Academy of Scientific Research and Technology
27th National Radio Science Conference
Faculty of Electronic Engineering, Menoufia Univ., Menouf, Egypt
16-18 March 2010

DSP Implementation Aspects for a Generic Frequency Hopped Transceiver

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ABSTRACT
Frequency hopping is a foremost type of spread spectrum technology that has many advantages. Particularly, frequency hopping is a well-known technique for combating narrow-band interference, jamming and multipath with inherent security and selective addressing capabilities. Therefore, it is increasingly utilized in the license-free Industrial, Scientific and Medical (ISM) band. Owing these enormous consequences of Frequency Hopping Spread Spectrum (FHSS), we develop a generic FHSS transceiver that can be employed in many applications such as Cellular Mobile, Bluetooth Personal Area Networks (PAN), Wireless Local Area Networks (WLAN), Code Division Multiple Access (CDMA) systems and Radar systems. In order to implement such generic transceiver we utilize one of the most powerful modern implementation techniques namely; the Digital Signal Processor (DSP). The performance of our proposed FHSS transceiver is evaluated via the BER calculation.

KEYWORDS

DSP, Frequency Hopping, Spread Spectrum, Transceivers, Bluetooth, Implementation.

I.INTRODUCTION

Considerable effort since the introduction of radio systems has occurred in the area of both civilian and military communications, leading to the emergence of spread spectrum communications appearing over the last half century. The application of spread spectrum communications ranges from low probability of intercept and anti–jamming communications, through to provision of multiple access capability through Code Division Multiple Access (CDMA) [1].
Spread spectrum systems can be classified on the basis of the modulation technique. The most common modulation techniques we concern are Direct Sequence and Frequency Hopping.
In traditional Frequency Hopping (FH) systems, the transmitter hops in a pseudo-random manner among available frequencies according to a pre-specified algorithm. The receiver operates accordingly in exact synchronization with the transmitter's hopping pattern. Depending on the Hop Rate, two main categories 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 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 [5].
The rest of this paper is organized as follow; Section II presents the recent related work. Section III illustrates the performance evaluation via the BER calculations. Section IV presents an

overview of the experimental setup. The DSP implementation of the proposed FHSS transceivers is illustrated in Section V. Finally, the conclusions are drawn in Section VI.

II. RELATED WORK

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 [6]. 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 [7].

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 [8].

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 [9], 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 [10] for mobile ad hoc networks (MANETs) with frequency-hopped (FH) CDMA and multiple antennas.

In our previous work [11] we described, and simulated a FHSS transceiver. First, a generic slow rate FHSS pass-band system was simulated using matlab simulink. We utilized the serial search detector to acquire synchronization between the transmitter and receiver by forcing the receiver to recognize and follow the transmitter hop pattern. Second, a base-band model for Bluetooth frequency hopping system was presented. Several modulation techniques, such as QPSK, 8-FSK and 16-QAM, were exploited to achieve a bit rate of 2Mbps, 3Mbps and 4Mbps.

In this work, we propose an implementation of the FHSS pass-band transceiver and the Bluetooth FHSS base-band transceiver using the C6713 floating point DSP. The C6713 DSP Starter Kit (DSK) is used as an experimental platform. The physical output signals of each building block of the implemented FHSS pass-band transceiver are demonstrated via the DSK codec output with a digital storage oscilloscope. On the other hand, the functionality of the implemented Bluetooth base-band FHSS transceiver is tested via the Real Time Data Exchange (RTDX) technique supported by the TMS320C6713 DSK

III.EXPERIMENTAL SETUP

The proposed FHSS 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 available today for Digital Signal Processing. It is a complete DSP system with the necessary hardware and software support tools for real-time signal processing.

The 32-bit stereo codec AIC23 embedded in the C6713 DSK uses a sigma–delta technology that provides ADC and DAC. It is connected to a 12-MHz system clock. Variable sampling rates from 8 to 96 kHz can readily be set. The architecture and instruction set of the C6713 are discussed in more details in [12].

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. More details regarding CCS exist in [13]

Finally the functionality of the implemented system is tested via Real Time Data Exchange (RTDX) supported by both the C6713 DSK and the CCS. TI provides a tool called General Purpose Display (GPD) to observe and compare the values sent via RTDX. The powerful 100 MHz TDS2014 digital storage oscilloscope from Tektronix Inc. is utilized to exhibit the DSK codec output waveforms.

IV.BIT ERROR RATE CALCULATIONS

In the previous work [11] we have proposed the simulation of pass-band and base-band FHSS transceiver models using Matlab Simulink. In this section we present the performance evaluation of the simulated models via the calculation of the Bit Error Rate (BER) by means of Monte Carlo and theoretical analysis methodologies. The BER is computed with the aid of Matlab by which the BER of our proposed transceiver is plotted against different bit energy to noise ratios (Eb/No).

The solid line curves in Fig. (1) represent the BERs for the standard BFSK, QPSK, 8-FSK and 16-QAM modulation schemes computed with the aid of the theoretical analysis. On the other hand, the discrete points in the same figure represent the BERs for our proposed base-band FHSS Bluetooth transceiver while utilizing the pre-mentioned modulation schemes calculated and traced by means of the Monte Carlo analysis technique. The pass-band model performance is traced in the same manner as shown in Fig. (2). From both figures it is pretty clear that the simulated models agree with the standard modulation techniques performance.

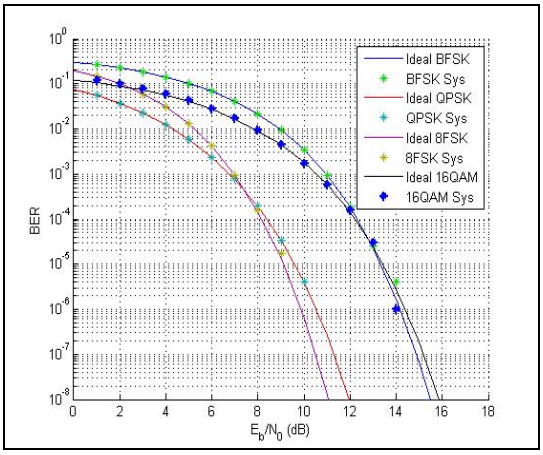

Fig (1) BER of Bluetooth Transceiver with BFSK, QPSK, 8-FSK, and 16-QAM modulation schemes.

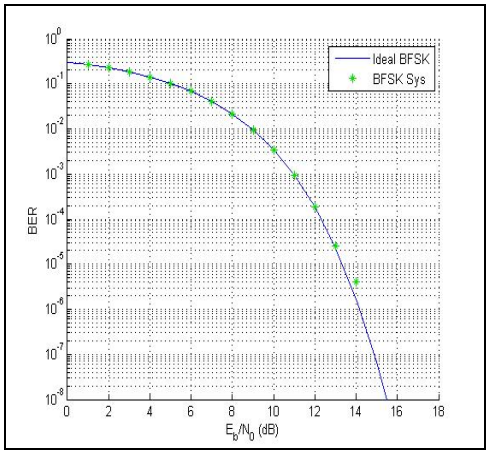

Fig (2) BER of pass-band FHSS transceiver

V. TRANSCEIVER IMPLEMENTATION

In this section we will go through the realization of our proposed FHSS transceiver utilizing the C6713 DSK.
The implementation is accomplished with the aid of the Matlab Simulink and the CCS [14]. To convert a simulation model to an implementable one the following steps are required:

- Convert all continuous blocks (like analog filters) into digital ones.
- Set the simulation configuration parameters to Fixed-step-solver and Discrete (no continuous state).
- Add the c6713DSK target from the following library:
  Embedded target for TI C6000 DSP\ C6000 target preferences

Typically, we present two methods for implementing FHSS transceivers namely; pass-band and base-band transceivers. For the FHSS pass-band transceiver, we develop all the constituting blocks such as modulation and demodulation blocks as there is no Matlab Simulink component to carry out the pass-band modulation and demodulation. The required carrier generators utilized in these blocks and in the frequency synthesizer block are in real form.
On the other hand, for the base-band transceiver the Matlab Simulink offers base-band modulation and demodulation components in the communication toolbox. The carrier generators utilized in these components and in the frequency synthesizer block are represented in complex form (amplitude and phase).

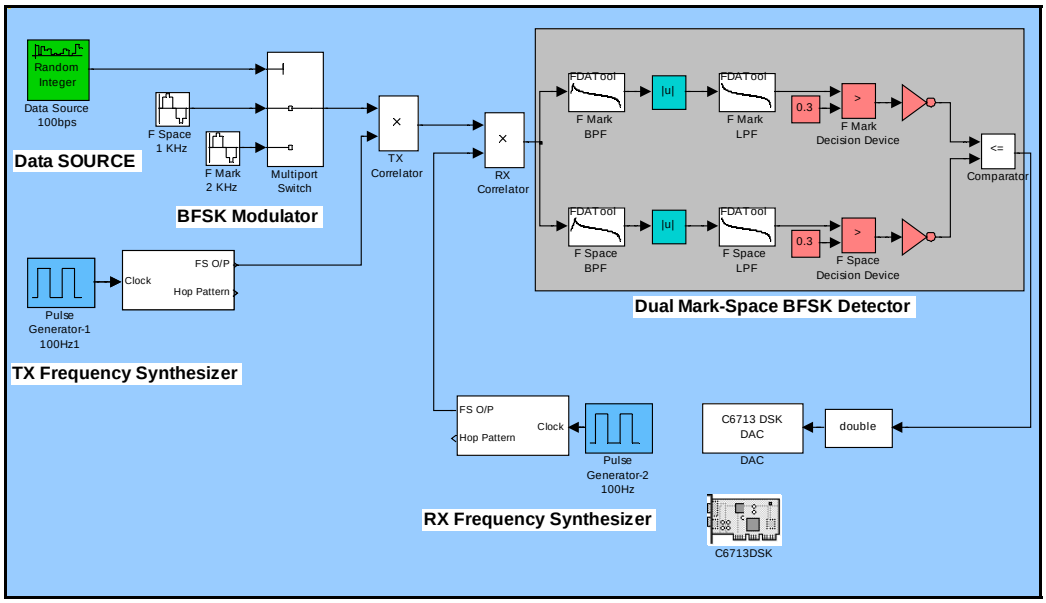

Fig. (3) The Block Diagram of the C6713 DSK Implementation of the FHSS pass-band transceiver.

Pass-Band FHSS Transceiver

Figure (3) shows the building blocks of the implemented pass-band transceiver. The implemented transceiver utilizes a Digital to Analog Converter (DAC) with a sampling rate of 48Ksps to obtain the desired output signal in analog form. The proposed FHSS transceiver operates at a data rate of 100bps. The data streams are modulated with BFSK modulator utilizing mark and space frequencies of 1KHz and 2KHz respectively. The frequency

synthesizer generates a hop set of 15 different carriers starting from 8KHz to 22KHz with a step of 1KHz. The physical outputs of the FHSS pass-band transceiver for different test points are traced by the digital storage oscilloscope from the codec output of the C6713 DSK.
Figure (4) represents the random digital transmitted data at 100bps while Fig. (5) illustrates the output of the BFSK modulator of mark and space frequencies of 1KHz and 2KHz respectively.

The output of the frequency synthesizer with frequency hop set of 8 KHz up to 22KHz is demonstrated in Fig. (6). This figure clearly confirms the ability of the synthesizer to provide the phase continuity between successive hops. The output of the transmitter correlator that multiplies the BFSK modulated signal by the frequency synthesizer output to achieve the spreading or hopping concept is depicted in Fig.(7).

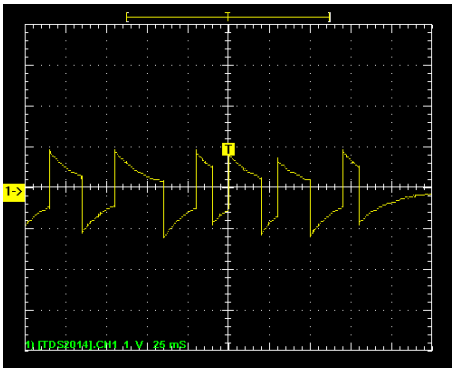

Fig. (4) Transmitted Data

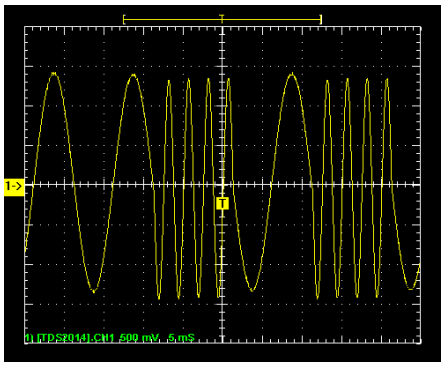

Fig. (5) The BFSK Modulator Output

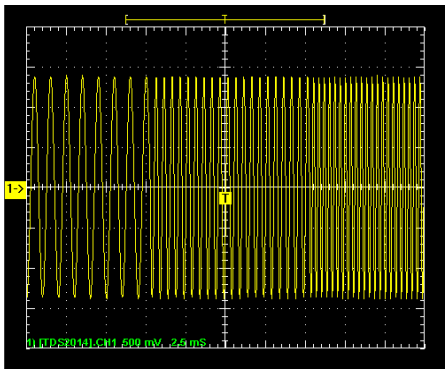

Fig. (6) The o/p of Tx Frequency Synthesizer

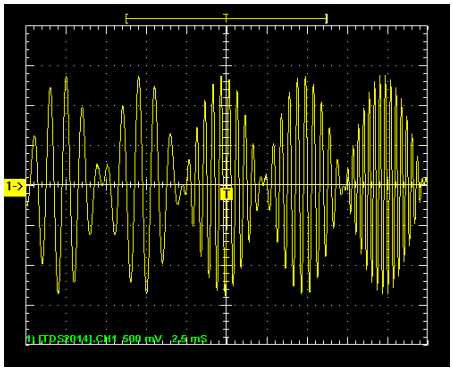

Fig. (7) The output of Pass-Band FHSS Tx

At the receiver a locally generated copy of the frequency synthesizer output is produced and correlated with the received signal to de-hop the received signal. The physical output of the implemented correlator is depicted in Fig. (8). The resulting signal of Fig. (8) encloses the mark and space frequency components required by the BFSK demodulator and undesired high frequency components. The Band-Pass Filter (BPF) of subsequent data demodulator eliminates these undesirable components. The BFSK demodulator is divided into two similar branches namely Mark branch and Space branch. Each branch contains a BPF to select the desired Mark or Space frequency and reject the other frequency as depicted in Fig. (9).

The output of the BPF is fed to a Low Pass Filter (LPF) to extract the DC component as shown in Fig. (10). The outputs of that LPF for both Mark and Space branches are compared with each other and the resulting signal represents the received data as shown in Fig. (11).
By analyzing our pre-mentioned implemented model we realize that the codec represents a bottle nick from the sampling rate perspective. Thus, according to the sampling theory and the fact that the maximum sampling rate that we achieve with the C6713 DSK equal 48Ksps, the maximum frequency that should be utilized in the FHSS transceiver is less than 24KHz.

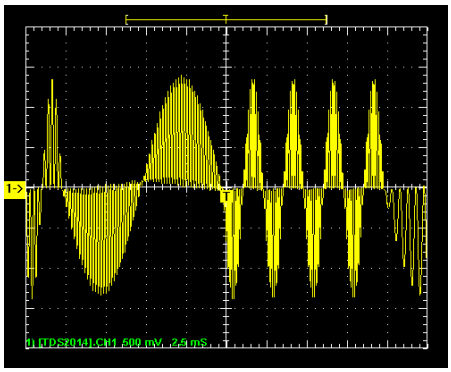

Fig. (8) Receiver Correlator Output

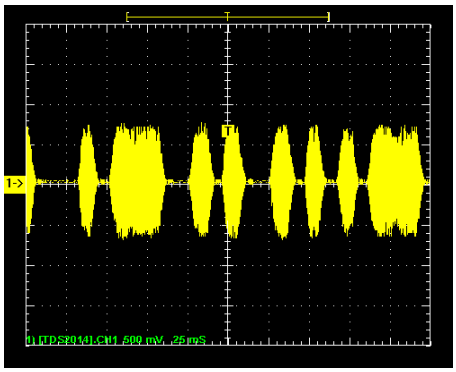

Fig. (9) BPF O/P of Mark or Space BFSK Demodulator

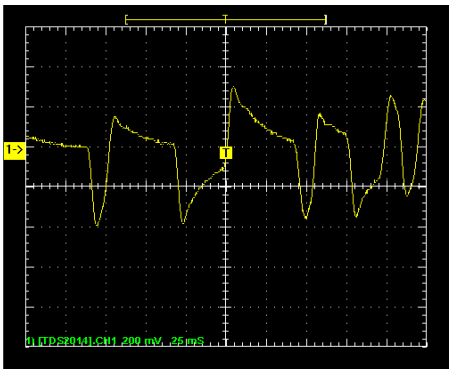

Fig. (10) LPF o/p of Mark or Space BFSK Demodulator

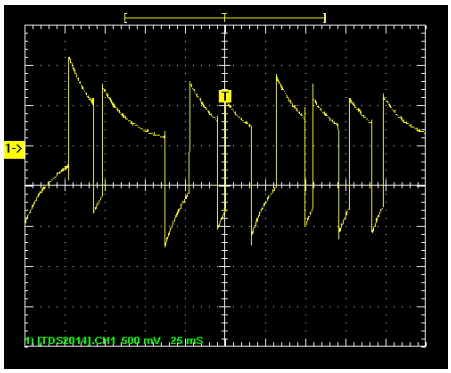

Fig. (11) Received Data

Thus, we need another technique rather than the codec to monitor the output of the implemented FHSS transceiver at higher frequencies than 24KHz. We make use of the RTDX capabilities of the C6713 DSK to compare the transmitted and received data streams instead of the codec.
By utilizing the RTDX we successfully implement the previous pass-band transceiver with a maximum frequency of 135KHz which is equivalent to sampling rate of 270Ksps. Higher sampling rates than 270Ksps cause the DSK to halt and no output results are displayed on the RTDX display window.
In order to converge to the practical communication systems applying the Frequency Hopping technique with high performance we proposed the base-band implementation for the FHSS transceiver. The base-band implementation allows us to attain higher frequencies by representing the high frequency signals in complex (base-band) representation. In the next

section we will further explain the implementation of the base-band transceiver with the aid of the RTDX for comparing the transmitted and received data streams.

Bass-Band Bluetooth FHSS Transceiver

In this section, we propose the implementation of the base-band Bluetooth FHSS transceiver.

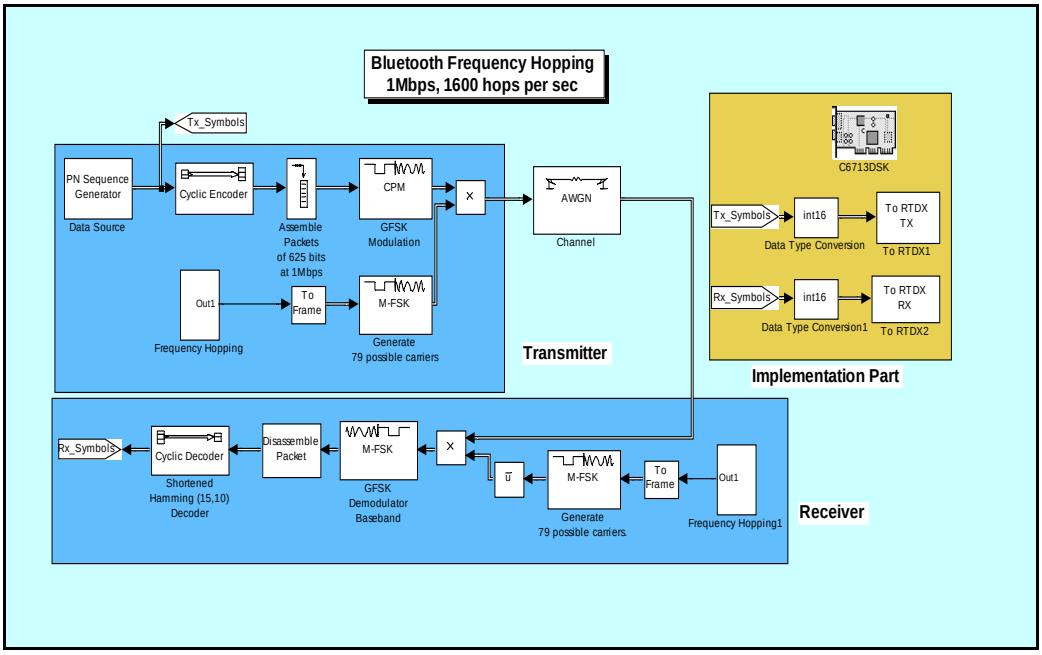

Fig. (12) Implementation Model for Bluetooth FHSS Base-band Transceiver.

The proposed Bluetooth FH transceiver has the following specifications:

- Data rate of 1Mbps,
- Slow Frequency hopping with 625 bit per hop,
- 79 hop frequency synthesizer,
- Hop band from 1MHz to 79MHz,
- Hopping rate of 1600hps,
- Gaussian Frequency Shift Keying (GFSK) data modulation.

Figure (12) represents the implemented Bluetooth FHSS base-band transceiver. The RTDX blocks are utilized to view and hence compare the transmitted and received data sequences. Table (1) represents a snapshot of the RTDX output for typical random binary data.

In order to increase the bit rate we follow the methodology suggested by [15] by employing higher-order modulation techniques such as QPSK, 8-FSK and 16-QAM for attaining 2Mbps, 3Mbps, and 4Mbps data rates respectively. The implementation process is repeated for each of the above mentioned modulation schemes and the RTDX in this case compares between the transmitted and received data symbols. These symbols are displayed in the RTDX channel window as shown in Table (2), Table (3) and Table (4), respectively. By inspecting these tables we see that all RTDX results provide a full agreement between the transmitted and the received data and this reflects the correctness of implementation process.

Table (1) RTDX O/P for System With BFSK

	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

Table (2) RTDX O/P for System With QPSK

	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

Table (3) RTDX O/P for System With 8-FSK

	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

Table (4) RTDX O/P for System With 16-QAM

	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

VI.CONCLUSIONS

In this paper, we realize an implementation for a generic slow rate FHSS pass-band transceiver using the C6713 floating-point DSP. The proposed FHSS pass-band transceiver is featured with a data rate of 1Kbps, BFSK modulation, a PN code of ML-LFSR with [6,1] taps, 63 hop frequency synthesizer with hop rate of 1Khps and frequency hop set from 10KHz to 630KHz with a 10KHz step. The output of every stage of our developed transceiver is demonstrated by monitoring the physical DSK codec outputs using a digital storage oscilloscope to recognize the

transceiver behavior. This pass-band transceiver is limited by the low actual reached sampling rate of the codec (48 ksps). By utilizing the RTDX instead of the codec to compare the transmitted and received data streams, we attained a maximum sampling rate of 270ksps for C6713 DSP Kit.

Moreover, we realize an implementation for the base-band Bluetooth FHSS transceiver. The developed transceiver is characterized by a data rate of 1Mbps, slow frequency hopping with 625 bit per hop, 79 hop frequency synthesizer with hop rate of 1600hps and frequency hop set from 1MHz to 79MHz with a 1MHz step and GFSK modulation. We repeat the implementation of the Bluetooth FHSS base-band transceiver with several higher-order modulation techniques, such as QPSK, 8-FSK and 16-QAM, to achieve higher bit rates of 2Mbps, 3Mbps and 4Mbps respectively. The output of our Bluetooth FHSS base-band transceiver is monitored by means of the RTDX capability of the C6713 DSK Kit. An excellent agreement between transmitted and received data proves the success of the implementation process.

We verified the performance of our developed pass-band and base-band transceivers via comparing their BER against the BERs of different standard modulation techniques. The comparison shows an excellent agreement between the BER of our transceivers and the BER of the standard modulation schemes.

Based on our pre-mentioned realizations we conclude that the implementation of the pass-band FHSS transceiver greatly assists in validating the functionality and evaluating the performance of our FHSS transceiver. Furthermore, the pass-band transceiver outs real signals that are supposed to be fed to the RF frontend. Due to the limited resources capabilities of our implementation platform especially the slow codec, the pass-band transceiver implementation cannot realize high frequencies.

On the other side, the base-band FHSS transceiver implementation permits the realization of higher frequencies to meet the standard specifications on the account of representing the signals in complex (base-band) form that cannot be directly fed to RF frontend.

REFERENCES

[1] C.C. Ko, W. Zhi, and F. Chin, “ML-Based Frequency Estimation and Synchronization of Frequency Hopping Signals,” IEEE Transactions On Signal Processing, vol. 53, no.2, pp. 403-410, FEB 2005.

[2] R. Dixon, Spread Spectrum Systems with Commercial Applications, 3rd edition, John Wiley, 1994.

[3] D. Torrieri, Principles of Spread-Spectrum Communications Systems, Springer Science + Business Media, Inc. 2005.

[4] S. Haykin, Communication Systems, 4thedition, John Wiley, 2001.

[5] IEEE 802.15 WG on Wireless Personal Area Networks, Sept. 2004; http://www.ieee802.org/15/

[6] T. Li, Q. Ling and J. Ren, “A Spectrally Efficient Frequency Hopping System Design for Wireless Networks,” in proceedings of the IEEE Global Telecommunications Conference (GLOBECOM’07), pp. 2997-3001, NOV 2007.

[7] O. A. Bamahdi and S. A. Zummo, “An Adaptive Frequency Hopping Technique With Application to Bluetooth-WLAN Coexistence,” in proceedings of the IEEE International Conference on Networking, International Conference on Systems and International Conference on Mobile Communications and Learning Technologies (ICNICONSMCL’06), pp.131, 2006.

[8] J. S. Min and H. Samueli "Analysis and Design of a Frequency-Hopped Spread Spectrum Transceiver for Wireless Personal Communications," IEEE Transactions on Vehicular Technology, vol. 49, no. 5, pp. 1719- 1731, SEP 2000.

[9] Z. Li, J. Cai, and Y.Chang "Determining the Complexity of FH/SS Sequence by Approximate Entropy," IEEE Transactions On Communications, vol. 57, no. 3, pp. 812-820, MAR 2009.

[10] H. Sui and J. R. Zeidler "Information Efficiency and Transmission Range Optimization for Coded MIMO FH-CDMA Ad Hoc Networks in Time-Varying Environments," IEEE Transactions On Communications, vol. 57, no. 2, pp. 481-491, FEB 2009.

[11] H. E. Ahmed, A. A. Zekry, A. E. Elhennawy and A. M. Hassan, "Frequecy Hopping Spread Spectrum Transceiver Implementation Using Floating-Point DSP," in proceedings of the 2nd International Conference on Advanced Computer Theory and Engineering (ICACTE'09), pp. 659-670, SEP 2009.

[12] Spectrum Digital, TMS320C6713 DSK Technical Reference, 2003.

[13] Texas Instruments Inc., Code Composer Studio ver3.1 IDE, white paper, MAY 2005, SPRU509F. www.ti.com.

[14] S. K. Hasnain, A. D. Daruwalla, and A. I. Saleem, "A unified approach in Audio Signal Processing using the TMS320C6713 and Simulink Blocksets," in proceedings of the IEEE 2nd International Conference on Computer, Control and Communication (IC4'09), pp.1 – 5, FEB. 2009.

[15] A. K. Arumugam, S. M. D. Armour, B. S. Lee, M. F. Tariq and A. R. Nix, "Consumer Electronics Application and Coverage Constraints using Bluetooth and Proposed Bluetooth Evolution Technologies," IEEE Transactions on Consumer Electronics, vol. 47, pp.283 – 293, AUG. 2001.