Simulation of Digital Modem Based on Software Defined Radio (SDR)

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Abstract: The Radio Frequency (RF) transceiver performs various functions and the use of software defined radios (SDRs) is increasing day after another. The SDRs are characterized by their flexibility where the software can change the functionality of the device without changing its hardware. This paper presents a flexible SDR-based communication system. The simulated system has the ability to perform the following modulation / demodulation modes: AM, DSB, SSB, QAM, FM and PM. These modes are achieved by software at the baseband frequency components that are in-phase component (I) and quadrature phase component (Q) in accordance to the modulator / demodulator instead of achieving this process digitally at IF or RF frequency directly. The simulated results proved the efficiency of the implemented system in case of noiseless or noisy channel. To simplify the use and evaluation of the proposed system a Graphical User Interface (GUI) has been implemented for the system.

Keywords: Software Defined Radio, Modulator, Demodulator.

1. Introduction

Radio is the most common type of the wireless communication devices in use today. The RF transmitter / receiver performs various functions including converting voice or data to and from radio frequency signals. The processing of analog RF signal, baseband signal and waveform modulation / demodulation are epitomes of RF functions [1]. The RF communication is continuously moving towards digitizing RF signals by replacing analog components with digital signal processors (DSPs), field programmable gate arrays (FPGAs), or the general purpose processors (GGPs). This led to the development of the so-called Software Defined Radios (SDRs).

The SDR is characterized by its flexibility where modifying or replacing software programs can completely change its functionality and thus providing the possibility of upgrading and improving the system without the need of replacing the hardware [2]. Over the years several SDR systems have been implemented to serve different purposes such as the systems in [3-7].

The aim of this work is to design and implement different modulation / demodulation modes including (AM, DSB, SSB, QAM, FM and PM) using SDR. These modulation / demodulation modes are achieved by software at the baseband frequency as (I-Q) modulator / demodulator.

The rest of the paper contains the following: section 2 introduces the background information related to the topic of this research; section 3 presents the details of the implemented communication system, and its Graphical User Interface (GUI); section 4 presents the experiments and results for evaluating the performance of the implemented system; and section 5 contains the conclusions of this work.

2. SDR Technology

The transceiver system mainly consists of two sections that are modulator and demodulator. A general block diagram of the modulator section is shown in Figure (1) which consists of two subsections the multimode (baseband) (I/Q) signals and up-conversion stage. The first subsection is called the multimode baseband (I/Q) signals because the operation of this subsection is achieved digitally (by software) in baseband frequency. It produces two output baseband components which are called in-phase (I) and quadrature phase (Q) components in accordance to the modulation mode (scheme) [8-10]. The difference between the in-phase (I) and quadrature phase (Q) signal is 90 degrees phase shift. Then these output baseband (I and Q) components are applied to upconversion stage to translate their frequencies from baseband to intermediate frequency (IF) through mixing these components with local carrier signal to produce the bandpass (IF) modulated signal [4], [11].

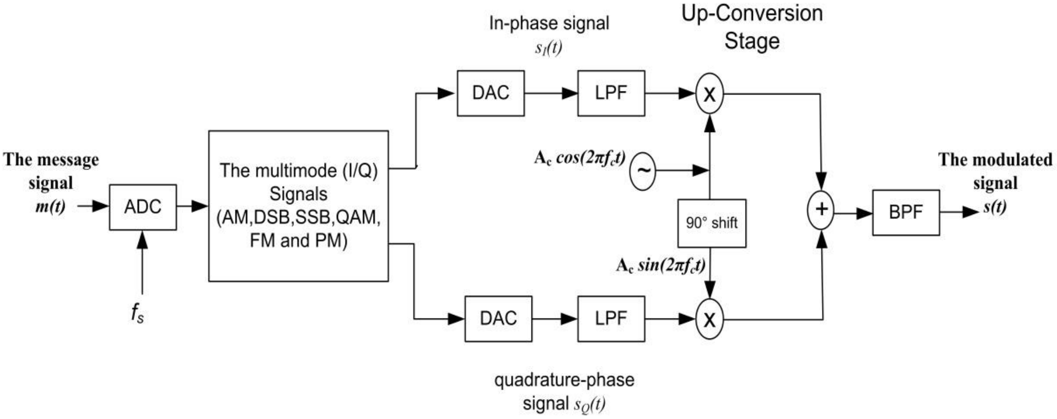


Figure (1): General block diagram of the modulator section

The second essential section of transceiver system is the demodulator section which is shown in Figure (2). The demodulator consists of two sections the down-conversion stage and the multimode (I/Q) signals stage.

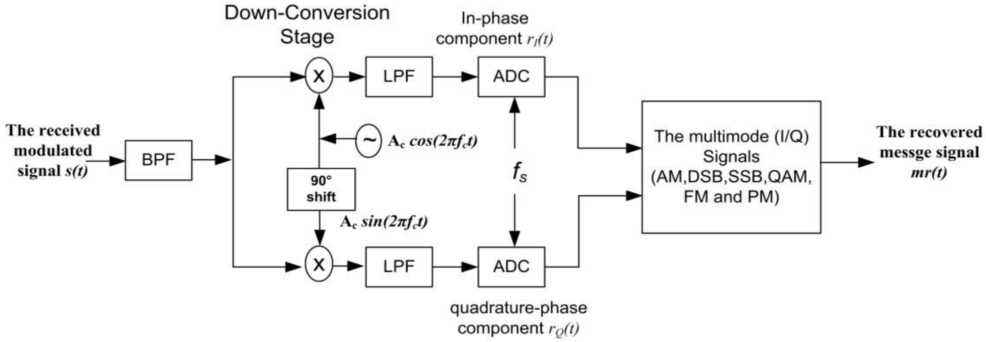


Figure (2): General block diagram of the demodulator section.

The targeted system of this work is a multimode communication system capable of performing six types of modulation / demodulation processes that are:

- Amplitude Modulation (AM), where a carrier wave with the upper and lower sidebands transmitted [12].
- Double sideband-suppressed carrier (DSB-SC) modulation, where only the upper and lower sidebands are transmitted [13].
- Single sideband (SSB) modulation, where only one sideband (the lower sideband or the upper sideband) is transmitted [14].
- Quadrature Amplitude Modulation (QAM); In this form of modulation, two independent message signals are transmitted and the upper and lower sidebands are transmitted for both messages (modulating) signals [14].
- Frequency Modulation (FM) is an angle modulation in which the instantaneous frequency is varied linearly with the message signal [1, 14].
- Phase Modulation (PM) is an angle modulation in which the angle is varied linearly with the message signal [1].

3. The Proposed Modulator / Demodulator System

This section presents the flowcharts of the proposed programmable (multimode) modulator/demodulator system in addition to the implemented graphical user interface (GUI) of the system. In the proposed multimode (I-Q) transceiver system the channel has been added to the modulator / demodulator sections to make the simulation more realistic. The channel section gives option to add noise to the modulated signal. The general block diagram of the multimode modulator / demodulator system is shown in Figure (3). The details of the proposed system are explained in the next subsections.

Figure (3): The general block diagram for the proposed multimode modulator / demodulator system

3.1: Modulator Section

This section receives the sampled message (modulating) signal to generate the bandpass modulated signal for any mode of the following: AM, DSB, SSB, QAM, FM and PM according to the desired mode. The modulator consists of two subsections: the multimode baseband (I-Q) modulator and the up-conversion. The multimode baseband (I-Q) stage processes the incoming sampled message signal which is either a singletone or a multi-tone. The upconverting stage performs the up-convert the frequency of the two baseband modulated components the (I and Q) components received from the (I-Q) modulator subsection from baseband frequency to IF or RF frequency by using carrier oscillator. Figure (4) shows the flowchart for the implemented modulator section.

3.2: Channel Section

This section gives the system more realistic features. The channel section gives two options: the first option generate RF signal without noise by assuming the channel is free of noise. The second option allows adding rate of noise to the incoming band-pass modulated signal from the modulator section to generate RF signal.

3.3: Demodulator Section

The essential operation of this section is to retrieve the original message signal. This demodulator can demodulate the received radio signal from the channel section. The demodulator section also consists of two subsections, the first subsection is the down-conversion stage and the second subsection is the (I-Q) demodulator.

The down-conversion stage represents the first subsection in the multimode demodulator section. It is used to reduce the sampling rate for the incoming radio signal which is high frequency signal, through down-convert the RF signal to baseband signal. The received RF signal is multiplied with locally generated sinusoidal wave. This local oscillator signal is assumed exactly coherent or synchronized, in both frequency and phase, with the carrier wave.

The main operation of the demodulator subsection is recovering the message signal digitally through receiving the sampled baseband components the (I and Q) components from the down-conversion subsection and using these components to demodulate the message signal according to the same selected mode in the modulator section. Figure (5) shows the flowchart for the implemented demodulator section.

The reader can refer to the references [12-14] for the basics, detailed information, and equations to calculate $s_I(t)$, $s_Q(t)$, $r_I(t)$, and $r_Q(t)$.

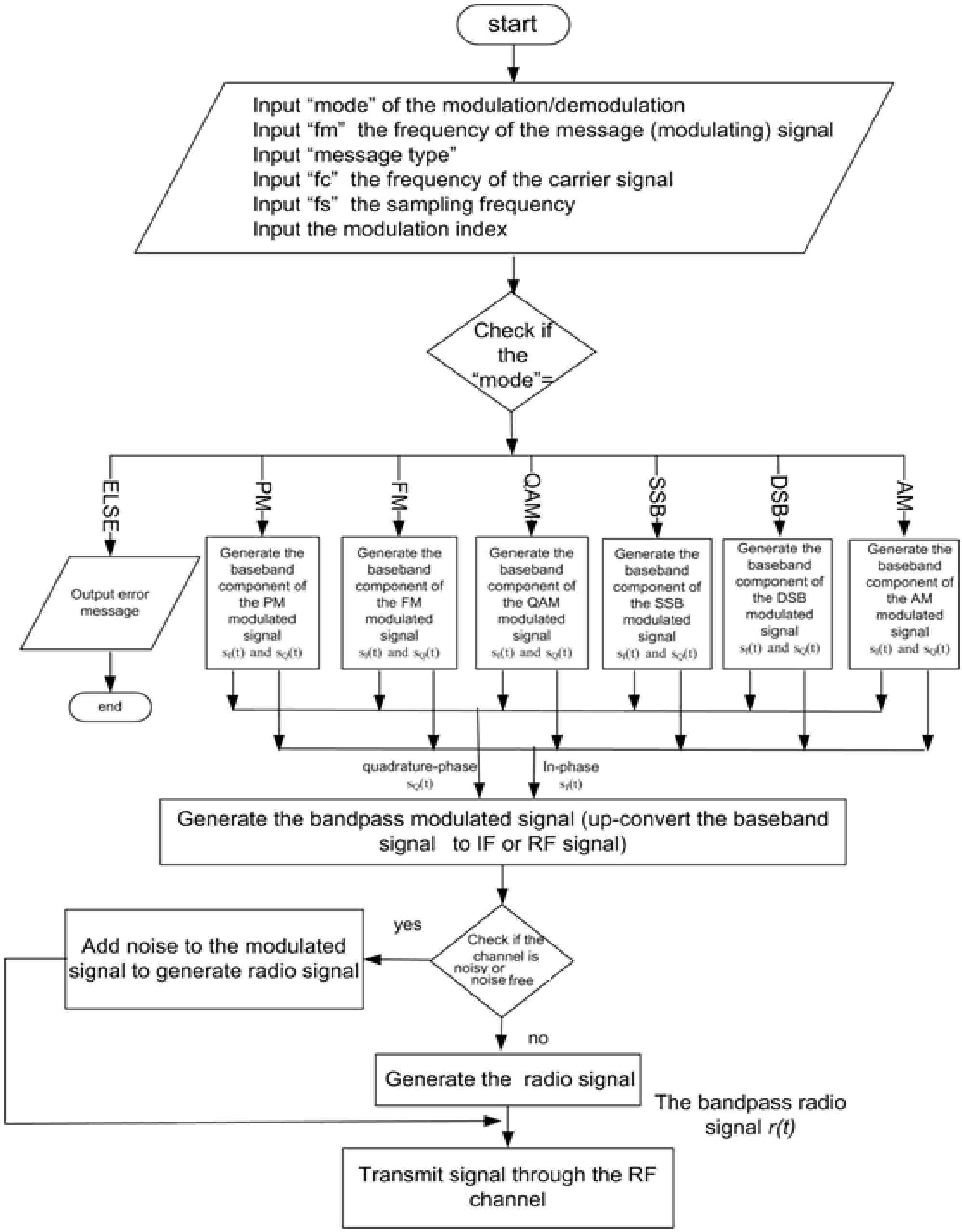


Figure (4): The general flowchart of the implemented modulator.

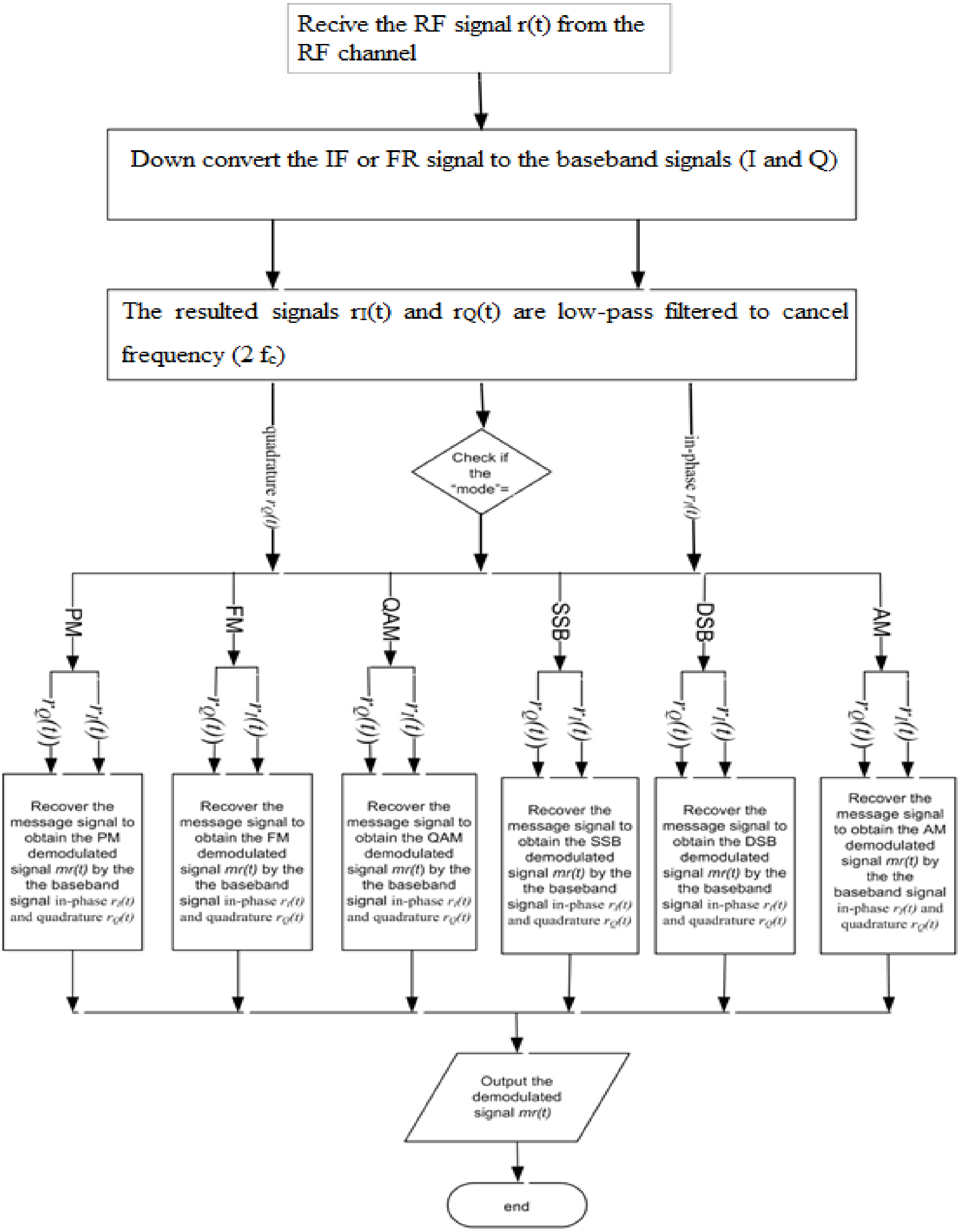


Figure (5): The general flowchart of the implemented demodulator.

3.4: GUI for the Proposed System Simulator

The proposed system has been implemented on Pentium IV computer of 2400 MHz CPU clock frequency using MATLAB programming tools (version 7.0). The simulator is programmed and developed, the graphical user interface (GUI) is shown in Figure (6) to simplify the testing and employment of the implemented system. Table (1) illustrates the details of each parameter in the implemented GUI.

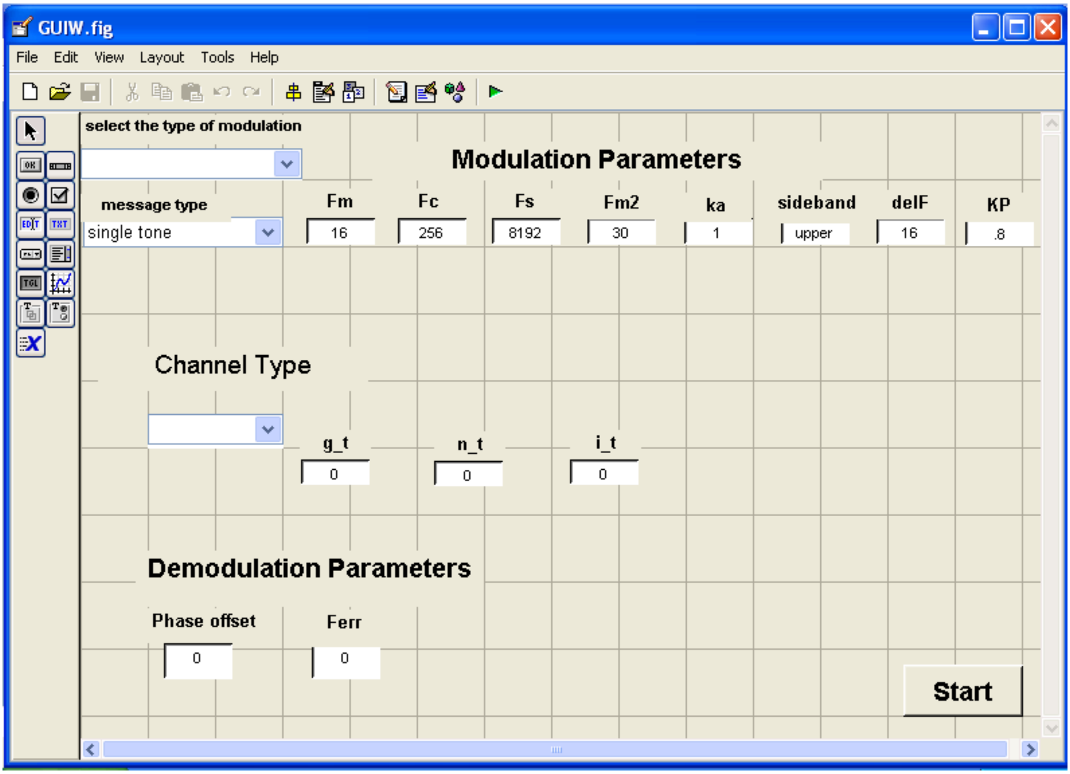


Figure (6): The main window of the implemented system.

The simulation program gives the user the flexibility to select the following features:

- Different modulation modes can be applied AM, DSB, SSB, QAM, FM, PM).
- The type of the message (modulating) signal can be selected as a single-tone or multi-tone signal.

- Different frequency values of message (modulating) signal can be selected.
- The program can select the value of the carrier frequency produced by the Oscillator.
- The program can select the sampling frequency.
- The program can add noise to the modulated signal to evaluate the performance of the demodulator.
- The program can use local oscillator at the demodulator different from carrier at the modulator in the values of the frequency and the phase.

Table (1): Parameters of the implemented GUI

Parameter	Explanation
mode	desired type of the modulation / demodulation.
message type	type of message (modulating) signal options which is either single tone or multi tone signal.
fm	frequency of the message(modulating) signal.
fm2	frequency of the second message (modulating) signal (its used with the QAM modulation only).
fc	the frequency of the carrier signal.
fs	the sampling frequency.
ka	amplitude sensitivity of the modulator.
kf	frequency sensitivity of the modulator.
kp	phase sensitivity of the modulator.
sideband	Type of the modulated sideband in SSB modulation.
channel type	Noisy channel or Free of noise channel.
Ferr	the rate of the difference in the frequency between the carrier signal at the transmitter and the local oscillator at the receiver.
phase offset	the rate of the difference in the phase between the carrier signal at the transmitter and the local oscillator at the receiver.

4. Experiments and Results

The experiments have been conducted to evaluate the performance of the implemented system for single tone or multi-tone signals. The following subsections illustrate the details of the experiments and their results.

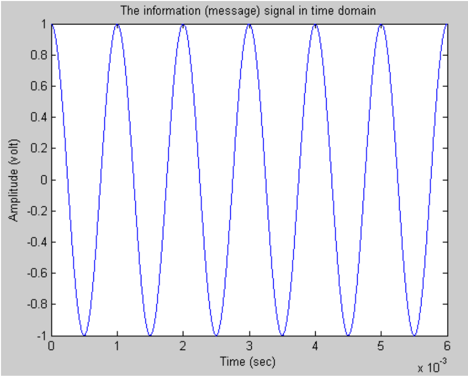
4.1: Single tone experiments

A single tone signal has been used to check the simulator for the following modes: AM, SSB, and PM. The parameters used in the simulation for the above modes are shown in Table (2).

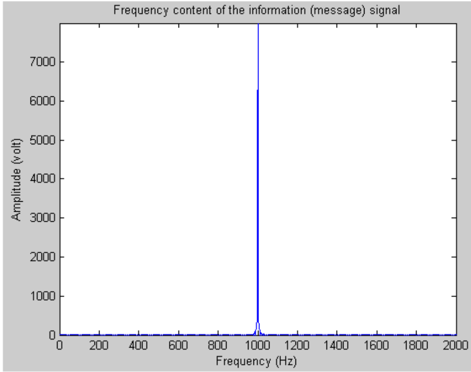
Table (2): Input parameters for single tone experiments

Parameter	AM Mode	SSB Mode	PM Mode
fm	1000 Hz	500 Hz	1000 Hz
fc	100 KHz	50 KHz	100 KHz
fs	400 KHz	200 KHz	400 KHz
ka	0.8	1	--
kp	--	--	1
channel type	Noisy channel or free of noise channel		

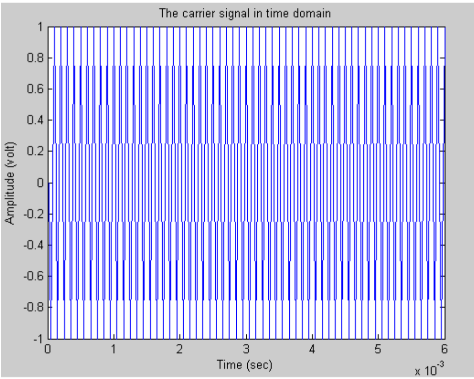
The results of AM mode experiments are shown in Figure (7) to Figure (9). The modulating signal, its spectrum, carrier signal, and its spectrum are shown in Figure (7). If the modulation index is selected to be less than unity (*ka*=0.8), and the carrier frequency *fc* is much greater than the frequency of the modulating signal, the obtained modulated signal has envelope essentially the same as that of baseband message signal. The modulated signal is band-pass filtered to pass the desired frequency component, and then the resulted signal is passed to the channel which is selected as noise free channel. Therefore the resulted radio signal is similar to the modulated signal because there is no added noise as shown in Figure (8). The demodulator section used locally generated oscillator coherent with the oscillator used in the modulator by setting the "phase offset" and "ferr" parameters to "0". The recovered (demodulated) signal which is obtained from the AM demodulator unit is shown with its spectrum in Figure (9).



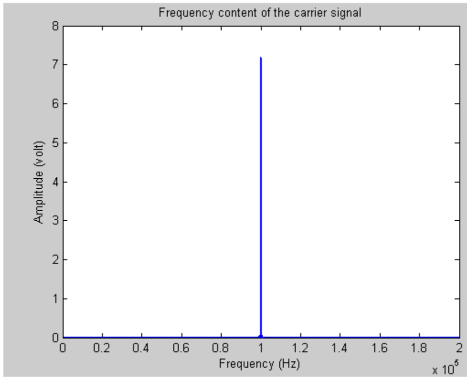
(a) Modulating signal



(b) Spectrum of Modulating signal

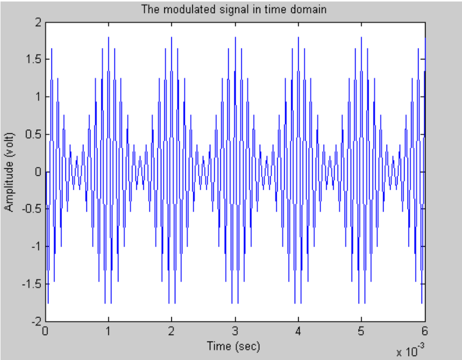


(c) Carrier signal

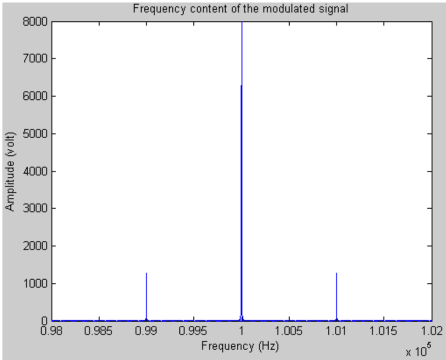


(d) Spectrum of Carrier signal

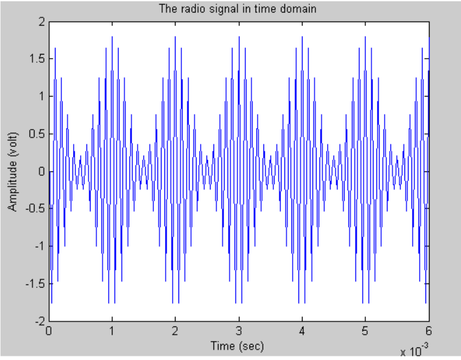
Figure (7): AM mode modulating and carrier signals.



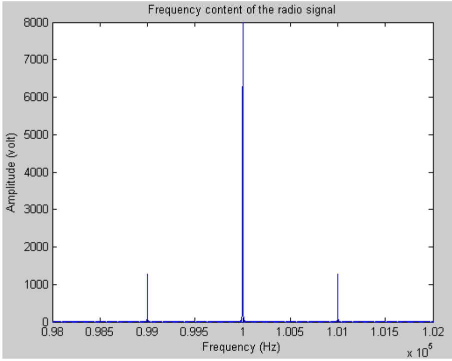
(a) AM modulated signal



(b) Spectrum of AM modulated signal

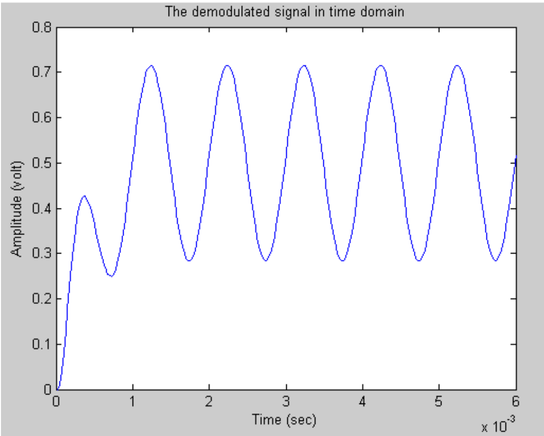


(c) The AM radio signal

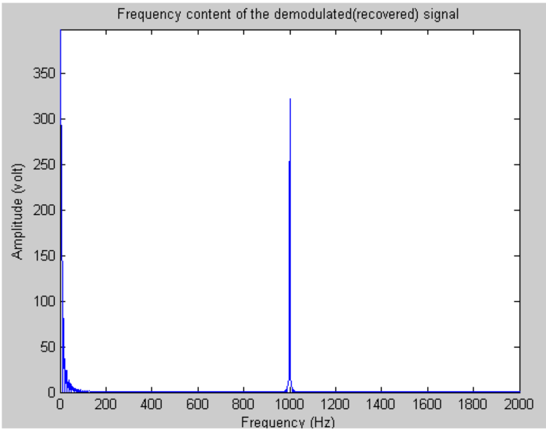


(d) The Spectrum of AM radio signal

Figure (8): AM mode modulated signal.



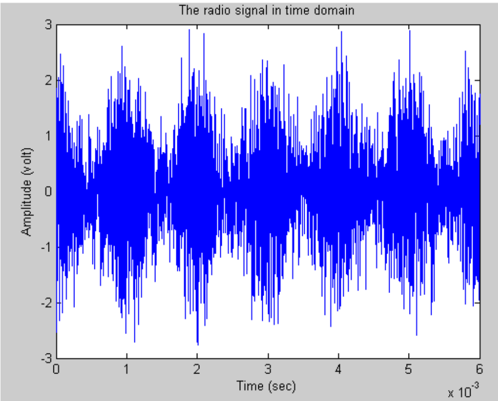
(a) The AM demodulated signal



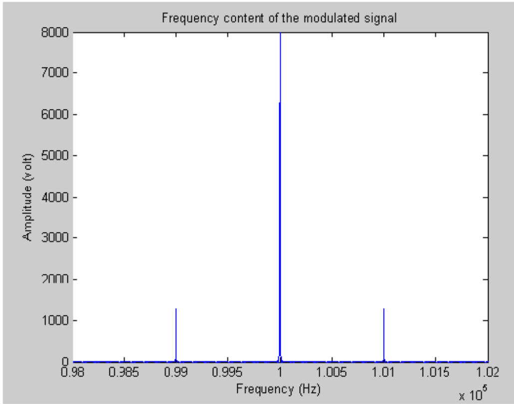
(b) The spectrum of AM demodulated signal

Figure (9): AM mode demodulated signal.

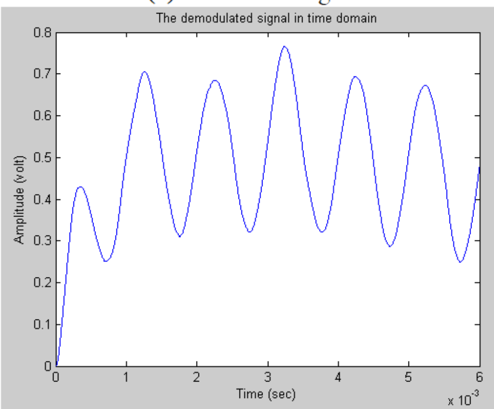
When the AM experiments are conducted using the same previous parameters but with noisy channel, the recovered signal is close to the original signal (i.e. the distortion is little). The results of the noisy channel are shown in Figure (10).



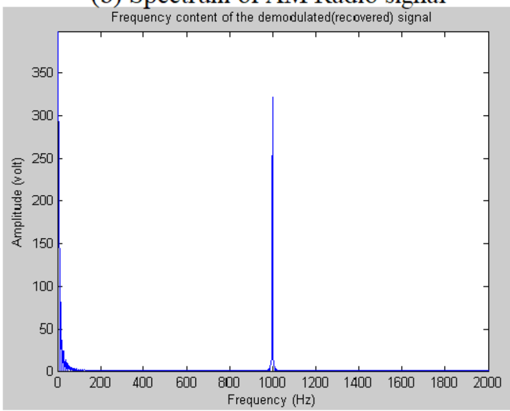
(a) AM Radio signal



(b) Spectrum of AM Radio signal



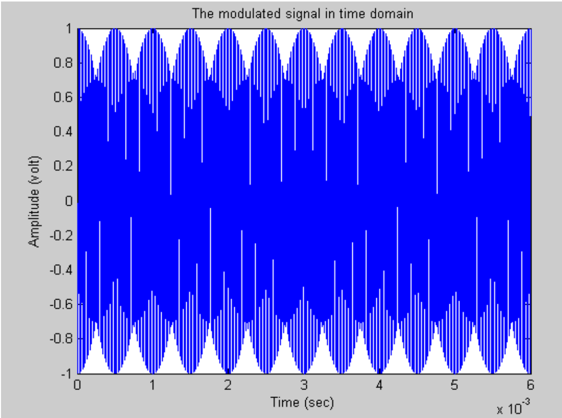
(c) AM demodulated signal



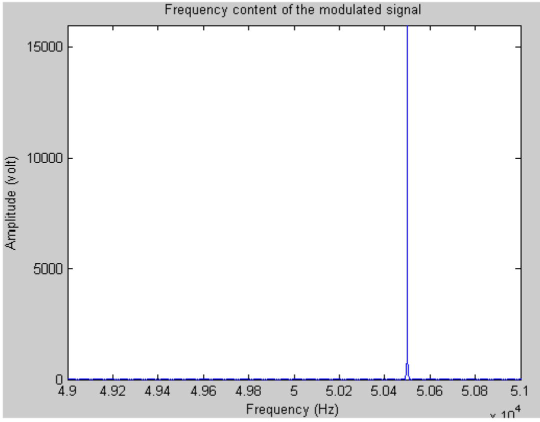
(d) Spectrum of AM demodulated signal

Figure (10): AM radio and demodulated signals using noisy channel.

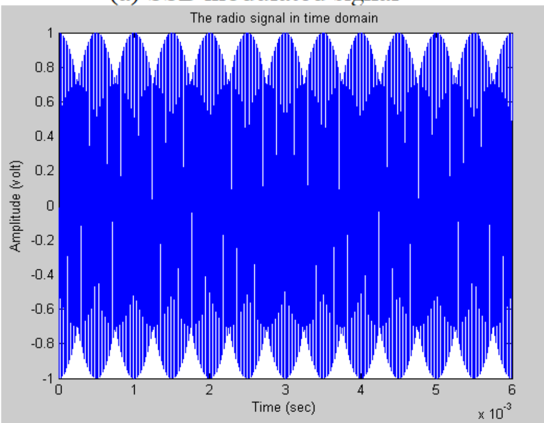
The results of SSB and PM experiments are shown in Figure (11) and Figure (12) respectively.



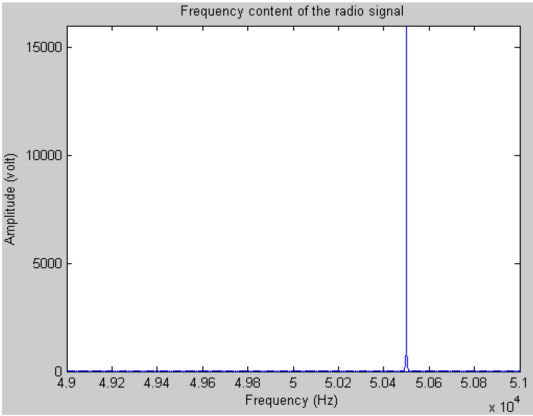
(a) SSB modulated signal



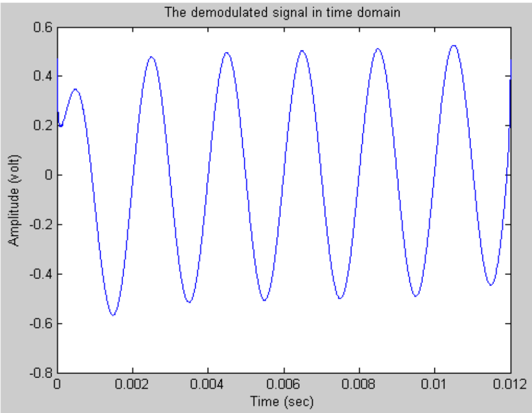
(b) Spectrum of SSB modulated signal



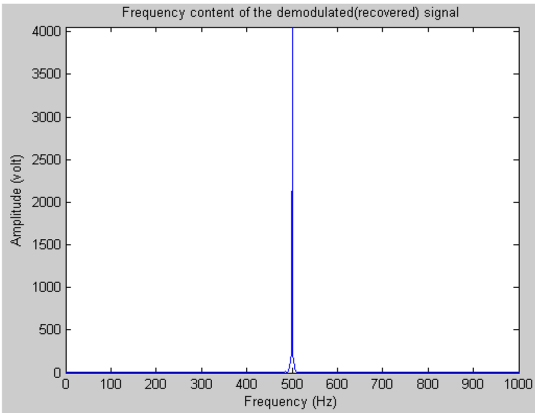
(c) SSB radio signal



(d) Spectrum of SSB radio signal

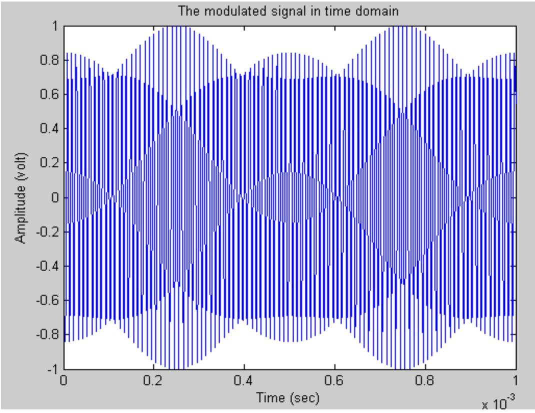


(e) SSB demodulated signal

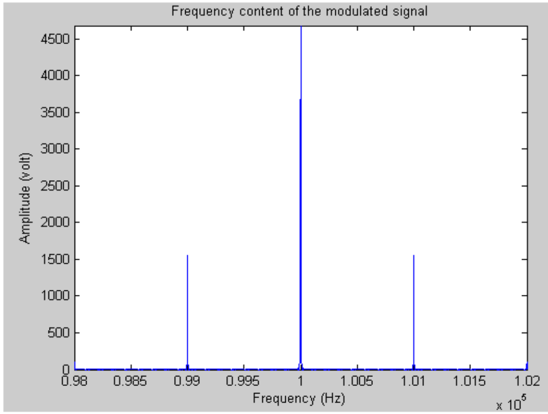


(f) Spectrum of SSB demodulated signal

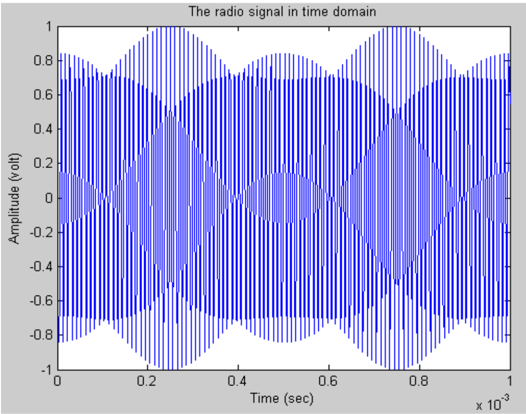
Figure (11): SSB modulation and demodulation results.



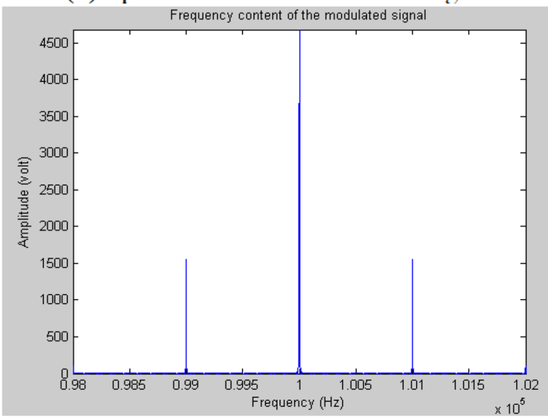
(a) PM modulated signal



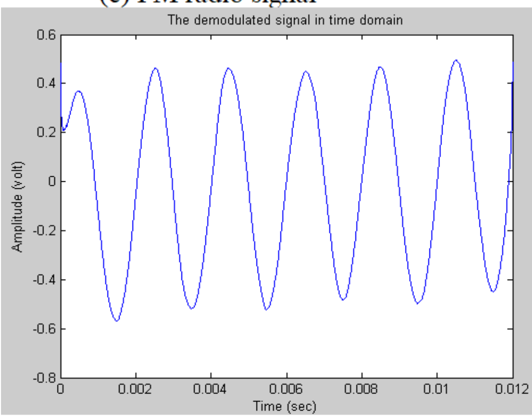
(b) Spectrum of PM modulated signal



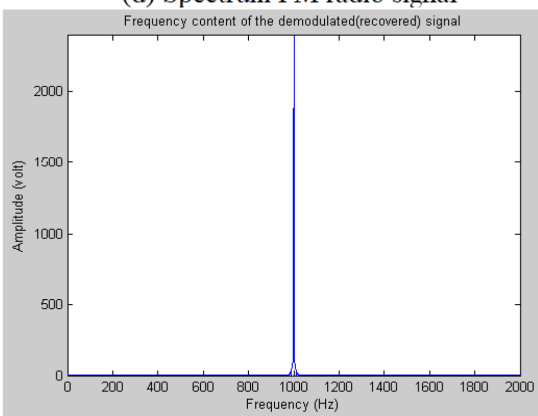
(c) PM radio signal



(d) Spectrum PM radio signal



(e) PM demodulated signal



(f) Spectrum of PM demodulated signal

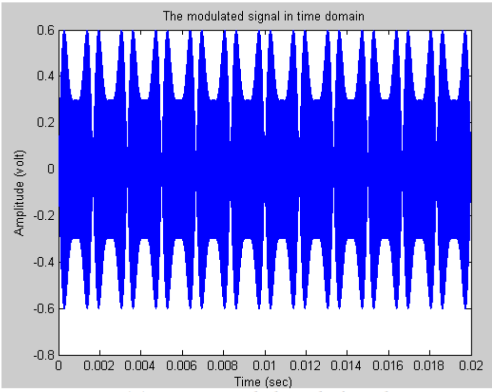
Figure (12): PM modulation and demodulation results

4.2 Multi-tone experiments

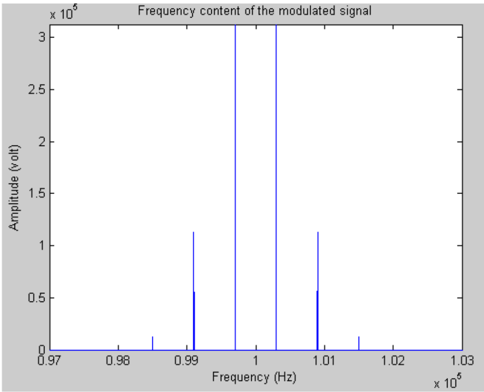
The second part of experimental work used a multi tone message (modulating) signal using the simulator for (DSB, QAM and FM) modulation / demodulation modes. The modulated and demodulated signals for each mode are shown in Figure (13) to Figure (15), for DSB, QAM, and FM respectively (the noise free case). The parameters used in the simulation for the above modes are shown in Table (3).

Table (3): Input parameters for Multi-tone experiments

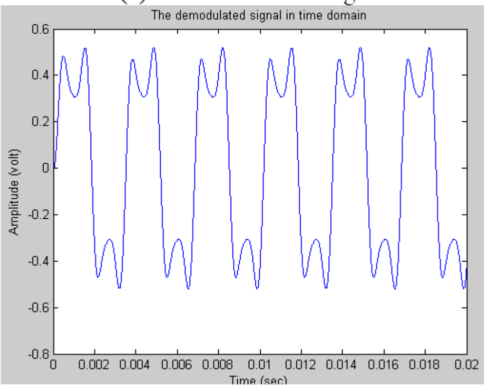
Parameter	DSB Mode	QAM Mode	FM Mode
fm1	300 Hz	400 Hz	250 Hz
fm2	--	600 Hz	--
fc	100 KHz	120 KHz	100 KHz
fs	400 KHz	400 KHz	400 KHz
ka	0.1	0.1	--
kf	--	--	0.1
channel type	Noisy channel or free of noise channel		



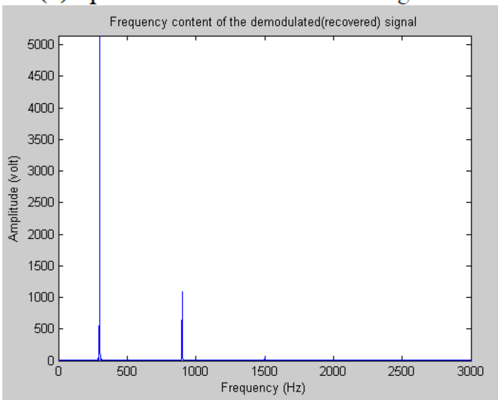
(a) DSB modulated signal



(b) Spectrum of DSB modulated signal

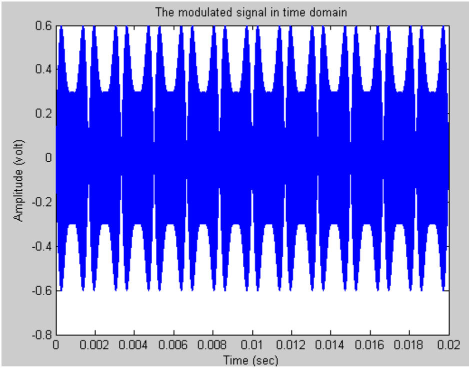


(c) DSB demodulated signal

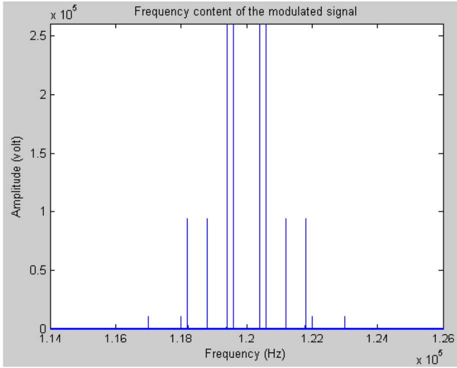


(d) Spectrum of DSB demodulated signal

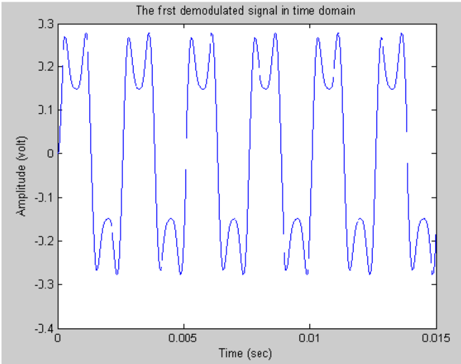
Figure (13): DSB modulation and demodulation results.



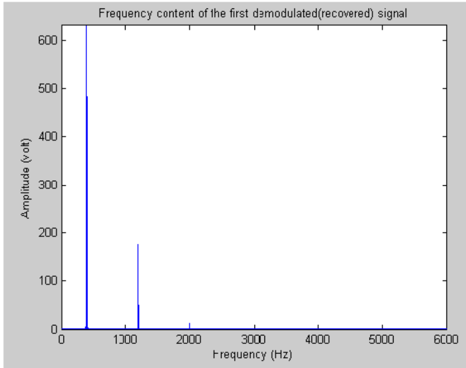
(a) QAM modulated signal



(b) Spectrum of QAM modulated signal

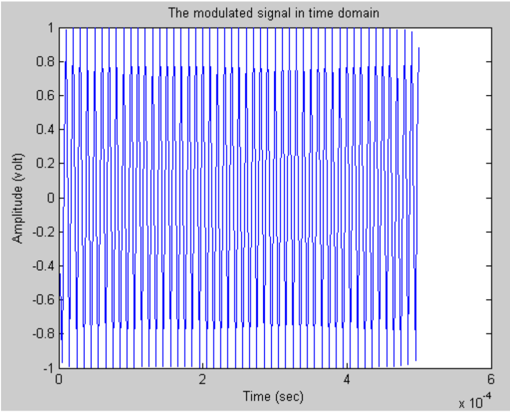


(c) QAM demodulated signal

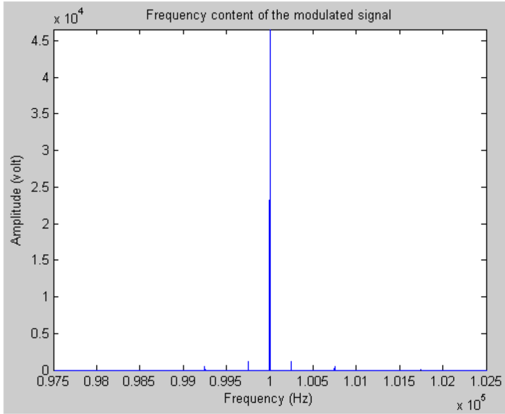


(d) Spectrum of QAM demodulated signal

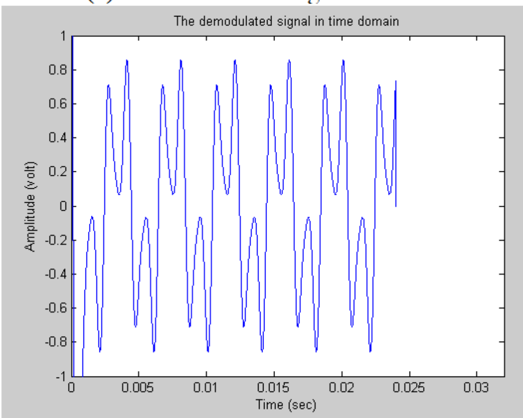
Figure (14): QAM modulation and demodulation results.



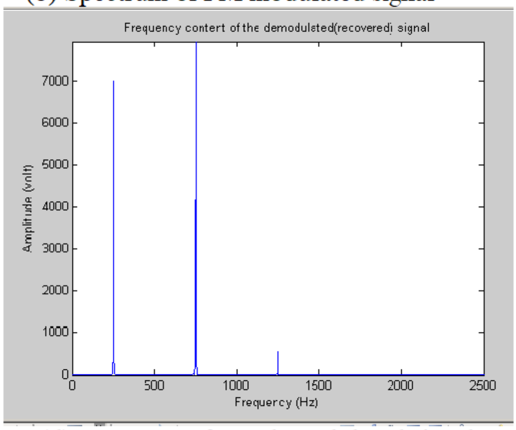
(a) FM modulated signal



(b) Spectrum of FM modulated signal



(c) FM demodulated signal



(d) Spectrum of FM demodulated signal

Figure (15): FM modulation and demodulation results.

The results obtained from testing the implemented multimode modulator / demodulator system for AM, DSB, SSB, QAM, PM and FM are satisfactory compared with theoretical analysis for modulated and demodulated (transmitted and received) signals shapes. In general, this fact is clear for the results related to AM, DSB, SSB, QAM and PM modes which are close to the ideal results; when noise is added to the modulated signal, the results stay in the acceptable range although the SNR is 5dB. In general the obtained results from testing different modes of the proposed system indicate the efficiency of the implementation and operation of the proposed multimode modulator / demodulator system.

5. Conclusions and Future Works

The simulated system in this paper is based on using SDR technology which is characterized by its flexibility. It can be used to implement and perform different modes operating on the same system allowing dynamic configuration of the system by just selecting the appropriate software to run without the need to change the hardware components. The results of testing the implemented system (i.e. simulator) proved its efficiency for different modes including AM, DSB, SSB, QAM, PM, and FM. For the future work the flexibility of transceiver can be increased by adding the digital modulation modes to the previous modes such as ASK, FSK, PSK, MSK…etc.

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محاكاة وحدة مضمن / مستخلص رقمية متعددة الاغراض

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المستخلص: يؤدي جهاز الإرسال والاستقبال للترددات الراديوية وظائف مختلفة مثل معالجة إشارة التردد الراديوي التناظري, تضمين الموجة / إزالة التضمين, و معالجة اشارة النطاق الأساسي. يتزايد استخدام المكونات والبرمجيات الرقمية يوماً تلو الآخر مما أدى إلى تطوير أجهزة الراديو المعروفة ب(SDR). تتميز هذه الاجهزة بمرونتها حيث يمكن تعديل أو إستبدال البرنامج و بالتالي تغيير وظيفة الجهاز دون تغيير المكونات المادية للجهاز. يقدم هذا البحث نظاماً مرناً للأتصالات القائمة على (SDR) يتيح النظام الذي تم بناءه القدرة على إنجاز أساليب التضمين / إزالة التضمين التالية (AM, DSB, SSB, QAM, FM and PM). يتم تحقيق هذه الأساليب بواسطة برامج عند تردد النطاق الأساسي (I-Q) بدلاً من تحقيق هذه العملية رقمياً في التردد IF أو الترددات الراديوية مباشرةً. أثبتت النتائج التجريبية كفاءة النظام الذي تم بناءه في حالة عدم وجود ضوضاء أو في حالة وجود ضوضاء. لتبسيط إستخدام النظام المقترح وتقييمه، تم تطبيق واجهة مستخدم رسومية للنظام.

الكلمات المفتاحية: راديو معرف بالبرمجيات ومغير ومزيل التشكيل.