FREQUENCY HOPPING SPREAD SPECTRUM TRANSCEIVER IMPLEMENTATION USING FLOATING-POINT DSP

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ABSTRACT

Mechanisms based on frequency hopping have been widely used in many applications such as the personal communications services and the wireless networks. In this paper, we describe, simulate and implement a frequency hopping spread spectrum transceiver. A baseband model for Bluetooth Frequency Hopping Transceiver is presented. Several modulation techniques, such as QPSK, 8-FSK and 16-QAM, are exploited to achieve a bit rate of 2Mbps, 3Mbps and 4Mbps respectively. We clacutate the bit error rate of the described transceiver model with the aid of Monte Carlo analysis technique. The proposed model is then implemented using the C6713 floating-point DSP. The functionality of the implemented system is tested via Real Time Data Exchange (RTDX).

1. INTRODUCTION

Because of the great progress in the communication all over the world Spread Spectrum (SS) has been used in wide scale in civilian applications. Special type of sprad spectum, Frequency Hopping Spread Spectrum (FHSS) is widely used in different digital communication systems such as Cellular Mobile, Bluetooth Personal Area Networks (PAN), Wireless Local Area Networks (WLAN) and Code Devision Multiple Access (CDMA) systems. That is because it is a well-known technique for combating narrowband interference, jamming and multipath with inherent security and selective addressing capability. Therefore it is becoming increasingly popular for use in the license-free industrial, scientific and medical (ISM) bands [1].

In traditional Frequency Hopping (FH) systems, the transmitter hops in a pseudo-random manner among available frequencies according to a prespecified algorithm, and the receiver operates accordingly in exact synchronization with the transmitter's hopping pattern. Depending on the Hop Rate, two main categoriess of FHSS are used; Slow FH (SFH) and Fast FH (FFH). In SFH-SS, several bits are sent for each hop, so the signal stays in a particular sub-band for a long time relative to the data rate.In FFH-SS, the reverse is true. The signal switches sub-bands several times for each bit transmitted, so the signal stays in a sub-band for a very short time relative to the data rate [2-4].

Bluetooth [5] is a prime example of a FH-based networking technology with unlicensed operation. Bluetooth represents an instance of the wireless personal area network (WPAN), which has been further standardized within the IEEE 802.15 Working Group for WPAN [6].

Recently the FHSS has become a hot research topic. In multiple access systems, a collision may happen when more than one FH users transmit in the same frequency band simultaneously. To solve this problem a new concept called, "Collision-Free Frequency Hopping", (CFFH) can achieve high information capacity and can successfully resolve the strict synchronization limitation [7].

A new Adaptive Frequency Hopping (AFH) technique has been proposed in an attempt to mitigate the interference between Bluetooth (IEEE 802.15) and wireless local area networks (WLANs) (IEEE 802.11b). The new AFH technique optimizes the carrier spacing according to the network load and noise level [8].

Personal Communications Services (PCS) require low-power radio technologies. Min and Samueli Presented one such transceiver architecture employing frequency-hopped spread-spectrum techniques with the analysis and design of that transceiver [9].

High complexity of FHSS sequence is of a great importance to high-security multiple-access communication systems, for it makes FHSS sequence difficult to be analyzed. With the growing development in the design of FHSS sequence, in much wider fields, the well-known complexity measures, the linear complexity (LC), the linear complexity profile (LCP) and the k-error linear complexity (k-error LC) are widely used but not sufficient to evaluate the complexities of the sequences available. In [10], a new complexity metric to evaluate the unpredictability of FHSS sequence based on the approximate entropy (AE) is proposed in the view of the maximal randomness of the sequences with arbitrary length. The proposed AE works effectively to discern the changing complexities of the FHSS sequences with small number of samples, which provide superior performance over its candidates.

Finally optimization of the transmission range in terms of maximizing information efficiency is studied in [11] for mobile ad hoc networks (MANETs) with frequency-hopped (FH) CDMA and multiple antennas.

In this work we describe, simulate and implement a FHSS transceiver. First, a generic slow rate FHSS passband system is simulated using matlab simulink. The bit error rate of the system is calculated, analysed and compared with ideal BFSK. Second, a baseband model for Bluetooth frequency hopping system is presented. Several modulation techniques, such as QPSK, 8-FSK and 16-QAM, are exploited to achieve a bit rate of 2Mbps, 3Mbps and 4Mbps.

Finally, we propose an implementation of the baseband model using the C6713 floating point DSP. The C6713 DSP Starter Kit (DSK) is used as an experimental platform. The functionality of the implemented base band FHSS tranceiver is tested via the Real Time Data Exchange (RTDX) technique supported by the TMS320C6713 DSK Kit.

The rest of this paper is organized as follow; Section 2 presents an overview of the experimental setup. The system description, simulation and bit error calculations are represented in Section 3. The DSP implementation of the proposed FHSS transceiver is shown in Section 4. Finally, the conclusions are drawn in Section 5.

2. EXPERIMENTAL SETUP

In simulating the FHSS transceiver the Matlab Simulink from "Mathworks Inc" is used. The required libraries to build the transceiver are the simulink library, communication library, DSP library and Embedded Target for TI C6000 DSP library. The proposed transceiver is implemented using the C6713 floating-point DSP.The C6713 DSP Starter Kit (DSK) is used as an experimental platform. The C6713DSK is one of the most resourceful kits avaliable today for Digital Signal Processing [12]. It is a complete DSP system with the necessary hardware and software support tools for real-time signal processing. The DSK board includes the C6713 floating-point DSP and a 32-bit stereo codec TLV320AIC23 (AIC23) for input and output. The onboard codec AIC23 uses a sigma–delta technology that provides ADC and DAC. It connects to a 12-MHz system clock. Variable sampling rates from 8 to 96 kHz can be set readily.The DSK board includes 16MB of Synchronous Dynamic Random Access Memory (SDRAM) and 256kB of flash memory. Four connectors on the board provide input and output: MIC IN for microphone input, LINE IN for line input, LINE OUT for line output, and HEADPHONE for a headphone output.The status of the four user dip switches on the DSK board can be read from a program and provides the user with a feedback control interface.The DSK operates at 225MHz [13][14].

Code Composer Studio (CCS3.1) from Texas Instruments includes tools for code generation, such as a C compiler, an assembler, and a linker.It provides an easy-to-use software tool to build and debug programs. The C compiler compiles a C source program with extension .c to produce an assembly source file with extension .asm. The assembler assembles an .asm source file to produce a machine language object file with extension .obj. The linker combines object files and object libraries as input to produce an executable file with extension .out. This executable file represents a linked Common Object File Format (COFF),This executable file can be loaded and run directly on the C6713 processor [15].

Finally the functionality of the implemented system is tested via Real Time Data Exchange (RTDX) supported by C6713 DSK and CCS.

3. TRANSCEIVER SIMULATION

Typically, we have two types of simulation models, namely "passband model" and "baseband model". In passband model, all modulation and demodulation blocks are manually built and all required carrier generators used in these blocks and in the frequency synthesizer block are in real form and real frequency. On the other hand the baseband model is actually supported simulink model where all modulation and demodulation blocks are ready made and available in the communication toolbox [16] ,furthermore any carrier generator is not a real one instead each carrier is represented in complex form as amplitude and phase

1- Passband model

The complete simulink model is shown in Fig (1). In this model a binary random integer generator with data rate of 1kbps is used as data source. This data source feed a BFSK modulator of space and mark frequencies of 1 kHz and 8 kHz respectively. A PN sequence with maximum length type of [6,1] taps with the same rate (1kHz) is used as code generator. The code generator provide

63 different code words to select one of different 63 carrier frequencies of the frequency synthesizer. The frequency set of that synthesizer is 10, 20, 30,….,and 630 kHz which has a frequency spectrum shown in Fig (2). The time domain output of that synthesizer is depicted in Fig (3) we see that for every data bit of period 1ms a new carrier frequency is generated by the frequency synthesizer. The output of BFSK modulator which is a data modulated signal is multiplied with the output of frequency synthesizer to achieve the hopping nature of the FH spread spectrum system. The FHSS transmitted signal is depected in Fig(4).

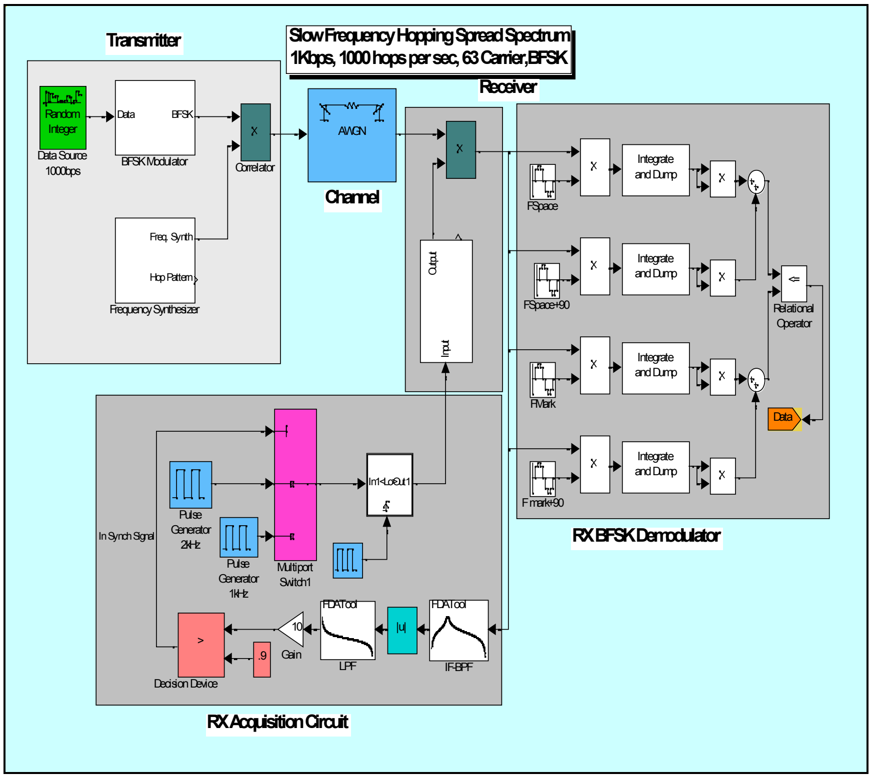

Fig (1) Block Diagram of Pass Band FHSS system

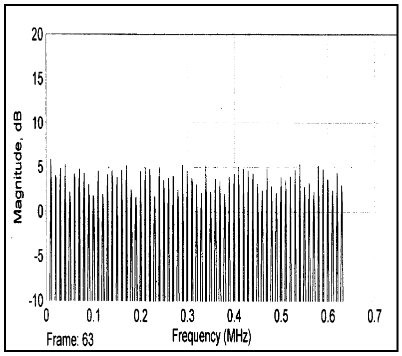

Fig (2) Frequency Synthesizer O/P in Frequency Domain

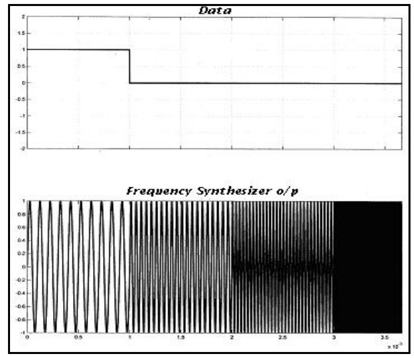

Fig (3) Frequency Synthesizer O/P in Time Domain

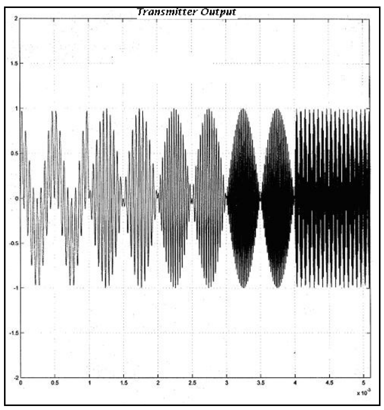

Fig (4) FHSS Transmitter Output

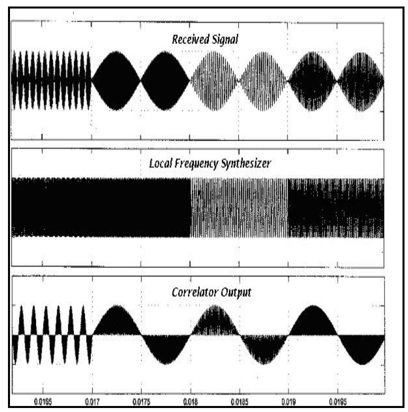

Fig (5) Correlator Inputs & Output

In the receiver the first stage is the dehopping stage where the incoming FH signal is correlated with a replica of the transmitter frequency hopping pattern, these two inputs of the correlator are shown in the first two traces of Fig (5) whereas the output of the correlator is shown on the third trace of that figure. The output of the dehopping correlator which has only two frequency components namely the space and mark components is now entered to the non coherent BFSK demodulator to recover the transmitted data again in the receiver.Typical waveforms at each test point of the demodulation section are plotted in Fig (6). We see from this figure that the dehopped signal is multiplied with the reference space carrier to generate the signal of the third trace which is all positive in parts of the signal having space frequency and bipolar in other parts of mark frequency , this signal is fed to the integrate and dump circuit which has output shown in the forth trace of Fig(6), the output shows a positive integration value for space signal parts while has zero integration value for mark signal part.The previous process is repeated but with local reference of space frequency +90 degree. And with mark frequency and mark frequency +90 degree.

The outputs of the four integrate and dump circuits are plotted in Fig (7). According to the simulink model the output of each integrate and dump block is squared and branch one and two are added together to form the first input of the decision device and so on branches three and four to generate the second input of the decision device. These inputs of the decision device are plotted in first and second traces of Fig(8) while the output is plotted in the third trace, which represent the recovered data. A comparison between the transmitted and received data waveforms are shown in Fig (9).

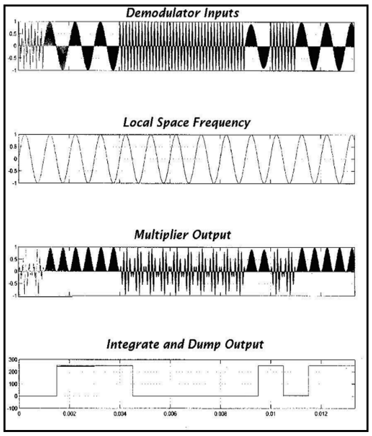

Fig (6) Non Coherent Detector (1-Rx signal 2-Carrier 3-Multiplier O/P 4- I&D O/P)

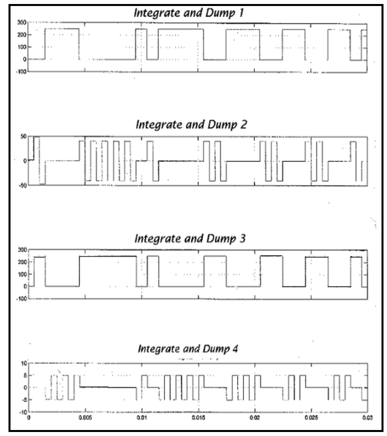

Fig (7) The Four I&D Outputs

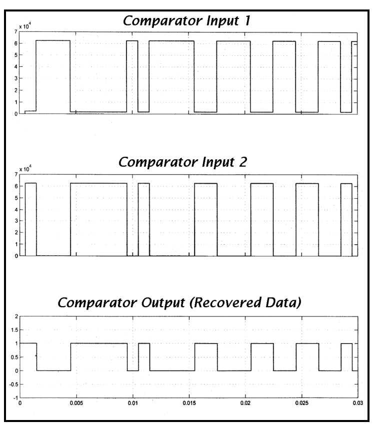

Fig (8) Decision Device I/Ps &O/P

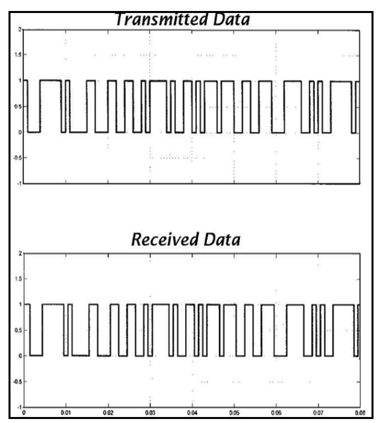

Fig (9) Tx and Rx data

For the acquisition process, there are many methods to perform this process but the simplest and most common method is the serial search acquisition circuit

[17]. In this method the received FH signal plus noise is correlated in a wide band mixer with the local hop sequence produced by a FH synthesizer driven by a PN generator whose epoch is controlled in accordance with the decision to continue the search. The result of this correlator is passed through an IF filter followed by an energy detector. Post detection integration of the energy detector output produces a signal whose mean value is nominally zero when the two hop sequences are misaligned and non zero when they are either partially or fully aligned. Thus comparing this signal with a preset threshold allows a decision to be made as whether or not FH acquisition has been achieved, or equivalently whether or not to step the PN code epoch and continue search.

The acquisition detector based on the above criteria (assuming clock synchronism) is a part of the system shown in Fig(1) while the result of this process is illustrated in Fig(10) from this figure it is clear that during the In Synch signal is "0" the two hop patterns are not the same so the receiver hop pattern clock is steped twice faster than the transmitter one until the two patterns are synchronized so the IF filter has a significant output that detected by the energy detector and the decision device output make the In Synch signal switches from "0" to "1" allowing the receiver hop pattern clock to return to the normal clock rate, this points out that the acquisition process is acomplished.

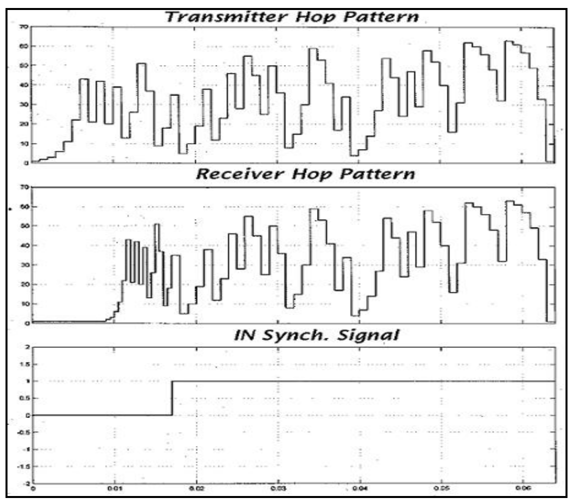

Fig (10) Reference & acquired Patterns and In Synch Signal

2- Baseband model

To show the importance of this model type let us assume an application that uses FHSS technology which is the Bluetooth Frequency Hopping system. The system has a data rate of 1Mbps ,79 hop slow frequency synthesizer with hop band from 1MHz to 79 MHz with hopping rate of 1600 hps and GFSK data modulation. The use of passband model in this system may be impossible for DSK iplementation because of high frequency band utilization, so the baseband model will be more practical and will greatly help in the implementation process as will be seen later.The simulation model is shown in Fig(11) where a data source of 2/3 Mbps is used and followed by a CRC (Cyclic Redundancy Check) block that converts every 10 bit of data into 15 bit code word by binary cyclic encoder, the resulting signal is data at 1Mbps that is used to modulate binary GFSK modulator.The output of GFSK block is correlated with the output of Frequency Synthesizer of 79 hop carriers each separated by 1MHz to perform spreading process. The reverse operation is done in the receiver section and finally the recovered data is obtained.

One of the drawbacks with current Bluetooth technology is its restrected bit rate. Although it is very desirable for low bit rate applications such as data modems, cordless phones and low bit rate vidiophones, it is unable to transport high bit rate VCR/TV quality digital video.

One method suggested by [18] to increase the bit rate is to use higher order modulation techniques such as QPSK, 8-FSK and 16-QAM to obtain 2Mbps, 3Mbs, and 4Mbps data rates respectively. To simulate such higher order modulator the same model of Fig(11) is used with different baseband modulation and demodulation blocks. And the system performance is compared with ideal modulator performance as we will see in next subsection.

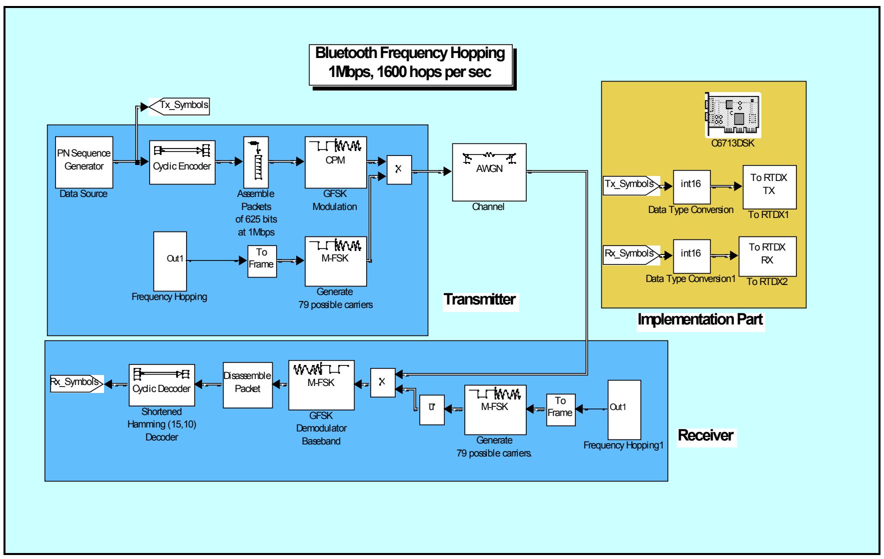

Fig (11) Simulink model for Bluetooth FH Baseband Transceiver.

3.1 BIT ERROR RATE CALCULATIONS

The performance of the simulated systems is determined through the calculation of the Bit Error Rate (BER) by Monte Carlo analysis and theoretical analysis supported by Matlab in which the system BER is plotted against different bit energy to noise ratio (Eb/No).

In Fig(12) the curves representing ideal BFSK, QPSK, 8-FSK and 16-QAM bit error rates are traced by theoretical analysis while the points represintig the

Bluetooth system using the previous modulation techniques are calculated and traced by the Monte Carlo abalysis. The Passband model performance is traced in the same manner in Fig (13). From both figures it is observed that the simulated models agree with the ideal modulation techniques performance.

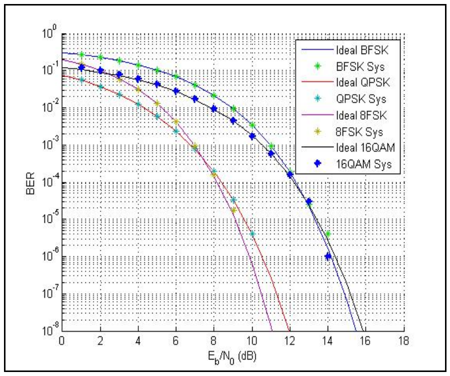

Fig (12) BER of Bluetooth Transceiver with BFSK, QPSK, 8-FSK, and 16-QAM

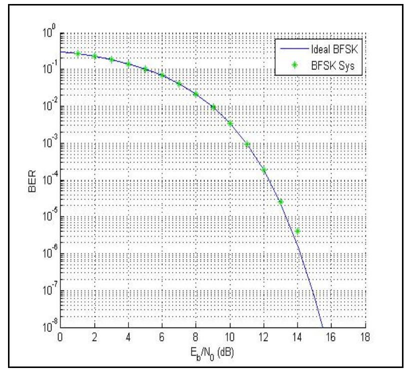

Fig (13) BER of Pass Band FHSS System

4. TRANSCEIVER DSP IMPLEMENTATION

The next step following the correcteness validation of the proposed baseband FHSS tranceiver model is the DSP implementation. We choose the C6713 floating-point DSK as the targeteted platform for the implementation.

The simulated model is transformed into an implementable model by adding the C6713DSK target from the Matlab TI C6000 DSP library. Next, we change the simulation parameter solver to fixed step solver of discrete (no continous state) option. Finally, we add the RTDX blocks as shown in implementation part of Fig (11).

Then CCS generates the required C Source files, Linker files and Include files corresponding to our Simulink design. CCS is now launched and the C6713 is connected. The last step in the process is building the executable .out file after which control is transferred to CCS and our program is run on the DSK in real-time.The results of RTDX for Baseband Bluetooth Frequency Hopping transceiver operating with BFSK, is captured in Fig (14) where the transmitted and received bits are the same.

In QPSK, 8-FSK and 16-QAM systems operating at data rates of 2Mbps, 3Mbps, and 4Mbps respectively, the transmitted and received symbols are displayed in the RTDX channel output window as shown in Fig (14), Fig (15), Fig (16) and Fig (17), respectively.

By inspecting these figures we see that all RTDX results provide a complete agreement between the transmitted and the received data.

	Tx_Data	Rx_Data
1	0	0
2	0	0
3	0	0
4	1	1
5	1	1
6	1	1
7	1	1
8	0	0
9	1	1
10	0	0
11	1	1
12	1	1
13	0	0
14	0	0
15	1	1
16	0	0
17	0	0
18	0	0
19	1	1
20	1	1
21	1	1
22	1	1
23	0	0
24	1	1
25	0	0

Fig (14) BFSK System RTDX O/P

	Tx_Data	Rx_Data
1	0	0
2	0	0
3	1	1
4	3	3
5	2	2
6	2	2
7	3	3
8	0	0
9	2	2
10	0	0
11	3	3
12	3	3
13	1	1
14	1	1
15	2	2
16	1	1
17	0	0
18	1	1
19	3	3
20	2	2
21	2	2
22	3	3
23	0	0
24	2	2
25	0	0

Fig (15) QPSK System RTDX O/P

	Tx_Data	Rx_Data
1	0	0
2	0	0
3	7	7
4	5	5
5	3	3
6	1	1
7	0	0
8	7	7
9	5	5
10	3	3
11	1	1
12	0	0
13	7	7
14	5	5
15	3	3
16	1	1
17	0	0
18	7	7
19	5	5
20	3	3
21	1	1
22	0	0
23	7	7
24	5	5
25	3	3

Fig (16) 8-FSK System RTDX O/P

	Tx_Data	Rx_Data
1	0	0
2	1	1
3	14	14
4	11	11
5	2	2
6	3	3
7	13	13
8	6	6
9	4	4
10	7	7
11	10	10
12	12	12
13	8	8
14	15	15
15	5	5
16	9	9
17	1	1
18	14	14
19	11	11
20	2	2
21	3	3
22	13	13
23	6	6
24	4	4
25	7	7

Fig (17) 16-QAM System RTDX O/P

5. CONCLUSIONS

In this work we described and simulated a frequency hopping spread spectrum Passband transceiver, The output of every functional block of the system is plotted, a serial search technique is used to acquire synchronization between transmitter hop pattern and receiver hop pattern. In addition a baseband model for bluetooth frequency hopping transceiver is presented as an application example of FHSS system. QPSK, 8-FSK and 16-QAM, modulation techniques are exploited to raise the bit rate from 1Mbps to 2Mbps, 3Mbps and 4Mbps respectively. The bit error rate of the described transceiver models is calculated and compared with the ideal systems of the same modulation types. The proposed model is then implemented using the C6713 floating-point DSP.The functionality of the implemented system is tested via RTDX. A complete agreement between transmitted and received data prove the sucsess of the implementation process.

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