Implementation of Re-configurable Digital Front End Module of MIMO-OFDM using NCO

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Abstract

This paper focuses on FPGA implementation of reconfigurable Digital Front end MIMO-OFDM module. The modeling of the MIMO-OFDM system was carried out in MATLAB followed by Verilog HDL implementation. Unlike the conventional OFDM based systems, the Numerically Controlled Oscillators (NCO) is used for mapping modulated data onto the sub carriers. The use of NCO in the MIMO-OFDM system reduces the resource utilization of the design on FPGA along with reduced power consumption. The major modules that were designed, which constitute the digital front end module, are Quadrature Phase Shift Keying (QPSK) modulator/demodulator,16-Quadrature Amplitude Modulation (QAM) modulator/demodulator and NCOs. Each of the modules was tested for their functionality by developing corresponding test benches. In order to achieve real time reconfigurability of the proposed architecture, the proposed approach is realized on FPGAs optimizing area, power and speed. Reconfigurability of the proposed approach is dependent upon user requirement. Hence the proposed approach can support future generation communication technologies that are based on MIMO-OFDM

Keywords: *OFDM, NCO, MIMO, QPSK, QAM, FPGA.*

1. Introduction

The increasing demand on wireless services, both for voice and data communications is a major motivational factor for developing MIMO-OFDM system. In particular the demand for multimedia services such as video-on-demand, downloading music and movies, video conferencing, etc, is expected to diversify services and increase the volume of data traffic. As a result, emerging wireless/mobile networks are those which can integrate voice and data services, opposed to traditional voice-oriented networks. It is necessary to clarify that this system works within a frequency limitation established by the FPGA. This means it will never be able to directly modify the value of the RF carrier frequency. However, a typical RF front-end with only one up-converter will be able to modify the RF carrier frequency to fit the transmission system requirements. The maximum RF that can be fed to the SPARTAN 3 FPGA board is 500 MHz. The number of subcarriers chosen was 64, with the bandwidth of each subcarrier as 7.8 MHz. Cyclic prefix chosen is 25% of the number of subcarriers used. Modulation schemes used are QPSK and 16-QAM. The data rate achieved is 100 Mbps.

1.1 MIMO

To multiply throughput of a radio link, innovative techniques, such as, multiple antennas (and multiple RF chains accordingly) at both the transmitter and the receiver, have been employed. These systems are termed as Multiple Input Multiple Output systems [5]. A MIMO system with similar count of antennas at both the transmitter and the receiver in a point-to-point link is able to multiply the system throughput linearly with every additional antenna. Figure 1.1 illustrates a 2x2 MIMO system which has the ability to double the throughput.

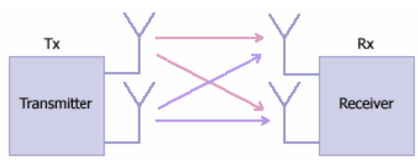


Figure 1.1 Multiple Input Multiple Outputs (MIMO 2x2)

A MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multi path scattering environment. MIMO systems may be implemented in a number of different ways to obtain either a diversity gain to combat signal fading, or to obtain a capacity gain.STBC is based on orthogonal design and obtains full diversity gain with low decoding complexity (Alamouti code is a special case with double Tx antennas). Space-time block coding (STBC) is a simple yet ingenious transmit diversity technique in MIMO technology.

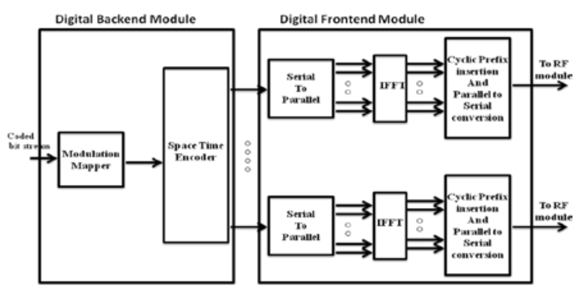
1.2 OFDM

OFDM is a multi-carrier technique that operates with specific orthogonally constraints between its sub-carriers[12]. This orthogonally yields very high spectral efficiency. Although the OFDM principle has been around 40 years, only the present technology level makes it feasible. OFDM allows the spectrum of each tone to overlap because they are orthogonal, and thus they do not interfere with each other. By allowing the tones to overlap, the overall amount of spectrum required is reduced.

The sinusoidal waveforms making up the tones in OFDM have the special property of being the only Eigen-functions of a linear channel. This special property prevents adjacent tones in OFDM systems from interfering with one another. To maintain the orthogonality in an OFDM system, a cyclic prefix is a critical concept.

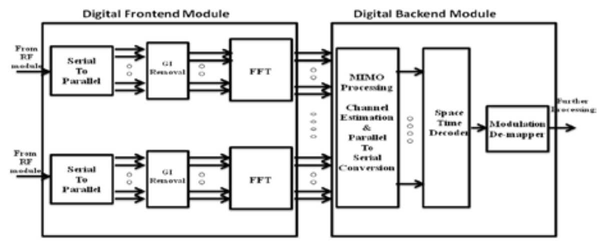
2. MIMO-OFDM

A MIMO-OFDM system [5] takes a data stream and splits it into N parallel data streams, each at a rate 1/N of the original rate, as depicted in fig 2.1 Each stream is then mapped to a tone at a unique frequency and combined together using the Inverse Fast Fourier Transform (IFFT) to yield the time-domain waveform to be transmitted.



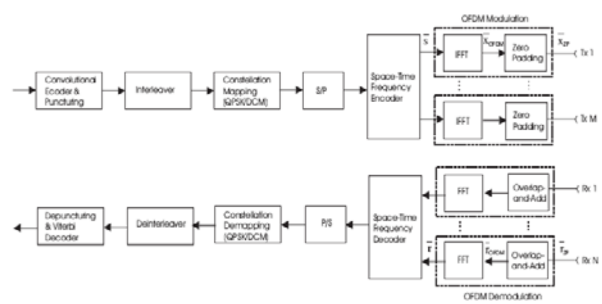
2.1 MIMO-OFDM transmitter section

The figure2.2 illustrates the digital module of receiver section of the MIMO-OFDM system. The OFDM signal is first de-serialized and then fed to the cyclic prefix removal system. After the cyclic prefix is attenuated from the OFDM signal, it is fed to the FFT section which de-maps the data from each of the subcarriers. This is then fed to the demodulator to recover the original data.



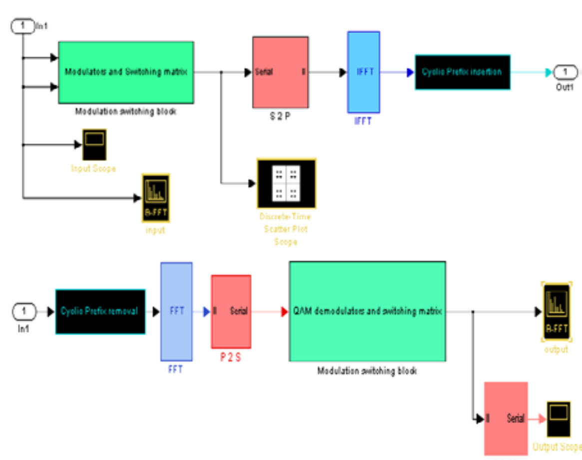
2.2 MIMO-OFDM Receiver section

Figure 2.3 shows the top level architecture of MIMO-OFDM, it consists of convolution encoder, interleaver, QPSK modulator, space time frequency encoder and OFDM modulation. The modified architecture proposed in this work consists of QPSK and QAM modulators that is run time reconfigurable depending upon the data rate and channel performance. Having both QPSK and QAM modulators achieves better performance for MIMO-OFDM modulators. The modulated data is space time-frequency encoded and is given to the OFDM modulator



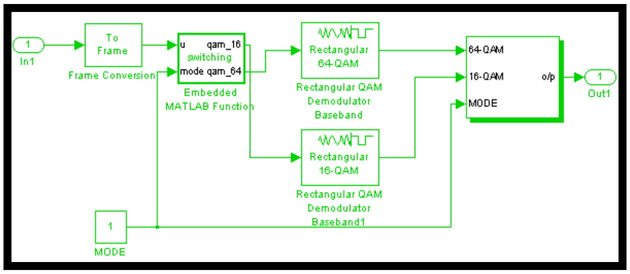
2.3 MIMO-OFDM Software reference model

Figure2.4 shows the Simulink model developed for MIMO-OFDM system. The developed model is as per the standard reference model reported in the literature.



2.4 Simulink model of MIMO-OFDM system

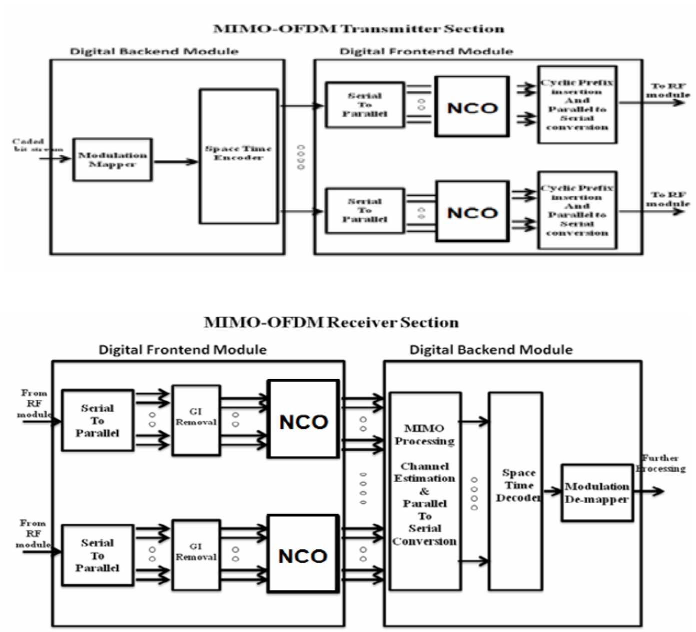
QAM modulator and demodulator is used to replace QPSK modulator and demodulator, QAM is used to enhance the data rate as well as reduce the bandwidth for signal transmission[8]. Figure2.5 shows the Simulink model of QAM modulator, in this work we have developed both 16 QAM and 64 QAM for modulation of data.



2.5 Simulink reconfigurable model of MIMO-OFDM system

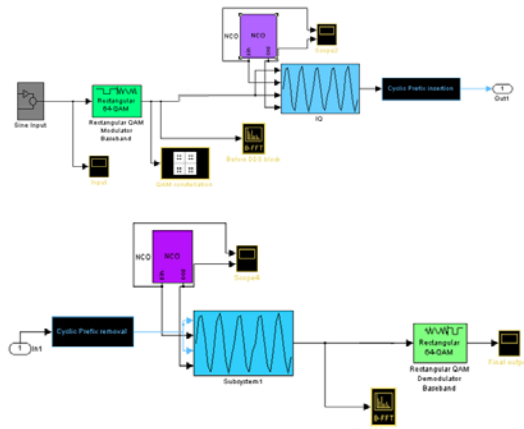
3. MODIFIED MIMO-OFDM

In order to enhance the performance of MIMO-OFDM, the FFT/IFFT blocks are replaced with NCO block. As the IFFT unit at the transmitter converts the incoming signal into multiple frequency band depending upon the phaseinformation, instead of IFFT, replacing with an NCO reduces the circuit complexity and also helps in achieving multiple frequency shifts. An NCO generates multiple frequency components based on corresponding phase information. Hence the modified system is more accurate than the existing architectures. The modified architecture is shown in figure 3.1 below



3.1 Modified MIMO-OFDM system

The modified architecture is modeled in Simulink and the results obtained based on an experimental setup for known sets of inputs are compared with the results of the software reference model. From the comparison of results it is found that the modified architecture achieves better accuracy and also more flexible. Figure 3.2 below shows the Simulink mode for modified MIMO-OFDM architecture.



3.2 Simulink model of modified MIMO-OFDM system

Table 1: Design specifications for OFDM model

Specifications	FFT-OFDM	NCO-OFDM
Maximum Input Frequency	100KHz	100KHz
Sample time	1/30000	1/30000
Modulation	64 QAM	64 QAM
FFT/IFFT size	256	-
Number of data points in look up table	-	17
Quarter wave sine look up table size	-	34 bytes
Spurious dynamic range	-	48dBc
Frequency resolution	-	30.5176 mHz
Channel	AWGN	AWGN
Channel SNR	60dB	60dB

4. DESIGN OF NCO

The NCO block generates a multichannel real or complex sinusoidal signal, with independent frequency and phase in each output channel. The amplitude of the created signal is always 1. The implementation of a numerically controlled oscillator (NCO) has two distinct parts. First, a phase accumulator accumulates the phase increment and adds in the phase offset. In this stage, an optional internal dither signal can also be added. The NCO output is then calculated by quantizing the results of the phase accumulator section and using them to select values from a lookup table. Given a desired output frequency F_0, calculate the value of the Phase increment block parameter with

Phase increment = $(F_0 . 2^N)/F_S$

where N is the accumulator word length and

$F_S = 1/T_S = 1/\text{Sample time}$

The frequency resolution of an NCO is defined by

$\Delta f = 1/(T_S . 2^N)$ **Hz**

Given a desired phase offset (in radians), calculate the **Phase offset** block parameter with

Phase offset = $(2^N .\text{desired phase offset})/2\prod$

The spurious free dynamic range (SFDR) is estimated as follows for a lookup table with entries, where P is the number of quantized accumulator bits:

SFDR = (6P) dB without dither
SFDR = (6P+12) dB with dither

This block uses a quarter-wave lookup table technique that stores table values from 0 to $\pi/2$. The block calculates other values on demand using the accumulator data type, then casts them into the output data type. This can lead to quantization effects at the range limits of a given data type. For example, consider a case where you would expect the value of the sine wave to be –1 at π. Because the lookup table value at that point must be calculated, the block might not yield exactly –1, depending on the precision of the accumulator and output data types. In this work the NCO designed can generate a maximum frequency of 49.9 MHz, which supports 64, 32 and 16 subcarrier applications. The 12-bit quantization along with the LUT of 4096 entries ensures a smoother sine and cosine oscillation generation. Figure 7 shows the NCO model designed. The 32-bit phase accumulator output is quantized to 12 bit output and is used to access the Contents of LUT. The LUT consists of sine and cosine data that is read out to generate the required signals for modulation.

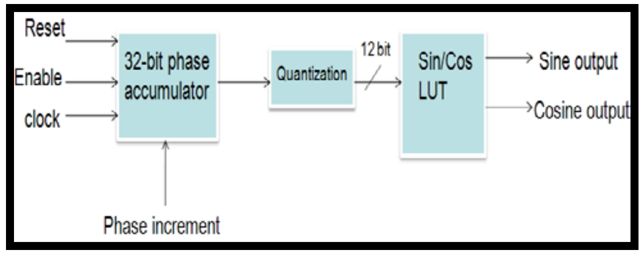


Figure: 4.1 NCO design

5. RESULTS

A sine wave input is applied as a test signal, the system developed is tested for its functionality, and results of the same are shown below.

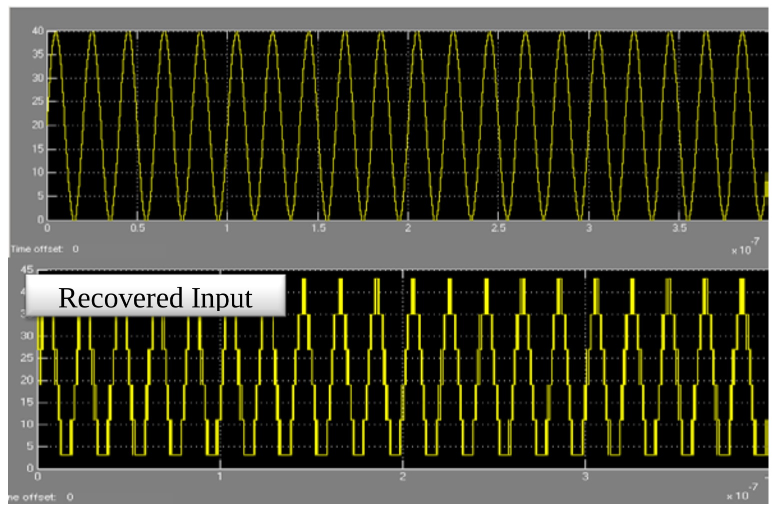


Fig 5.1 Simulation results of FFT based OFDM module

Figure shows the simulation results of OFDM with FFT and OFDM with NCO. The principle of orthogonality exists in the frequency spectrum shown below. The same set of orthogonality is also established in the NCO based OFDM module.

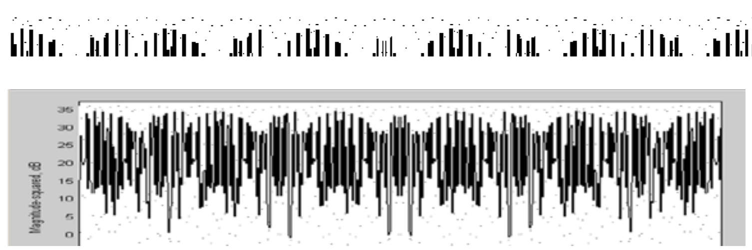


Fig 5.2: Simulation results of NCO based OFDM module.

Thus the proposed OFDM module using NCO achieves the same functionality as that of OFDM with FFT. Various test signals have been used to validate the developed modules. The results obtained are compared with the reference model. The simulink model developed is further modeled using Verilog HDL, the developed model is simulated using ModelSim and synthesized using Xilinx ISE for FPGA implementation. Spartan IIIE FPGA is targeted for implementation of modified architecture. The implementation results of modified architecture are compared with existing architecture and are presented in Table2 shown below.

Table 2: Comparison table of NCO with FFT/IFFT

Device Spartan 3 FPGA	Available resources	IFFT/ FFT	Utilization	NCO	Utilization
Slice Registers	19200	1231	6%	44	0.23 %
Slice LUTs	19200	971	5%	34	0.17 %
LUT-FF pairs	1289	913	70%	33	2.5%
Bonded IOBs	220	4	1%	83	37.7 %
Block RAM	32	0	0%	3	9.3%
Max. frequency		**372.75 MHz**		**469.39 MHz**	

5.1 Simulation results

System in QPSK mode

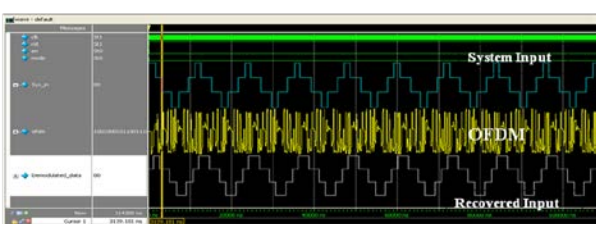


Fig 5.3 RTL Simulation of complete design in MODELSIM

System in QPSK mode switching to QAM mode

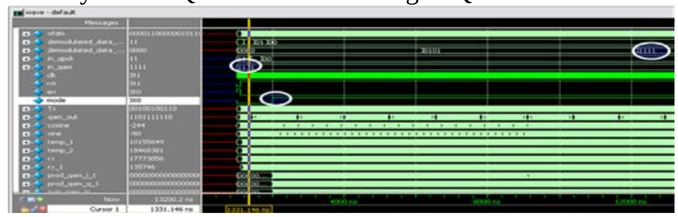


Fig 5.4 POST-SYNTHESIS Simulation of complete design in MODELSIM

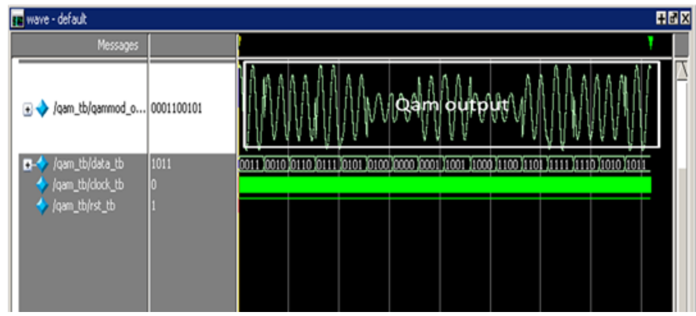


Fig 5.5 RTL Simulation of QAM in MODELSIM

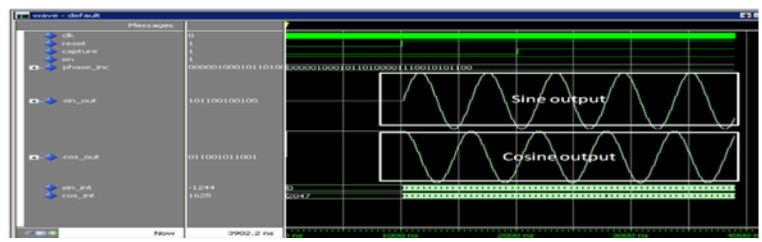


Fig 5.6 RTL Simulation of NCO in MODELSIM

System in QAM mode

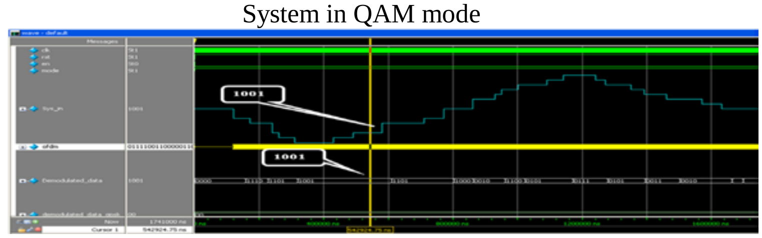


Fig 5.7 RTL Simulation of complete design in MODELSIM

6. CONCLUSIONS

The relevance of the MIMO-OFDM based systems is based on the fact that, these systems are immune to RF interferences, have high spectral efficiency, lower multipath distortion and support various modulation schemes for high data systems. The aforementioned facts suggest the Preference of FPGAs over ASIC implementation of the MIMO-OFDM system. The FPGA allows the rapid prototyping and implementation of the MIMO-OFDM system for its operational use. As the system evolves, the FPGA implementation provides the flexibility of reprogramability

The switching between the two modulation schemes, QPSK and 16-QAM, aids in re-configurability of the system, based on the channel characteristics ensuring least possible transmission errors. The NCO based design utilized just 30% of the available slice on SPARTAN 3 FPGA board, whereas the IFFT based design requires 103% of it. This is a 70% reduction in resource utilization. The maximum frequency achieved with NCO based was 25% higher than IFFT based design. The dynamic power of the NCO based architecture is 258.48 µW and leakage power at 20 µW, which is 10% lower than the IFFT, based design.

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