency
f_m = Modulating Frequency

Total bandwidth:
$BW = f_{USB} - f_{LSB}$ or $BW = 2f_m$

Sideband signals are illustrated in a **frequency domain** where the horizontal axis represents frequency, and the vertical axis represents the signal's magnitude, whether in voltage, current, or power amplitude. See *Figure 6***.**

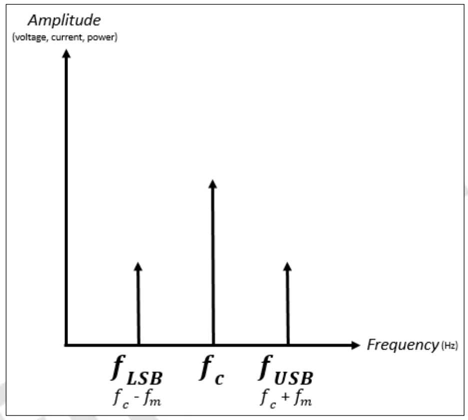

Figure 6. Retrieved from Frenzel, L. (2022). Principles of electronic communication systems: Fifth edition. McGraw Hill.

Modulation Index and Percentage Modulation (Frenzel, 2022)

The amplitude of the modulating signal must always be less than the amplitude of the carrier or $V_m < V_c$. Otherwise, distortion will occur and will transmit incorrect information, thus making the relationship between the amplitudes of the modulating signal and the carrier signal important.

This is known as the **modulation index** (m), also referred to as the degree of modulation or modulating factor/coefficient.

$$m = \frac{V_m}{V_c}$$

As stated, V_m and V_c are the peak values of the signals, and the carrier voltage is the unmodulated value.
65
To get the **percentage of modulation**, multiply the modulation index by 100**.**

An example if the carrier voltage is $8\ V$ and the modulating signal is $6.5\ V$:

$$m = \frac{V_m}{V_c}$$

$$m = \frac{6.5\ V}{8\ V}$$

$m = 0.8125$, to get the percentage of modulation:

$$\boldsymbol{m} = 0.8125\ x\ 100 = \mathbf{81.3}\%$$

Modulation Index Using Oscilloscope

An oscilloscope can be used to derive the modulation index (m) by measuring the values of the modulation and carrier voltages and then calculating the ratio. When the AM signal is seen on an oscilloscope, the modulation index is computed from V_{max} and V_{min}. The peak value of the modulating signal (V_m) is half the difference between the peak (V_{max}) and trough (V_{min}) values such as:

$$V_m = \frac{V_{max} - V_{min}}{2}$$

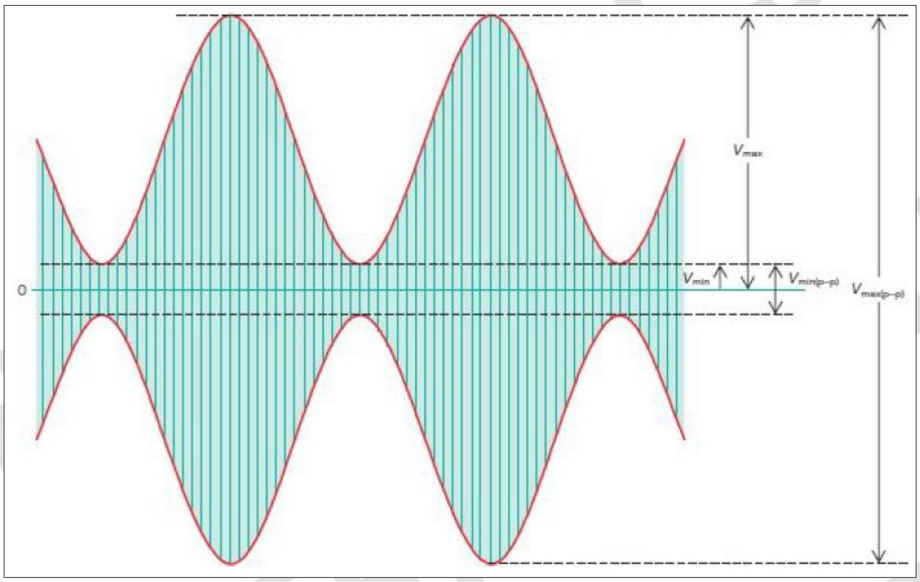

Figure 7. Retrieved from Frenzel, L. (2022). Principles of electronic communication systems: Fifth edition. McGraw Hill.

In *Figure 7,* $\boldsymbol{V_{max}}$ **is the peak value** of the signal during modulation, while $\boldsymbol{V_{min}}$ **is the lowest**, or the *trough* of the modulated wave. V_{max} is also one-half of the peak value of the AM signal, such as:

$$\frac{V_{\max(p-p)}}{2}$$

The values for $V_{\max(p-p)}$ and $V_{\min(p-p)}$ can be obtained from an oscilloscope screen and be used to compute the modulation index. Additionally, the depth of AM is more expressed as the percentage of modulation than as a fractional value.

Subtracting V_{min} from V_{max} gives the peak-to-peak value of the modulating signal, wherein one-half is the peak value. On the other hand, the peak value of the carrier signal V_c is the average of the V_{max} and V_{min} values.

$$V_c = \frac{V_{max} - V_{min}}{2}$$

The modulation index is:

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

Example: An AM signal is read with $4.9\ V$ divisions for V_{max} and $1.4\ V$ divisions for it's V_{min} from the graticule on the oscilloscope. What is the percentage of modulation?

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

$$m = \frac{4.9\ V - 1.4\ V}{4.9\ V + 1.4\ V}$$

$$m = \frac{3.5\ V}{6.3\ V}$$

$$m = 0.5555555$$

$$\boldsymbol{m} = 0.5555555\ x\ 100 = \mathbf{55.6}\%$$

References:

Frenzel, L. (2022). *Principles of electronic communication systems: Fifth edition.* McGraw Hill.

TechnologyUK (2023). *Amplitude modulation (AM).* [Web Article]. Retrieved on July 25, 2023, from https://www.technologyuk.net/telecommunications/telecom-principles/amplitude-modulation.shtml