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Diode Amplitude Modulation and Demodulation.

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Highlights

- **In wireless communication two important processes are needed to be achieved, modulation at the transmitting station and demodulation at the receiving side.**
- **Modulation is the process of encoding information in a transmitted signal,**
- **Demodulation is the process of extracting information from the transmitted signal.**

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ABSTRACT

Diode amplitude modulation and demodulation have been investigated and the modulation index and modulation percentage were calculated. Of the several amplitude modulation methods, the diode modulation has been chosen to execute the amplitude modulation process because it was the first method used and it is the simplest method. A 50 Hz sine wave is used as a modulating signal to amplitude modulate a 1 kHz sine wave used as a carrier wave. During the modulation process, the amplitude of the modulating signal was kept constant at a value of 6 V while the amplitude of the carrier wave was given values between 6 V to 12 V increasing the value in steps of 1 V. The shapes of the modulation stages and of the demodulation processes were displayed on the oscilloscope screen using the simulation programmed named NI Multisim 14.2. The experiments were also carried out practically in the advanced electronics laboratory in the Physics department/Faculty of Science/University of Benghazi using real electronic equipment and parts. The recovered audio signal in the demodulation process was the same as that used as a modulating signal.

1. Introduction

Communication is the process whereby information is transferred from one point called the source to an other point called destination (Maji, 2010). Wireless Communication has removed the need for wires in communication systems. This is achieved by modulation to transmit the signals through space to long distances without using wires. The amplitude modulation is defined as a modulation technique where the amplitude of a high frequency sine wave called a carrier wave is varied in a direct proportion to the modulating signal which contains the intended message or information to be sent. The carrier is modulated by combining it with the message signal using a mixer, which is a nonlinear operation because it generates new frequencies (https://www.technologyuk.net/telecommunications/telecom principles/amplitude modulation.shtml) The process of modulation plays a major role in the fast transmission of signals. The amplitude modulation (AM) signal is composed of low frequency and high frequency components. The amplitude of the high frequency (called the carrier) is controlled by the low frequency (modulating) signal. The envelope of the modulated signal is created by the low frequency signal as shown in Fig. 1. The low frequency signal could be an audio signal and the high frequency is the transmitting frequency (Heathkit Continuing Education/ Individual Learning Program in Electronic Circuits).

The two most popular types of modulation are the amplitude modulation (AM) and frequency modulation (FM). Those two types of modulation are used by most radio systems in the world to broadcast their programs (https//en.wikipedia.org/wiki/Modulation). In AM systems, the amplitude of the high frequency carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal. In FM systems, it is the frequency of the carrier is varied without varying the amplitude (Theraja and Theraja, 2005).

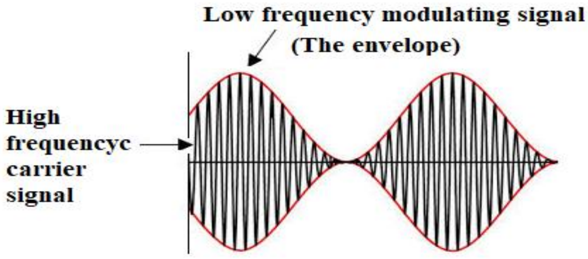

Fig. 1. AM signal in time domain.

1.1. AM modulation index

The amplitude modulation index describes the amount by which the modulated carrier envelope varies about the static level. This can be expressed in mathematical terms as follows (https://www.electronics- notes.com/articles/radio/modulation/amplitudr-modulation-am-index-depth.php):

$$\mathrm{M.I.} = \frac{\text{maximum amplitude of the modulating signal}}{\text{maximum amplitude of carrier wave}} = \frac{\mathrm{B}}{\mathrm{A}} \qquad (1)$$

Modulation index may also be defined in terms of the values referred to the modulated carrier wave (Theraja and Theraja, 2005).

$$\mathrm{M.I} = \frac{\mathrm{E_{c(max)}} - \mathrm{E_{c(min)}}}{\mathrm{E_{c(max)}} + \mathrm{E_{c(min)}}} \qquad (2)$$

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where Ec (max) and Ec (min) are the maximum and minimum values of the amplitude of the modulated carrier wave. Therefore, Eq. (1) and 2 are the two formulas for the modulation index. The modulation index or modulation depth is often denoted in percentage called a percentage of modulation. The modulation percentage is obtained by simply multiplying the modulation index value by 100% (Theraja and Theraja, 2005).

$$m = \frac{E_{c(max)} - E_{c(min)}}{E_{c(max)} + E_{c(min)}} x100\% \quad (3)$$

For a perfect modulation, the value of the modulation index should be 1, which implies the percentage of modulation to be 100% as shown in Fig. (2).

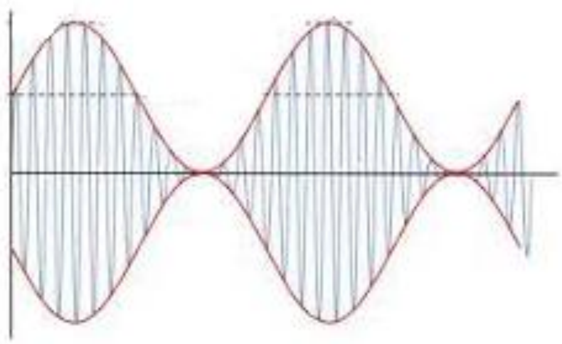

Fig. 2. 100% amplitude modulation.

If this value is less than 1, for example, 0.5, then the modulated output would look like the one shown in Fig. 3. Such a wave is called an under-modulated wave.

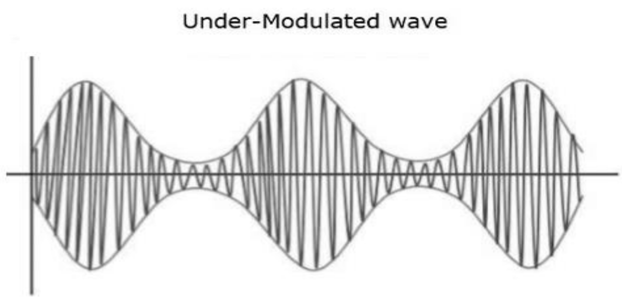

Fig. 3. The under-modulated wave.

If the value of the modulation index is greater than 1, for example, 1.5 or so, then the wave will be an overmodulated wave. It would look like the one shown in Fig. 4.

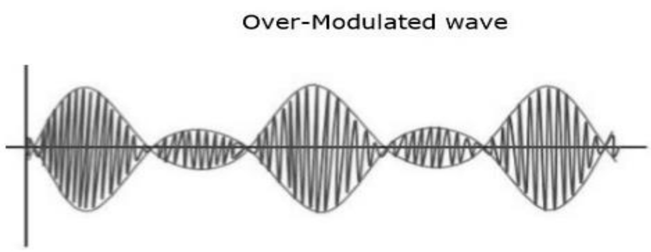

Fig. 4. The over-modulated wave

1.2. Demodulation or Envelope Detection

As the name indicates, the demodulation process is the opposite of modulation, it is the process of recovering the information from the carrier (https//wiki.analog.com/university/course/electronics/electronics-lab-envelope-detector). The information may be spoken words, music, pictures, or special code. Fig. 5 shows what the demodulator does (https://www.electronics-notes.com/articles/radio/modulation/samplitude-modulation-am-demodulation-detection.php).

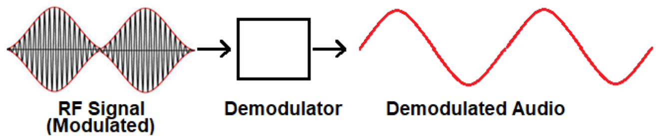

Fig. 5. A demodulation process.

The most popular AM demodulator is the diode detector. This circuit is very simple and is almost used in all AM receivers. Its purpose is to recover the envelope from the AM waveform (EXPERIMENT 8, 'Amplitude modulation and Demodulation' ECGR 3156, Electromagnetic and Electronic Devices Laboratory', University of North Carolina .33 at Charlotte).

2. Experimental Results and Discussion

The circuit of the diode modulator is shown in Fig. 6. It is the simplest circuit for producing amplitude modulation. The modulating signal (audio) is applied at the left side of R1 while the high frequency carrier is applied at the left side of R2. The signal at the junction of R1 and R2 is the sum of the carrier and the audio signals. The diode D is a series clipper, it conducts through R3 when the signal on the anode swings positive, when this signal swings negative, D cuts off. The purpose of the LC tank circuit, which is tuned to the carrier frequency is to resonate at each time D conducts, a pulse of current flows through the tank and the flywheel action of the tank produces a negative half-cycle for each positive input pulse. The high amplitude positive pulses cause high amplitude negative pulses (EXPERIMENT 8, 'Amplitude modulation and Demodulation' ECGR 3156, Electromagnetic and Electronic Devices Laboratory', University of North Carolina .33 at Charlotte).

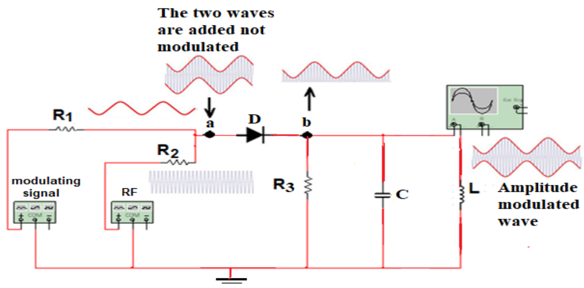

Fig. 6. Diode modulator and its waveforms.

The RF carrier performs two functions. First, its unique frequency prevents it from interfering with other transmissions. Second, it allows communications systems to use reasonable length antennas. Fig. 7 shows the circuit diagram of the diode modulation used to execute the amplitude modulation process. Two function generators were used, one to generate the low modulating signal and the other to generate the high RF signal, two resistors one kilo ohm each, one resistor 10 kΩ, one 1Ω resistor, one 10 µF capacitor, one 2.5 mH inductor, one 1N4001 diode, and a two-channel oscilloscope to view the shapes of the waveforms at the different stages of the cicrcuit. In this method of amplitude modulation, the modulating signal was a 50 Hz sinewave (f_m = 50 Hz) with 6 volts amplitude (V_m = 6 V). The RF signal was 1 kHz sinewave (f_c = 1 kHz).

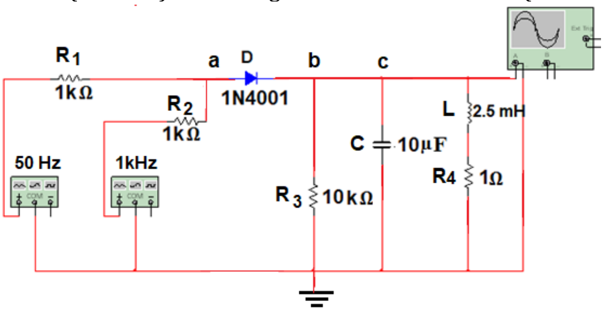

Fig. 7. The circuit diagra of diode amplitude modulation 1.

The frequencies and the amplitudes of the both signals were seen and measured by the oscilloscope. The frequencies were kept fixed at those values, and the amplitude of the modulating signal V_m was also kept fixed at 6V. Fig. 8 shows the waveform of the modulating signal produced by the first function generator. It can be clearly seen that the time between two successive peaks (T) is 20 ms. Since the frequency is calculated by

$$f = \frac{1}{T}, \text{ then } f_m = \frac{1}{20x10^{-3}} = 50Hz.$$

Fig. 9 shows the waveform of the RF signal, following the same method used to calculate f_m, it can be seen that

$$f_c = \frac{1}{1x10^{-3}} = 1kHz.$$

The amplitudes of the fm and fc can be measured by noting the number of Y divisions (volt/div) on the oscilloscope screen and then multiplying this number by the value of each division.

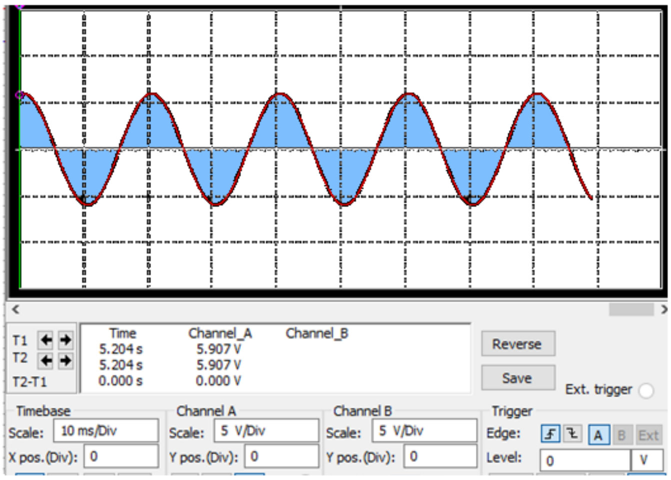

Fig. 8. The modulating signal (f_m=50 Hz.).

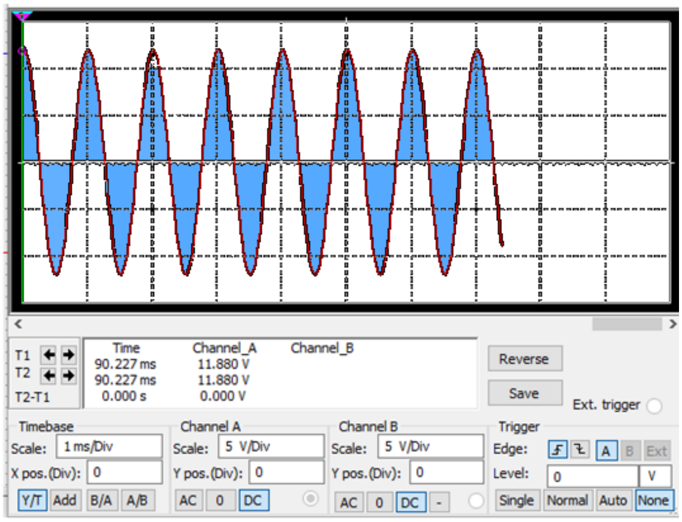

Fig. 9. The RF frequency (The carrier f_c= 1kHz.).

Viewing the shape of the modulated waveform on the screen of the oscilloscope, the amplitude of the RF signal was given values, it starts at 6 V (Vc = 6 V) and then increased in steps of 1 V until it reached 12 V (Vc = 12 V). At each step, the maximum and minimum values of the modulated signal were observed and measured. The modulation index (M.I.) and the modulation percentage were calculated.

Fig. 10 shows the waveform of the sum of the modulating signal f_m and the RF signal fc. This waveform can be seen at the test point (a) before the diode D (the diode is disconnected from point a). Notice that this waveform is not a modulated waveform, it is only the sum of the two signals. Fig. 11 shows the waveform shape at the output of the diode at test point (b) before going to the LC circuit (points b and c are disconnected when the shape of this wave was observed). As it can be seen that the negative part of the wave has been clipped. This waveform can be viewed on the screen of the oscilloscope across the resistor R3 at the output between the diode and the earth.

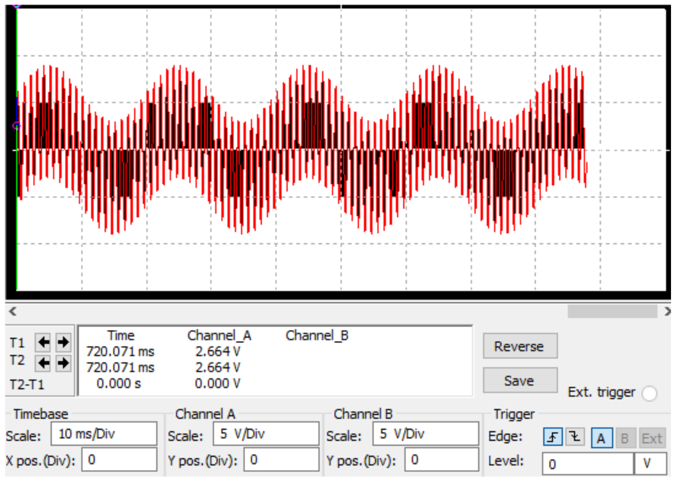

Figure 10. The sum of f_m and f_c at point a.

Fig. 11. The output after the diode at point b.

Figs. 12 to 18 show the shapes of the amplitude modulated waveforms for the Vc values started from Vc = 6 V to Vc = 12 V.

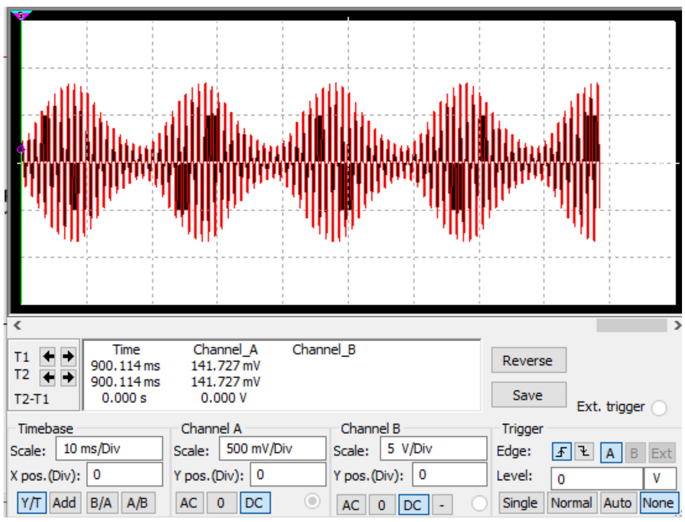

Fig. 12. The modulated signal when V_m = V_c= 6V.

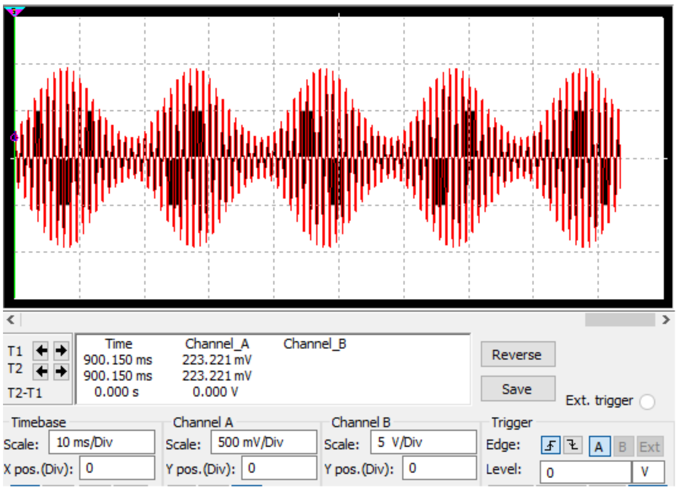

Fig. 13. The modulated signal when Vm = 6V and Vc= 7V.

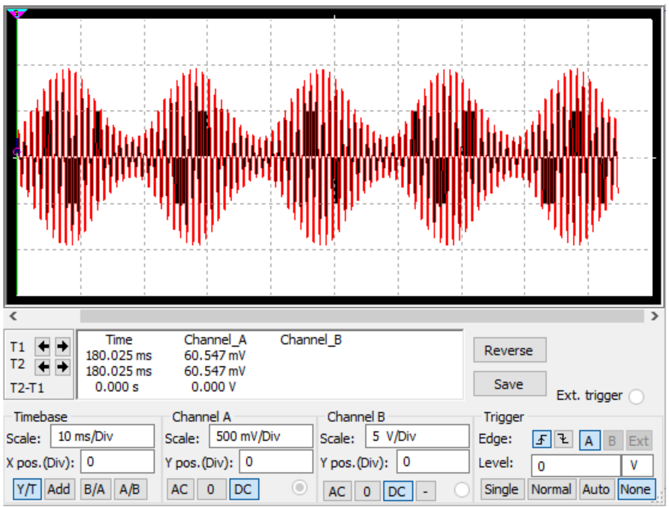

Fig. 14. The modulated signal when V_m = 6V and V_c= 8V.

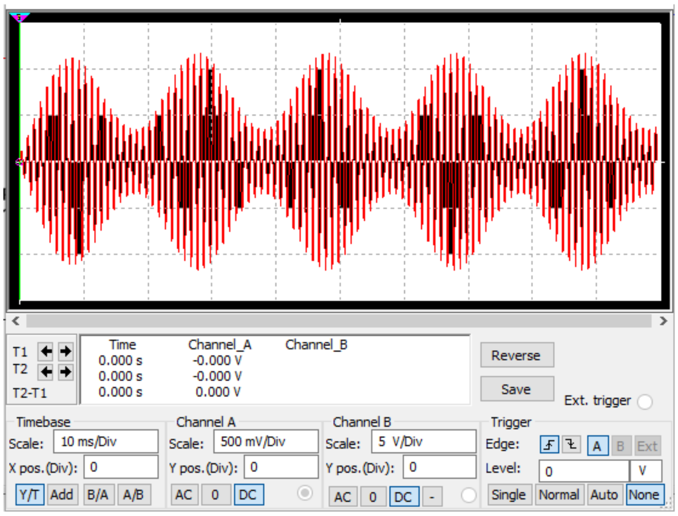

Fig. 15. The modulated signal when Vm = 6V and Vc= 9V.

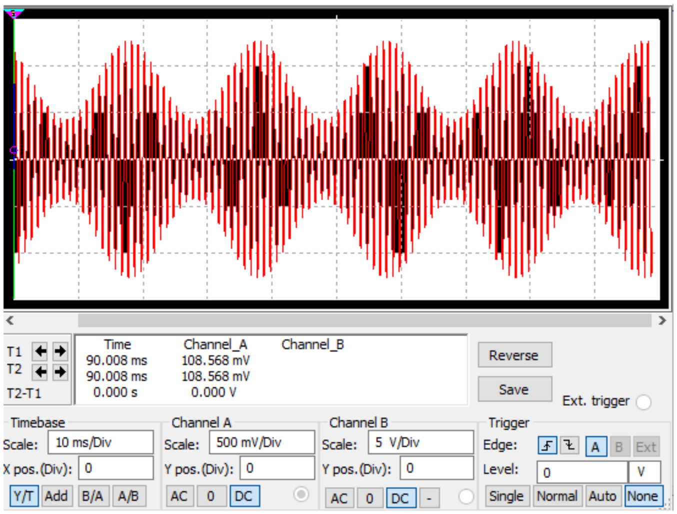

Fig. 16. The modulated signal when V_m = 6V and V_c= 10V.

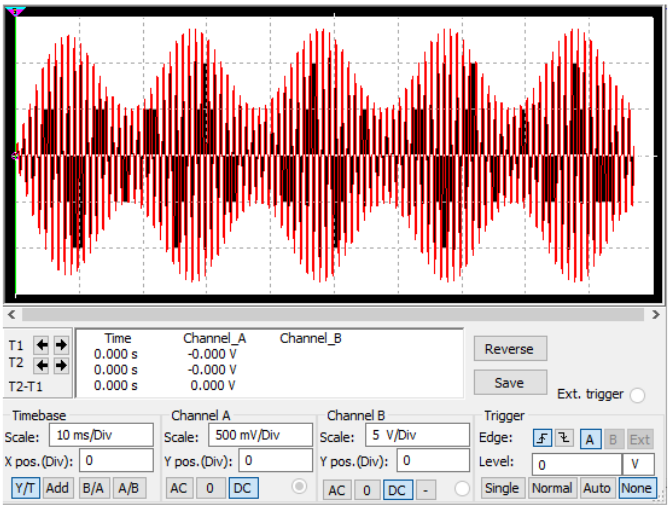

Fig. 17. The modulated signal when Vm = 6V and Vc= 11V.

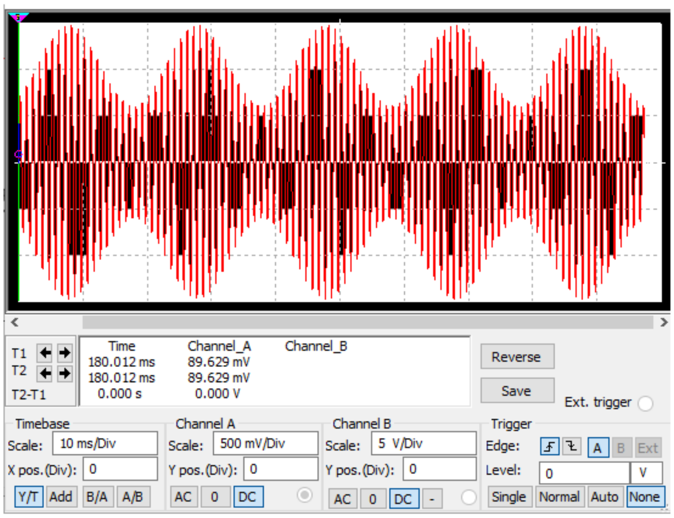

Fig. 18. The modulated signal when V_m = 6V and V_c= 12V.

Notice that the general shape of the waveforms is similar, but the maximum and minimum values are different. The maximum (E_{max}) and minimum (E_{min}) values of the amplitude of those modulated waveforms for every step were measured and the values of the M.I. and of the modulation percentage were calculated. The obtained results are listed in Table 1. As it can be seen from Table1, the maximum values of the M.I. and of the modulation percentage were obtained at Vc = 6 V (Vc = Vm = 6 V) and then decreased as the amplitude values of the RF signal were increased.

Table 1. (f_c = 1 kHz, f_m= 50 Hz, V_m= 6 V)

V_c Volts	E_{max} Volts	E_{min} Volts	$M.I. = \frac{Emax - Emin}{Emax + Emin}$	Modulation Percentage $m = M.I.x100\%$
6	0.833	0.167	0.666	66.6%
7	0.958	0.200	0.655	65.5%
8	1.083	0.250	0.625	62.5%
9	1.250	0.333	0.579	57.9%
10	1.333	0.417	0.524	52.4%
11	1.417	0.500	0.478	47.8%
12	1.500	0.667	0.384	38.4%

In Fig. 19 the values of the M.I. in Table 1 are plotted as a function of the carrier amplitude (Vc). Fig. 20 depicts the values of the modulation percentage as a function of Vc.

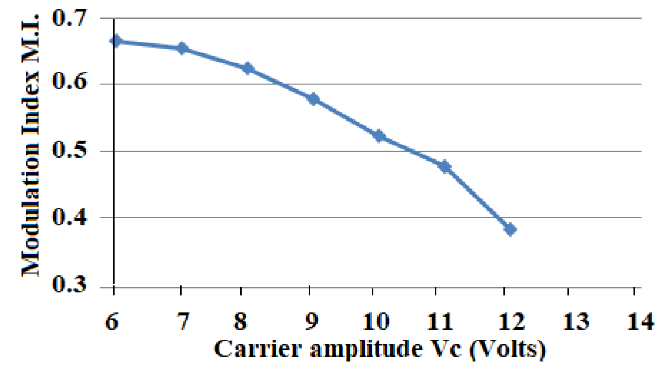

Fig. 19. Modulation index vs. carrier amplitude at constant modulating amplitude.

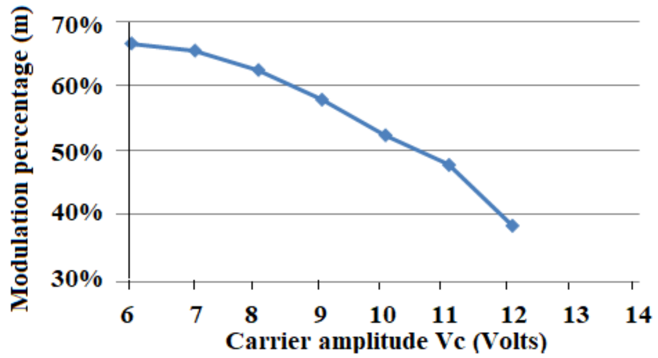

Fig. 20. Modulation percentage vs. carrier amplitude at constant modulating amplitude.

3. Demodulation of the amplitude modulation

The RF carrier performs two functions, the first one its unique frequency prevents it from interfering with the other transmitted signals. The second one, as was mentioned formerly, helps the communications systems to use reasonable antenna lengths. The human ear responds to frequencies in the range of 20 Hz. to 20 kHz, it cannot respond to the high RF carrier used to carry the audio information. So, we have to get rid of the carrier wave on the receiver side and recover the required intelligence. The circuit that can perform this function is called a demodulator or a detector. The simplest AM detector is the diode detector, which is used in almost all AM receivers. Fig. 21 shows the same circuit of Fig. 5, but in this circuit the demodulator part, is attached to its output, which consists of a rectification diode D_2 and a parallel R-C circuit (Low Pass Filter (LPF)). The modulated waveform is applied to D_2 which acts as a half-wave rectifier, it cuts off the negative half cycles of the AM waveform. Diode D_2 is followed by a low-pass filter which takes the high frequency of the RF to the earth and allows the low audio frequency to pass, i.e., the intelligence has been recovered. The time constant RC should verify the following condition so that the demodulation can occur (https://www.electronicsnotes.com/articles/radio/modulation/samplitude-modulation-am-demodulation-detection.php)

$$\frac{1}{f_c} \ll RC \ll \frac{1}{f_m}$$

Substituting the values of f_c, R_5, C_2, and f_m, we get

$$\frac{1}{1000Hz} \ll 10^4 \Omega x 1x10^{-6} F \ll \frac{1}{50Hz}$$

$$1ms \ll 10ms \ll 20ms$$

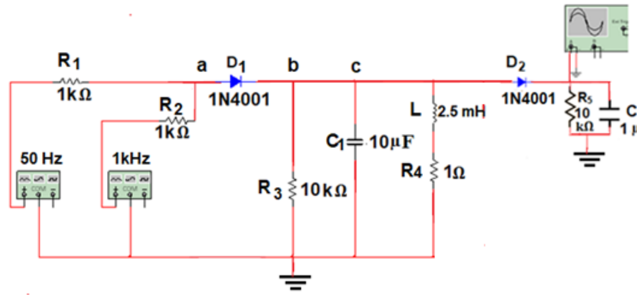

Fig. 21. Diode amplitude modulation and demodulation.

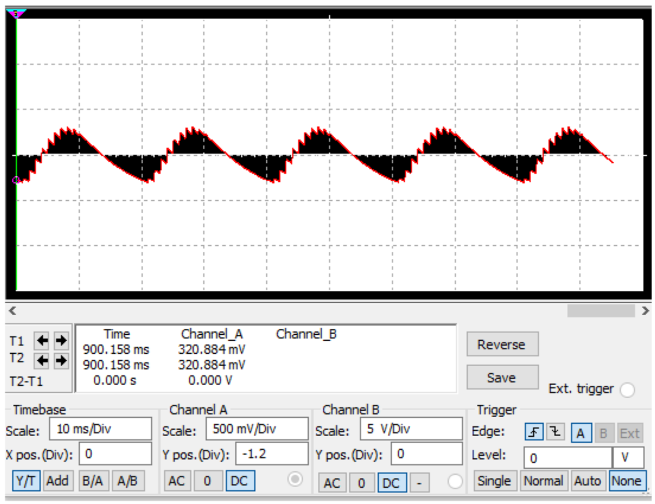

Fig. 22. The recovered original audio signal by the demodulator.

Fig. 22 shows the original audio signal after it has been recovered by the demodulation stage, as in can be noticed its frequency is 50 Hz. We are unable to give a reason for the nonlinearity of the up going part of the signal but we think it has to do something with the charging and discharging of the capacitor C_2. Then we carried out the diode amplitude modulation experimentally in electronics advanced laboratory in the physics department at Benghazi University. Fig. 23 shows the connection of the circuit.

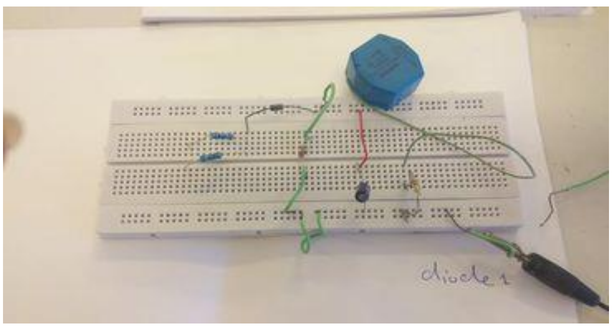

Fig. 23. Experimental connections for the diode amplitude modulation.

Fig. 24 shows the 50 Hz modulating signal with a 6 V amplitude which is kept constant throughout the experiment.

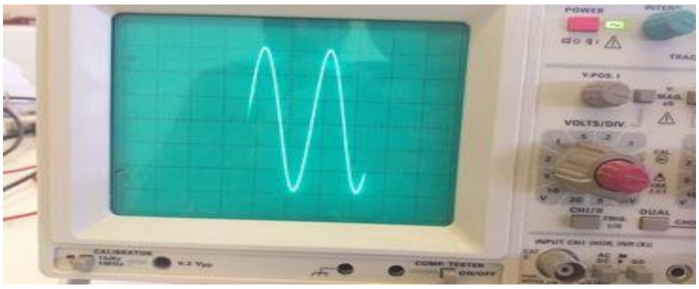

Fig. 24. The 50 Hz, 6 V modulating signal (fm).

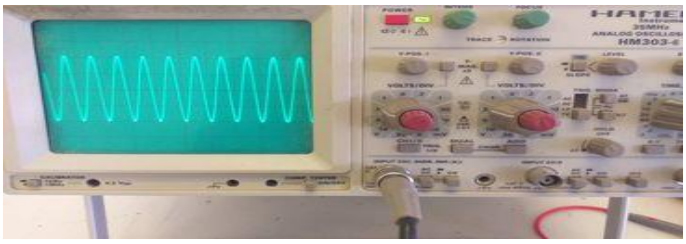

Fig. 25. The 1 kHz, 6 V cattier signal (fc).

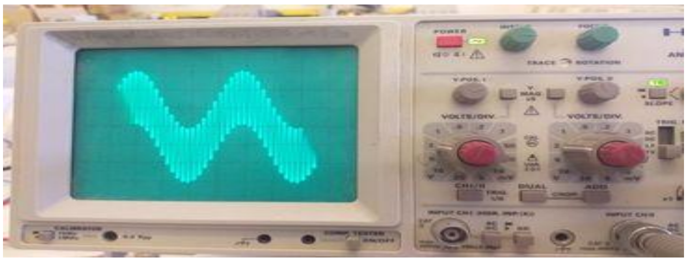

Fig. 26. The sum of fm and fc at point (a) in Fig. 7.

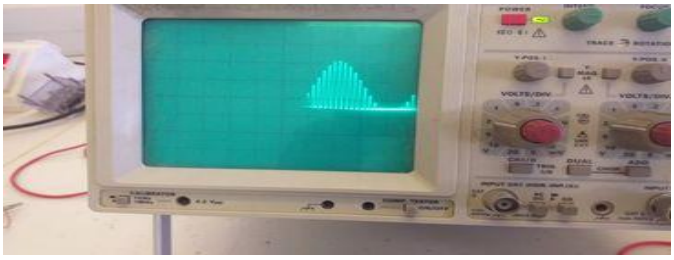

Fig. 27. The output wave at point (b) in Fig. 7.

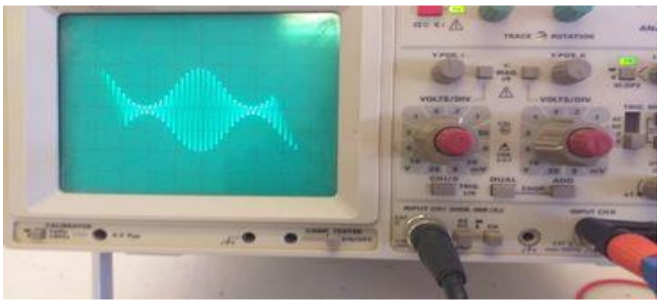

Fig. 28. The output amplitude modulated wave at point (b) after connecting the LC resonant circuit in Fig. 7. (Vm = 6 V, Vc = 9 V).

Fig. 29. The output amplitude modulated wave at point (b) after connecting the LC resonant circuit in Fig. 7. (Vm = 6 V, Vc = 10 V).

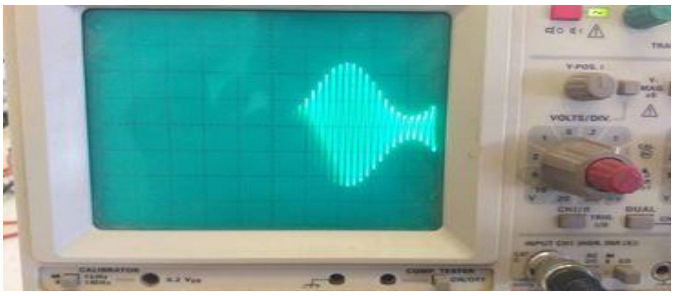

Fig. 30. The output amplitude modulated wave at point (b) after connecting the LC resonant circuit in Fig. 21 (Vm = 6 V, Vc = 11 V).

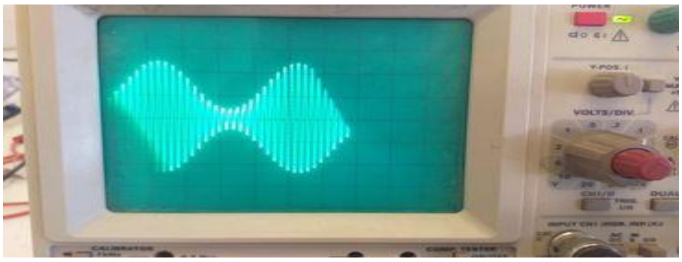

Fig. 31. The output amplitude modulated wave at point (b) after connecting the LC resonant circuit in Fig. 21 (Vm = 6 V, Vc = 12 V).

Fig. 32. The output amplitude modulated wave at point (b) after connecting the LC resonant circuit in Fig. 21 (Vm = 6 V, Vc = 13 V).

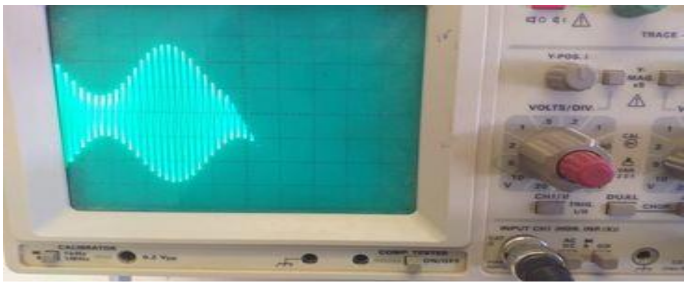

Fig. 33. The output amplitude modulated wave at point (b) after connecting the LC resonant circuit in Fig. 21 (Vm = 6 V, Vc = 14 V).

Fig. 34. The output amplitude modulated wave at point (b) after connecting the LC resonant circuit in Fig. 21 (Vm = 6 V, Vc = 15 V).

Table 2 shows the values of V_c, maximum (E_{max}) and minimum (E_{min}) of the modulated signals, the modulation index (M.I.), and the modulation percentage of the Figs. 28 to 34. Notice that the maximum modulation percentage is obtained when the amplitude of the carrier wave is 9 V.

Table 2. (f_c = 1 kHz, f_m= 50 Hz, V_m= 6 V).

V_c Volts	E_{max} Volts	E_{min} Volts	$M.I.=\frac{\text{Emax}-\text{Emin}}{\text{Emax}+\text{Emin}}$	Modulation (%) $m=M.I.x100\%$
9	0.4	0.025	0.88	88%
10	0.44	0.04	0.83	83%
11	0.48	0.08	0.71	71%
12	0.48	0.1	0.65	65%
13	0.52	013	0.60	60%
14	0.52	0.14	0.57	57%
15	0.56	0.17	0.53	0.53

By comparing the results in Table 1 with those in Table 2 it can be seen that the maximum values of the M.I. and of the modulatio percentage were obtained at Vc = 6 V (Vc = Vm = 6 v) and then decreased as the amplitude values of the RF signal were increased. In the practical work, those values as shown in Table 2 were also seen to be decreasing after the maximum value (at Vc = 9 V) as the amplitude of the RF signal were increased.

4. Conclusion

The main purpose of this work is to gain practical knowledge and experience in hardware assembly. The electronic circuits of the diode amplitude modulation method and the demodulation were carried out using function generators, capacitors, inductors, resistors, diodes, and oscilloscopes. The modulating signal and the carrier wave were allowed to be added together and then the modulation process was achieved by making the carrier wave convey the audio signal. The circuits used in this paper were executed by the simulation program named NI Multisim14.2 and were carried out and successfully tested experimentally on the breadboard. The practical and simulated results were almost similar. When there were minor differences between the two methods, the differences can be attributed to the difference between the practical circuit components and the ideal circuit nature of the simulation software. Graphical analysis of the obtained results of the modulation indices and the modulation percentages versus the amplitudes of the carrier was shown. The maximum modulation percentage is obtained in the simulation program when the amplitude of the carrier wave equals that of the modulating signal. In the experimental method, the maximum modulation percentage is obtained when Vc = 9 V and Vm = 6 V. In both cases the values of the modulation index and the modulation percentage decreased as the values of the amplitude of the carrier waves were increased. The recovered audio signal by the demodulation circuit was very similar to the original signal produced by the first function generator.

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