SOFTWARE DEFINED RADIO USING DIGITAL MODULATION TECHNIQUES – A MATLAB® SIMULINK® APPROACH

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Abstract— Software Defined Radio (SDR) has been one of the new techniques developed to change the way the traditional wireless communication systems work. SDRs enable us to build reconfigurable and interoperable radios that can be upgraded for future technologies. Designing a multi-modulation schemes system in term of hardware will cost a lot and definitely consume power and increase the interference. This paper presents the design of modulator and demodulator software subsystems of an SDR using MATLAB® SIMULINK® tool for various modulation techniques. The results of designed SDR system are verified through simulation results. The QPSK modulation technique provides better performance.

Keywords—Software Defined Radio, Amplitude Shift Keying, Frequency Shift Keying, Phase Shift Keying, Quadrature Shift Keying.

I. INTRODUCTION

Over a past couple of decades many Mobile communication standards have evolved and even today researches are going to develop new standards. Different standards of Mobile communication use different type of hardware circuitry. The existing mobile communication standards are primarily regional and not global. So efforts are going on to develop systems which can support multiple mobile communication standards using same hardware but swapping the software. This gave rise to Software Defined Radio which is a new technology being developed in the 21st century.

Among the technological innovations, the use of digital technologies is very relevant. The emerging digital audio broadcasting standards like DRM [1] and DAB [2] used in Europe, HD Radio [3] is used in United States. An overview of digital audio broadcasting standards, their frequency bands and channel bandwidth are given in Table 1 [4].

Table I

DIGITAL AUDIO BROADCASTING STANDARDS

Standard / Parameter	Frequency (MHz)	Band (KHz)	Typical Bitrates (Kbps)
DAB-III	174-230	1536	1152
DAB-L	1452-1492	1536	1152
DRM	0-30	4.5-20	4.8-72
DRM mode E	87.5-108	96	185
HD Radio (FM)	87.5-108	400	300

Today's continuously changing technology brings the need to build "future proof" radios. If the functions that were formerly carried out by hardware can be performed by software, new functionality can be deployed on a radio by updating the software running on it. Increasing traffic rates, but decreasing amounts of spectrum requires even more sophisticated signal processing algorithms be deployed on radios. The increase of variable-QoS, multi-component traffic, requires complex management of resources allocated in the operation of a user connection. There is a need to deploy a multiplicity of standards within a single device. In a software defined radio, multiple waveforms can be implemented in software, using the same hardware [5].

A SDR refers to reconfigurable or reprogrammable radio that can show different functionality with the same hardware. The modulation/demodulation functions of a waveform are defined in software. Today software defined technology offers advantages such as improvements or enhancements without altering the radio hardware, terminals that can cope with the unpredictable dynamic characteristics of highly variable wireless links, efficient use of radio spectrum and power, and many others. The users can use relatively generic hardware, and customize it to their needs by choosing software that fits their specific application [6, 7]. The difference between a digital radio and an SDR is that a digital radio is not reconfigurable. Although a digital radio has software running on it, the functionality of the components cannot be changed on air. New technology insertion is not available, either.

Radio is the backbone of the wireless industry. It forms the basis of all the mobile and portable communication systems we use today. In analog radios, the analog signal is processed at different frequencies by a chain of analog functional blocks using analog signal processors and heterodyne filters. Digital radios transforms the analog radio signal to a digital signal at some point in the chain with the help of an Analog-to-Digital Convertor (ADC), and processes the signal using Digital Signal Processors (DSP). The digitally processed signal is converted back to analog by a Digital-to-Analog Convertor (DAC) and transmitted through the antenna. The functional blocks in a dual-mode radio, that has both analog and digital processing is shown in Fig. 1.

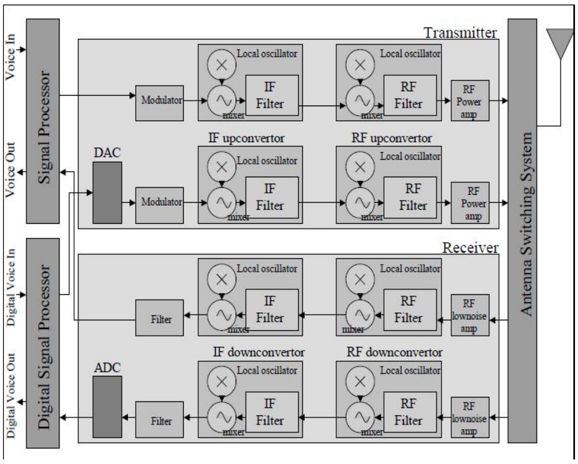

Fig. 1 Dual-Mode Radio

The technologies developed for radio communication are cellular phones, Advanced Mobile Phone Service (AMPS), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Global System for Mobile Communications (GSM), Wideband Code Division Multiple Access (WCDMA), Enhanced Data Rates for GSM Evolution (EDGE) and Universal Mobile Telecommunication System (UMTS). An SDR terminal can use any of these technologies, provided that it has the necessary software. If a new standard is developed, or if the user wants to switch to a system that is not present on the handset, the new software can be downloaded on air. SDR base stations take the burden of replacing the base station throughout the entire country off the system providers, by dynamically updating themselves. SDR enables the properties like: (i) new features and capabilities to be added to existing infrastructure without requiring major new capital expenditures, allowing service providers to quasi-future proof their networks (ii) The use of a common radio platform for multiple markets, significantly reducing logistical support and operating expenditures. Even though wireless communication standards are available; SDR is preferable because it can be easily reconfigurable, interoperability among different military units, emergency units and coalition armies, new technologies can be adapted quickly, easily, and for a much lower cost.

The paper is organized into five sections. Section 2 describes the background of SDR. The design of software subsystem of SDR using Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and Quadrature Phase Shift Keying (QPSK) modulation techniques in MATLAB® SIMULINK® provided in section 3. Simulation, results and discussions are presented in section 4 and 5 respectively. Finally conclusions are drawn in section 6.

II. BACKGROUND OF SOFTWARE DEFINED RADIO

One of the first software radios was the US Air Force's Integrated Communications Navigation and Identification Avionics (ICNIA) system, which was developed in the late 1970's. The system used a DSP-based modem that is reprogrammable for different platforms. ICNIA's technology has been the foundation for many other military radios.SDR is a radio communication technology which is capable of being re-programmed or reconfigured. SPEAKeasy is a joint Department of Defence and industry program initiated to develop a software programmable radio operating in the range from 2 MHz to 2 GHz, employing waveforms selected from memory, or downloaded from disk, or reprogrammed over the air [8]. The improvements in DSP and ADC technologies facilitated the shift to software defined radios. Modem functions can be implemented in software with today's high speed DSPs and General Purpose Processors (GPPs). The low power requirements of the processors enable them to be used in hand terminals. The increased dynamic operating ranges and higher conversion rates of modern ADCs enables digital processing at higher bands. The improvements in middleware technologies permit software functionality to be independent of the underlying hardware [7, 9].

The structural architecture of common SDR is shown in Fig. 2. SDR consists of both hardware and software sub systems. User interface provides the required inputs to the data processing system. In data processing system modulation and demodulation techniques are used during transmission and reception respectively. The retrieved original information is passed to user interface during reception.

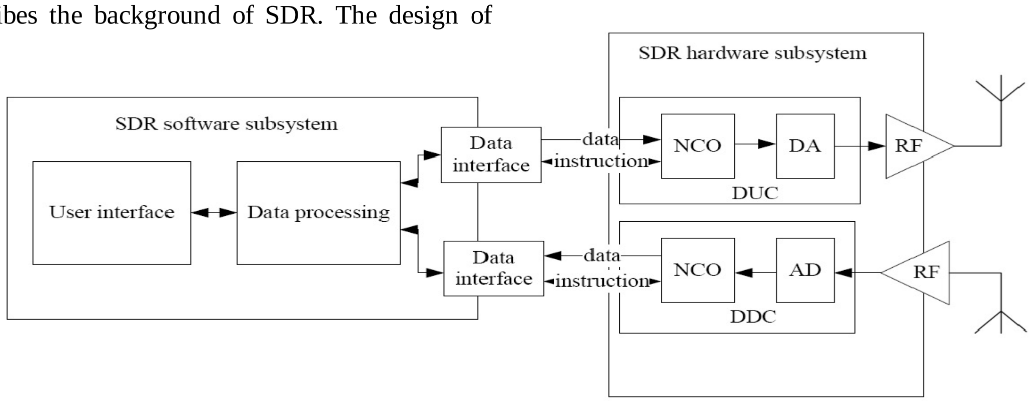

Fig. 2 Structural architecture of common SDR

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III. DESIGN OF SDR SOFTWARE SUBSYSTEM

The generalized block diagram of software subsystem of SDR for any modulation technique is designed using MATLAB® SIMULINK® and is shown in Fig. 3. The modulator and demodulator subsystems are shown as blocks and these blocks are to be designed depending upon the technique used. A constant input signal is given as message and is converted into digital form using an 8-bit switch input. The 8-bit input word is split into N time multiplexed output words using a parallel to serial block, where N is the ratio of number of input bits to number of output bits. These N words are given as input to the modulator.

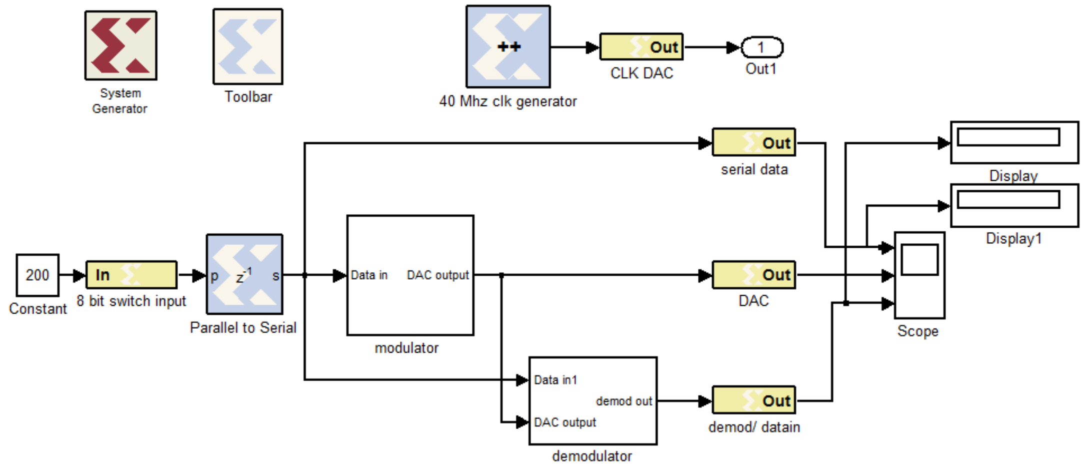

Fig. 3 Simulink diagram of generalized SDR software subsystem

A. *ASK Modulator and Demodulator*

In ASK, the amplitude of the carrier is switched depending on the input digital signal. ASK modulator is a sub system that consists of blocks as shown in Fig. 4.

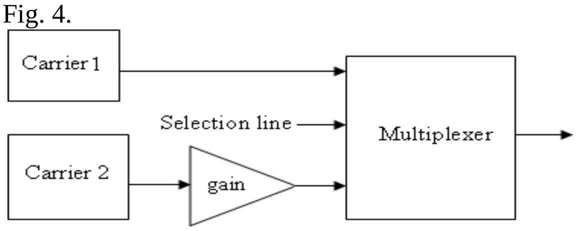

Fig. 4 ASK modulator

The two carriers are generated with same frequency and phase whereas the gain of carrier-2 is reduced 1½ times of carrier-1. The subsystem of ASK demodulator is shown in Fig. 5.

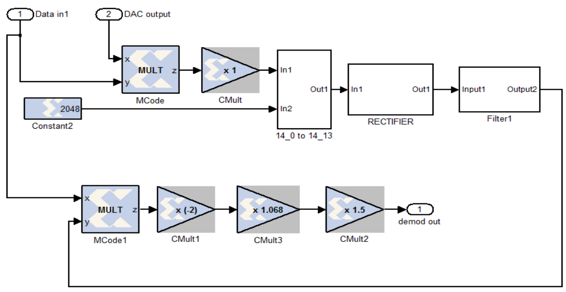

Fig. 5 ASK demodulator

The main Simulink blocks in ASK demodulator are rectifier, filter and Mcode blocks. The subsystem of rectifier is shown in Fig. 6. BitBasher performs the slicing operation. The rectified signals need to be smoothened to reconstruct the original message signals. This smoothing operation is performed by a series of recursive filters connected in cascade.

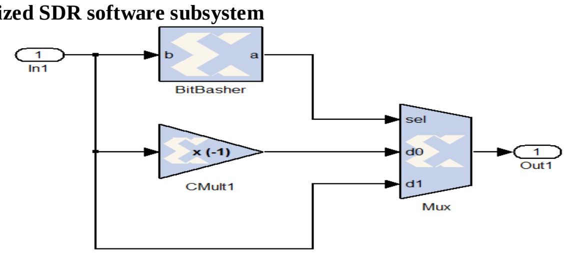

Fig. 6 Rectifier subsystem

B. *FSK Modulator and Demodulator*

The FSK modulator subsystem is shown in Fig. 7. The carrier-1 and carrier-2 blocks generate two different frequency signals. Based on the data input given, these two signal frequencies are switched that results in FSK modulation. The analog sine output shifts to alternative frequency whenever the data stream bit toggles from 0 to 1 and 1 to 0.

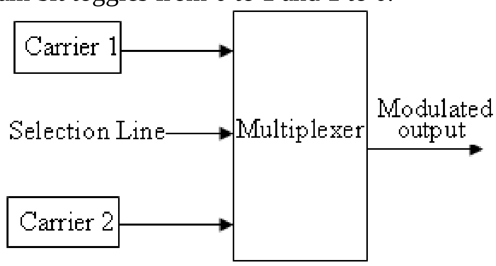

Fig. 7 FSK modulator

The FSK demodulator subsystem is same as ASK demodulator subsystem as shown in Fig. 5. The output of the filters is compared with a threshold of zero volts. If the output signal voltage is greater than zero then the receiver takes the data as 1 otherwise it takes the data as 0.

C. *PSK Modulator and Demodulator*

The PSK modulator and demodulator subsystems are same as FSK modulator and demodulator

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subsystems. In PSK modulator the carrier-1 and carrier-2 blocks generate the signals that are out of phase i.e. the phase of the first signal is 0^0 and the phase of the second signal is 180^0 but both signals are in synchronization.

D. QPSK Modulator and Demodulator

In PSK technique, the phase shift of the carrier signal is limited two states but it is not limited to two states only, it can be any number of states. This concept is used in QPSK, where the carrier signal undergoes four changes in phase and able to represent two binary bits of data per symbol. This enables effectively doubling the bandwidth of the carrier. The software subsystem of SDR using QPSK technique is shown in Fig. 8.

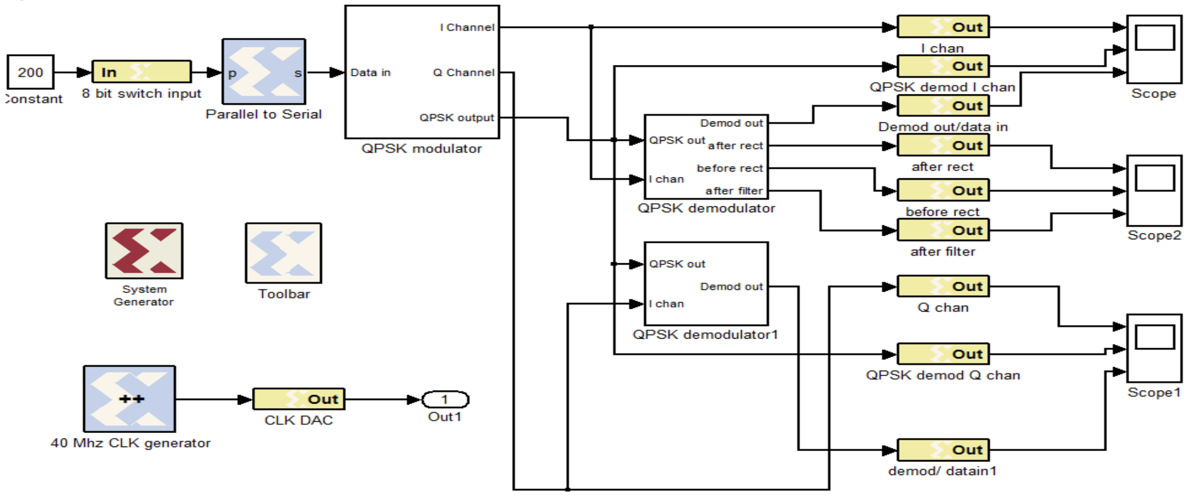

Fig. 8 Software subsystem of SDR using QPSK

The subsystem of QPSK modulator is shown in Fig. 9. Data clock generator block is basically a counter with an explicit period of 256 block sample rate. The idea of the Bit splitter is to split the input bit stream into odd and even bits i.e. In-phase and Quadrature phase and this is in spatial domain. Hence the delay calibration must be very precise.

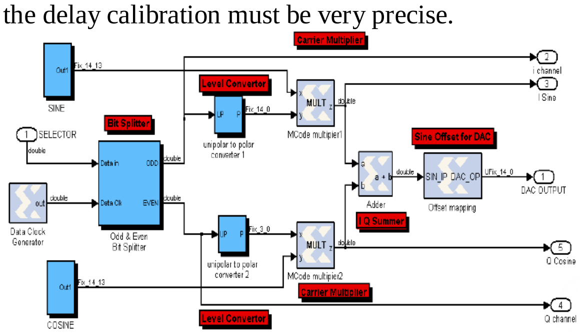

Fig. 9 QPSK modulator

The input data of D-FF1 and D-FF2 are controlled by the enable signal from the data clock. Whenever the clock is high, D-FF1allows the data to output, but D-FF1 to hold the output until D-FF2 gets high enable bit in the next clock edge. This idea is to delay one channel data until the other channel outputs data is generated and it is performed synchronously. In the proposed design, all the data bits are in digital format of '1's and '0's. Before taking the product of two carriers with two channels, I and Q, the voltage levels of data bits need to be converted to –1 and +1. This is performed by Uni-polar to polar converter block. The QPSK demodulator subsystem is shown in Fig. 10. Two Coherent quadrature carriers $COS(2\pi f_c t)$ and $SIN(2\pi f_c t)$ are applied as one of the input to two synchronous demodulators. The synchronous demodulator consists of multiplier and an integrator. The received signal is applied as second input to both the multipliers. The integrator integrates the product signal over two bit interval and it is sampled at the offset of one bit period.

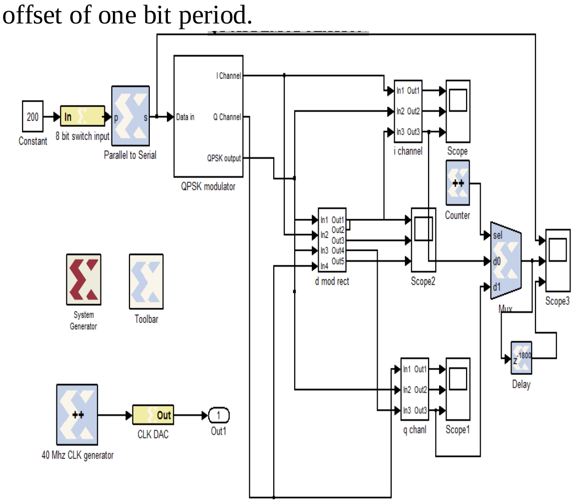

Fig. 10 QPSK demodulator

IV. SIMULATION RESULTS

The operational performance of the proposed SDR model is verified using ASK, FSK, PSK and QPSK techniques. The input data for all the modulation techniques is taken as 200 and is converted into digital form as 11001000. This digital data is the input to all the modulation techniques.

A. Using ASK Technique

The simulation results of software subsystem of SDR using ASK technique is shown in Fig. 11. The generated two carrier signals from carrier-1 and carrier-2 are with amplitude 1 V and 0.5 V respectively.

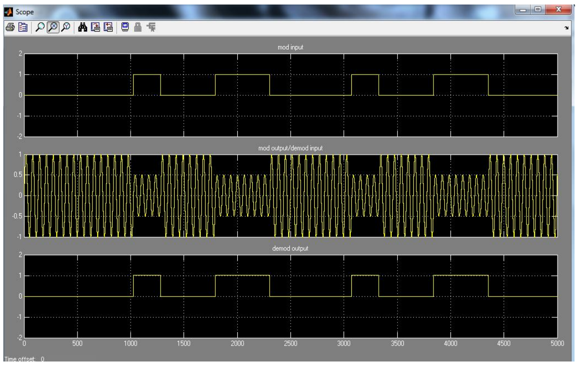

Fig. 11 Simulation result of ASK based SDR

The frequency of two carrier signal is 150 kHz. If the input data bit to the modulator is 0 then the output of the modulator is 1V carrier signal and similarly, if the input data bit to the modulator is 1 then the output of the modulator is 0.5V carrier signal. From Fig. 11, it is observed that the given input signal is recovered without any distortion using ASK demodulator.

B. Using FSK technique

The two carrier signals with frequencies 625 kHz and 1250 kHz and with constant amplitude of 1V are generated from carrier-1 and carrier-2 respectively. The modulated output signal is a combination of 625 kHz and 1250 kHz. If the input data is 1 then the modulated signal is with 1V, 625kHz. The FSK modulator subsystem gives 1V, 1250kHz signal when the input data is 0. The simulation results are shown in Fig. 12. From Fig., it is observed that the demodulated signal is exactly recovered from FSK demodulator subsystem.

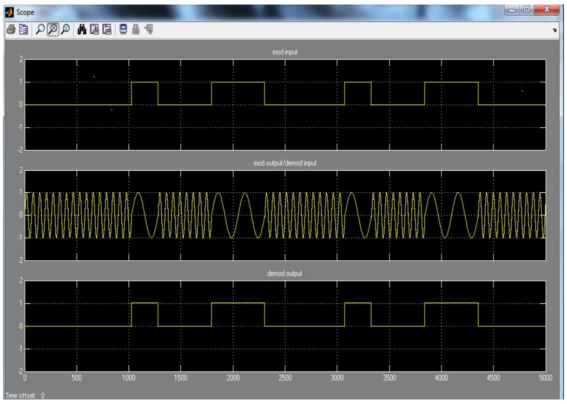

Fig. 12 Simulation result of FSK based SDR

C. Using PSK technique

Carrier-1 and carrirer-2 signal generators generates two carrier signals with same amplitude and frequency but differ in phase by 180^0. The PSK modulator takes the constant input digital data as the first input and carrier signal as second input. If any change at the input digital data then PSK modulator changes the carrier phase by 180^0; otherwise it generates the same carrier signal without any phase change. The modulated signal is given as input to the PSK demodulator. The demodulated output represents 0 when modulated signal undergoes positive shifting and 1 when it undergoes negative shifting. The simulation results are shown in Fig. 13. From Fig., it is observed that the demodulated signal is exactly recovered from PSK demodulator subsystem.

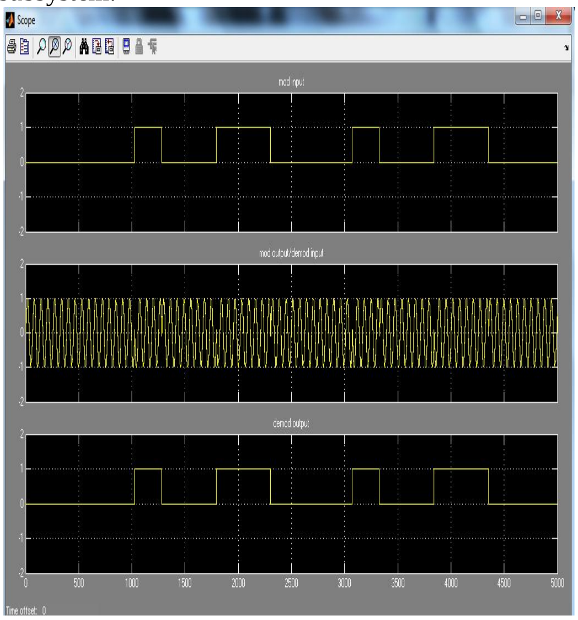

Fig. 13 Simulation result of PSK based SDR

D. Using QPSK technique

Constant digital data equivalent to 200 is given as the first input, and the two carrier signals, SIN and COS are given as second input to QPSK modulator. QPSK modulation encodes the data based on phase angle between two waveforms. These are represented as In-phase component (I-channel) and Quadrature component (Q-channel). The simulation results of SDR using QPSK modulator are shown in Fig. 14.

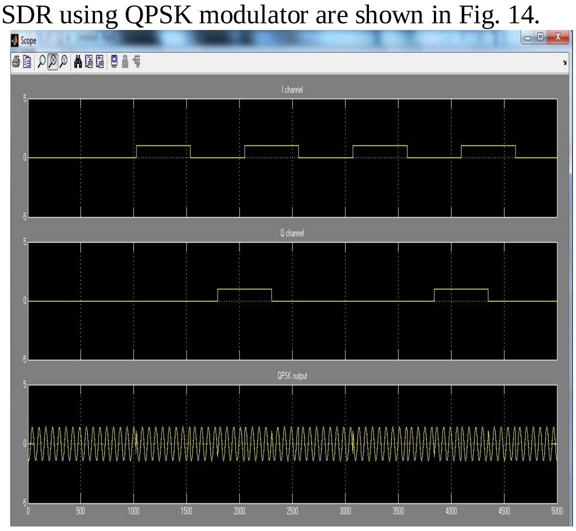
Fig. 14 Simulation result of SDR using QPSK modulator

The modulated signal is given as input of QPSK demodulator and the demodulated signal is similar to that of the input digital signal. The demodulated output is recovered from I and Q channel outputs at demodulation stage. The simulation results of SDR using QPSK demodulator are shown in Fig. 15.

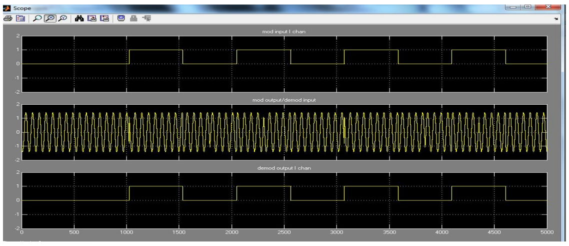

Fig. 15 Simulation result of SDR using QPSK modulator

CONCLUSIONS

This paper presents the design concepts of commonly used audio broadcasting system i.e. SDR development platform using various modulation techniques. The SDR platform is successfully designed in MATLAB® SIMULINK® using ASK, FSK, PSK and QPSK modulation techniques the performance of the system is also validated. QPSK technique gives better simulation results when compared with the remaining modulation techniques. But the limitations of this technique are carrier synchronization, and phase ambiguity wile decoding the data if any static phase error exists at the receiver end. The software structure design is more important which must be stable and flexible.

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