FPGA implementation of Bluetooth 2.0 Transceiver

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Abstract:- In our paper we aim at combining three different types of modulation techniques,GFSK , PI/4DQPSK and 8DPSK on one common hardware platform. Goal of our project is to implement Bluetooth 2.0 on FPGA. Bluetooth 2.0 uses Gaussian Frequency Shift Keying (GFSK) as modulation technique for the header and access code ,PI/4DQPSK for data (2Mpbs) and 8DPSK for data (3Mpbs).So whereas most commercial Bluetooth chips are low cost and inflexible, in our project flexibility and re-use of hardware is important. It is for that reason the Bluetooth transceiver will be done in the digital domain. The choice of the demodulation algorithm determines the channel selection requirements (better demodulation algorithms require less SNR).A simulation model was built to measure the performance of these algorithms. In our simulation model, Bluetooth signals are sampled with 16 MHz.To obtain a BER (Bit Error Rate) of 0.1%, specified by the Bluetooth standard, requires an SNR of about 15 dB.the design was synthesized using NU HORIZONS ELECTRONICS Spartan3 development board.(spartan3 400g 208) .

Key-Words:- Bluetooth- GFSK- DPSK-Timing Recovery-Carrier Recovery-FPGA.

I Introduction

In our paper we are focussing on the low area implementation of bluetooth2.0 transceiver using FPGA.We had a lot of choices in implementation of different components of the transceiver. we choiced the best one based on the lowest area criteria . This paper will discuss modulation and demodulation algorithms for Bluetooth GFSK, PI/4DQPSK and 8DPSK signals. In order to evaluate the performance of the algorithm, a Bluetooth simulation model has been built. In this model, Bluetooth packets are generated and transmitted and demodulated by demodulation algorithm.we took into consideration frequency offset , phase offset , timing offset and noise impairments. we choiced phase discrimination algorithm as demodulation algorithm because it can be used with GFSK, PI/4DQPSK and 8DPSK signals . First this paper will discuss the Bluetooth GFSK modulation and demodulation technique.then PSK modulationand demodulation technique .and finally how to combine both algorithm .The Bluetooth standard requires a maximum Bit Error Rate (BER) of 10^{-3} . we can obtain it using SNR of 15 dB.any Bluetooth 2.0 device gives a two fold improvement in the data rate and thereby allows a maximum speed of 2 Mbps. This is achieved by using pi/4 differential quaternary phase shift keying (pi/4 DQPSK). This form of modulation is significantly different to the GFSK that was used on previous Bluetooth standards in that the new standard uses a form of phase modulation, whereas the previous ones used on frequency modulation. Using quaternary phase shift modulation means that there are four possible phase positions for each symbol. Accordingly this means that two bits can be encoded per symbol, and this provides the two fold data increase over the frequency shift keying used for the previous versions of Bluetooth.To enable the full three fold increase in data rate to be achieved a further form of modulation is used. Eight phase differential phase shift keying (8DPSK) enables eight positions to be defined with 45 degrees between each of them. By using this form of modulation eight positions are possible and three bits can be encoded per symbol. This enables the data rate of 3 Mbps to be achieved. Table1.1 shows Bluetooth core versions and the transmission rates.

Table 1.1: Bluetooth core versions and transmission rates.

Bluetooth core	mode	bit rate
1.1	basic rate	1 Mbps
2.0	high rate	2 or 3 Mbps

2 Bluetooth2.0 Modulation

In normal continuous phase Frequency Shift Keying(FSK) a ’0’ is represented by an harmonic signal with frequency f0 and a ’1’ by frequency f1 , both per interval of Ts Continuous FSK uses an numerically-Controlled Oscillator (NCO) that is driven by the bit signal. In this implementation no phase shifts occur between bit transitions, which explains the name continuous phase FSK.

However due to the binary nature of the input signal, fast frequency transitions occur and therefore results in a large bandwidth. It is for that reason that GFSK uses a Gaussian pre-modulation filter.Fig.1 shows a Bluetooth2.0 modulator. First the bits are converted to signal elements. A ’0’ is being represented by a signal with value -1 and a ’1’ by a signal with value1, each with a duration of T seconds. The filter output is then connected to a numerically controlled oscillator(NCO) that translates the amplitude of the filtered bits into a frequency shift.. The Gaussian filter reduces the bandwidth of the input signal of the NCO.This reduces also the bandwidth of the output signal and therefore GFSK is more spectrum efficient compared to normal Frequency Shift Keying (FSK) at the cost of an increased BER, al- though the noise is also reduced by the smaller band. For FSK signals with a modulation index,

h = 0.3 in an Additive White Gaussian Noise (AWGN) channel, the required SNR for a BER of 0.1% is about 15dB. The Gaussian pre-modulation filter, however, removes higher frequencies of the modulating signal. This reduces the bandwidth of the NCO output signal but also reduces the bit energy which has a negative effect on the BER. In Bluetooth systems, the modulation index h may vary between 0.28 and 0.35. The modulation index h is defined as:h= 2 fd/R .

For the DPSK modulator. First the bits are converted to Symbols using serial to parallel converter then i&q mapping .then RRC filtering The filter output is then connected to a numerically controlled oscillator (NCO) that translates the amplitude of the filtered bits into an phase shift. The RRC filter reduces the bandwidth of the input signal of the NCO.the Bluetooth2.0 transmitter is shown below in Fig1 .

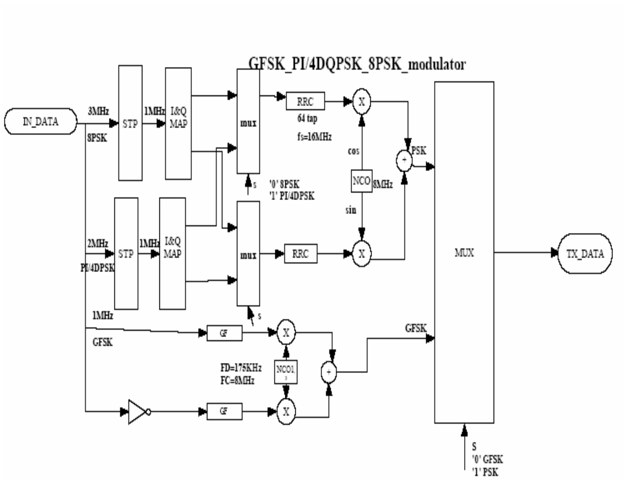

Fig1.Bluetooth2.0Transmitter

3 Bluetooth2.0 Demodulation

The phase-shift discrimination, utilizes only the phase of the signal, the amplitude is not used. Fig.2 shows a phase-shift discriminator. The first step is to down convert the incoming IF signal The two paths, In-phase (I) and Quadrature (Q) path, are low-passed filtered to eliminate the high frequency products caused by mixing. Then the phase is extracted by the arctan block In order to retrieve the NRZ signal, the output of the arctan block has to be differentiated for the GFSK demodulation.

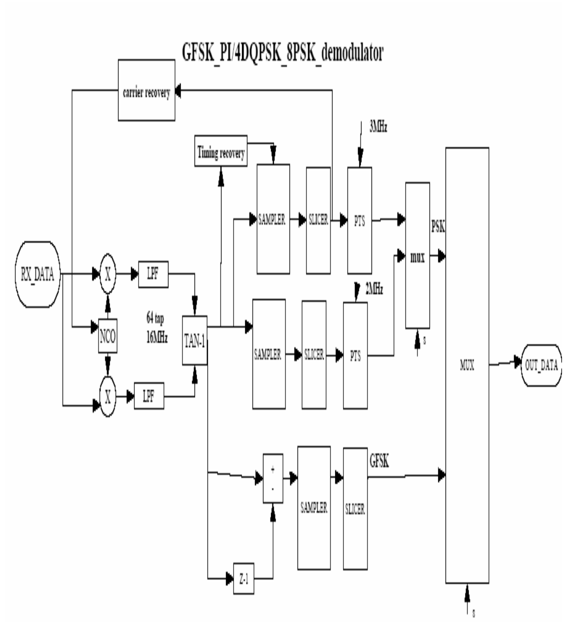

Fig2.Bluetooth2.0 Receiver

The carrier recovery and timing recovery block digrams are shown below where the carrier recovery consist of (Numerically controlled oscillator and phase detector and second order loop filter and the symbol recovery consist of(numerically controlled clock and timing error detector (using gardner algorithm) and second order loop filter

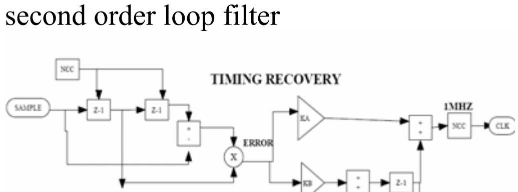

Fig3.bluetooth2.0 timing and carrier recovery.

4 Simulink Model

This section discusses the Bluetooth2.0 simulation model we used to evaluate the bluetooth2.0 modem .Fig. shows the top view of the simulation model. The t ransmitter creates packets Then, the packet is transmitted according theBluetooth specs using a carrier frequency of 8MHz.

To get realistic performances we assumed that the Bluetooth signal was sampled with a sample rate of16 MHz. Noise and phase offset and frequency offset is added and the distorted signal is filtered by 64-taps Finite Impulse Response (FIR) filter which has a 1 MHz bandwidth with center frequency of 16MHZ

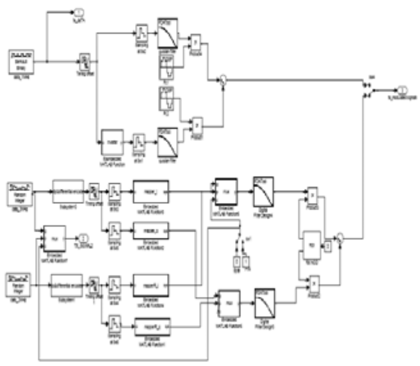

Fig4.Simulink model for Bluetooth2.0 transmitter.

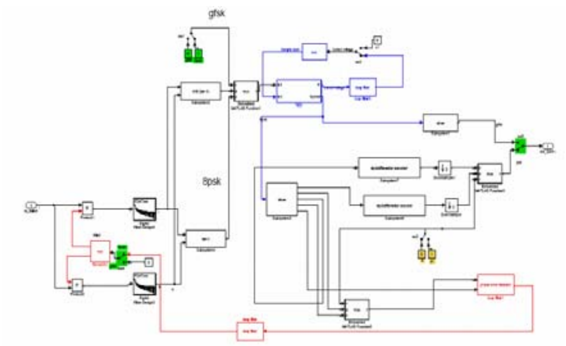

Fig5.Simulink model for Bluetooth2.0 Receiver.

	Bluetooth specification	This simulation without timing recovery	This simulation With timing recovery
Modulation format:	GFSK	GFSK	GFSK
GFSK BT:	0.5	0.5	0.5
Modulation data rate	1E6	1E6	1E6
Frequency deviation (khz)	175	175	175
Modulation index	0.28-0.35	0.35	0.35
Input power	1mW	1mW	1mW
If center frequency (MHZ)	--	8	8
Frequency offset (KHZ)	75	75	75
Phase offset (RAD)	--	0.05	0.3
Timing offset (µS)	--	0.05	0.5
SNR (db):	15	15	15
BER:	0.1%	0.1%	0.1%

Table2.Bluetooth1.1 hardware system specification

simulink simulation results are shown in the following figure for GFSK.

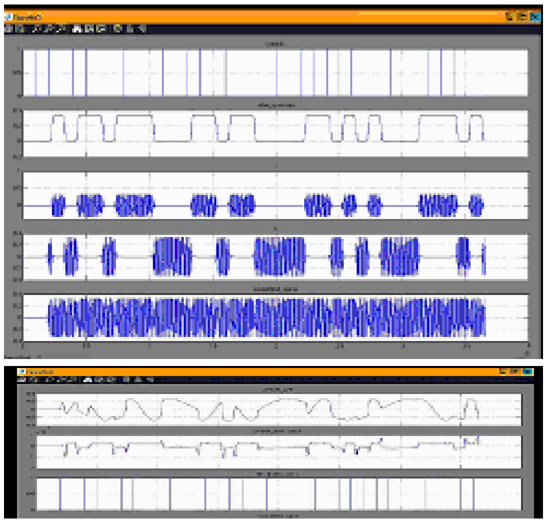

Fig6.simulink results for GFSK

Table2 show comparison between our results and Bluetooth Specification for DPSK with timing and carrier recovery and

Without Timing /carrier Recovery.

We note that the simulation result is better in the presence of both timing and carrier recovery

	Bluetooth spec	This simulation without timing/carrier recovery	this simulation with timing/carrier recovery
Modulation format:	8DPSK, π/4DQPSK	8DPSK, π/4DQPSK	8DPSK, π/4DQPSK
Modulation data rate	3E6,2E6	3E6, ,2E6	3E6, ,2E6
Input power	1mW	1mW	1mW
If center frequency (MHZ)	--	8	8
Frequency offset (KHZ)	75	0.05	75
Phase offset (RAD)	--	0.01	0.5
Timing offset (µS)	--	0.05	0.5
SNR (db):	15	15	-2
BER:	0.1%	0.1%	0.1%

Table3.Bluetooth2.0 hardware system spec.

Fig7.shows the simulation result for 8DPSK and Fig8.shows the simulation result for pi/4DQPSK.

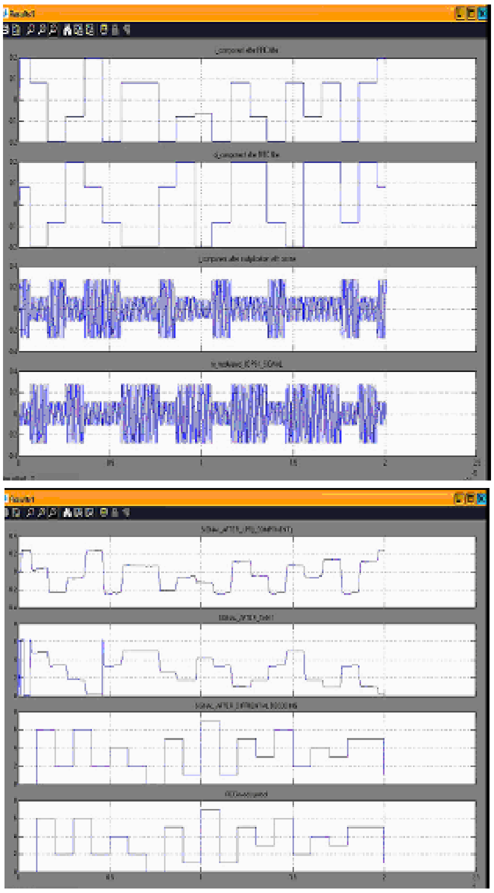

Fig7.simulink results for 8DQPSK

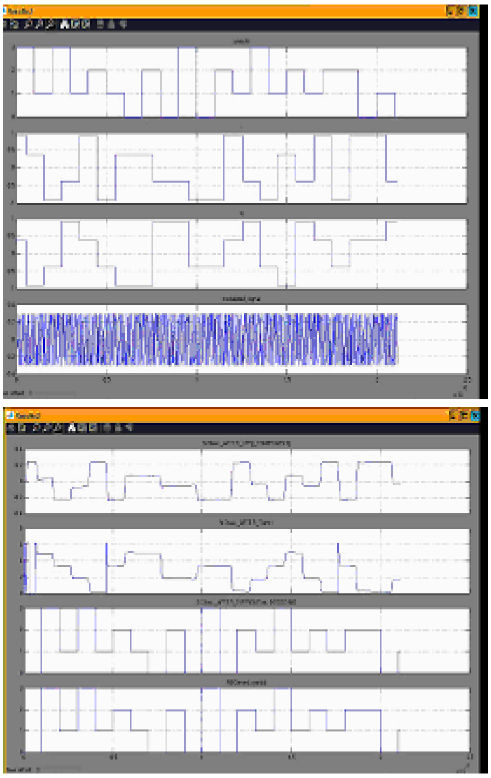

Fig8.simulink results for π/4DQPSK

5 VHDL Model

The top level of the vhdl model of the Bluetooth2.0 Transceiver is shown below in figure9.

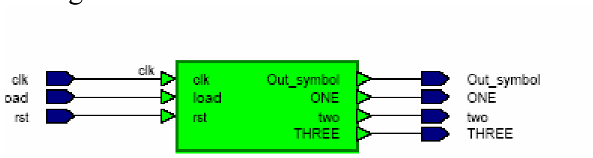

Fig9. vhdl model for Bluetooth2.0 Transceiver.

The main building blocks in this model is

1-The numerical controlled oscillator and arctan function was built using cordic theory

Rotation mode

$X_{i+1} = x_i - s_i\, 2(-2i)\, y_i$

$y_{i+1} = y_i + s_i\, 2(-2i)\, x_i$

$\Phi_{i+1} = \Phi_i - s_i \arctan 2(-2i)$

$S_i = 1$ if $\Phi_i > 0$ else -1

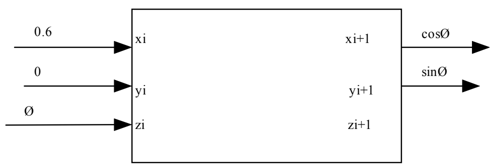

Fig10.rotation mode cordic algorithm to generate sine and cosine

Vectoring mode

The difference from rotation mode is that direction of rotation is determined by the sign of y instead of Φ

$S_i = 1$ if $y_i < 0$ else -1

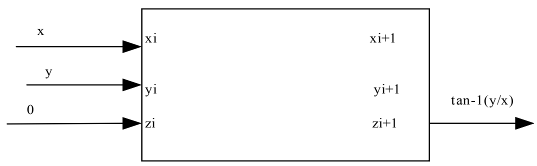

fig11.vectoring mode cordic algorithm(arctan).

2-the FIR filter coefficient and vhdl code for it was generated using FDATOOL in matlab

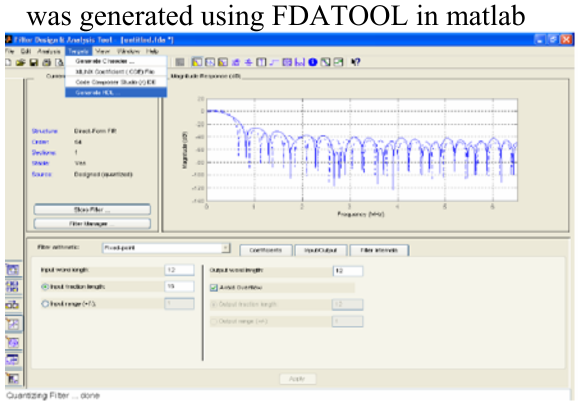

Fig12.fdatool in matlab to generate vhdl code for FIR filter

The mapping process as shown in the following table.the synthesis was done using spartan3 (400g208p)

Resource type	**used**	**available**	**utilization**
Logic utilization			
Number of slice flip flops	3,387	7,168	47%
Number of 4 input LUTS	4,658	7,168	64%
Logic distribution			
Number of occupied slices	3,582	3,584	99%
Number of slices containing only related logic	3,244	2,526	90%
Number of slices containing unrelated logic	338	2,526	9%
Total number of 4 input LUTS	5,843	7,168	81%
Number used as logic	4,658		
Number used as route-thro	1,177		
Number used as shift registers	8		
Number of bonded IOBS	57	173	40%
Number of mult 18 x18	4	16	25%
Number of GCLKS	1	8	12%
Total equivalent gate count for design	104,280		

Table4.Mapping results for Bluetooth2.0 transceiver.

The following figures shows the vhdl simulation results

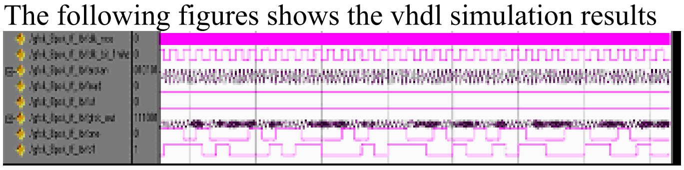

Fig6.vhdl simulation results for GFSK

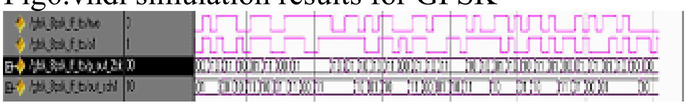

Fig6.vhdl simulation results for π/4DQPSK

Fig6.vhdl simulation results for 8DPSK

6 Results

1-implementation of (nco) and(arctan) function using cordic algorithm is better than using LUT

2- Implementation of (DTAN-1) is better than (tan-1 then differentiate it) if we implement GFSK modem only but because we implement bluetooth2.0 we should have arctan block for 8DPSK

3-implementation of fir filters using fdatool is better than hand-made filter in area consumption.

4-implementation of carrier recovery and symbol ecovery improve the BER at the same SNR.

7 Conclusion

In this paper we have analyzed implementation of bluetooth2.0 modulation and demodulation algorithm and the phase-shift discriminator algorithm, for the use in Bluetooth systems. Two scenarios were investigated, a scenario in which 1 No carrier recovery or symbol recovery is used And 2nd scenario where both are used For FSK signals with a modulation index, h = 0.3, in an Additive White Gaussian Noise (AWGN) channel, the required SNR for a BER of 0.1% is about 15dB And for 8dpsk with full synchronizatioin we need-3dB .

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