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Cognitive Radio's OFDM Window Management

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Abstract: ***Cognitive radio (to generate, transmit, receive and process of wireless signals) and a cognitive brain which learns from the environment and performs rational processes and predicts probable consequences and remembers past successes and failures. CR technology enables radio devices to use radio frequency spectrum in entirely and Sophisticated ways. CR is a novel concept that allows wireless systems to sense the environment, adapt, and learn from previous experience to improve the communication quality. Using Complex calculations cognitive radio can identify potential impairments to communications quality in their environment – interference, path loss, shadowing and multipath fading. CR radio designed to transmit information in the presence of incumbent users, deactivating subcarriers located in the vicinity of these users to avoid interference. OFDM is the prom sizing technique that enables efficient spectrum sharing and resource allocation. But the one of the problem in OFDM is out band emission or spectral leakage that makes interference among CR user and primary user. There are Novel Interaction Techniques to reduce it by window management with overlapping windows Techniques: tabbed windows, turning and peeling back windows, and snapping and zipping windows. In this project a novel two-step side lobe suppression technique for OFDM-based cognitive radios designed to minimize the amount of out-of-band emissions that could potentially interfere with incumbent licensed transmissions in adjacent frequency bands. This paper is done by using the technique as a model which combines both constellation expansion (CE) and cancellation subcarrier (CC) side lobe reduction approaches in order to achieve lower out- of-band interference levels relative to their individual application. The above said work is going to be implementing on Blade RFx40 SDR platform and the performance is going to be analyzed. BladeRFx40 is a Software Defined Radio (SDR) platform designed to enable a community of hobbyists and professionals to explore and experiment with the multidisciplinary facets of RF communication. It supports, 2x2 MIMO configurable with SMB cable, expandable up to 4x4, RF frequency range 300MHz - 3.8GHz, Stable Linux, Windows, Mac and GNU Radio software support, On-board 200MHz ARM9 with 512KB embedded SRAM (JTAG port available), On-board 15KLE or 115KLE Altera Cyclone 4 E FPGA (JTAG port available).***

Keywords: Cognitive Radio, OFDM, SDR, out-of-band interference, Blade RFX40 SDR, etc

1. Introduction

This paper provides an introduction to OFDM-based cognitive radio (CR) communications. OFDM modulation is well-suited for CR communications due to its ability for achieving high data rate and low inter symbol interference (ISI). However, OFDM uses sinc-type pulses to represent symbols transmitted over all the subcarriers per time constant. Consequently, large side lobes may occur that could potentially interfere with the signal transmissions of the neighbouring legacy systems or with the transmissions of other rental users. Several existing techniques which can be used to suppress high sidelobe are also introduced. The main objective of this research is to develop a number of performance enhancing techniques that are applicable to an OFDM-based cognitive radio system, including:

1.1 OFDM Sidelobe Suppression via Genetic Algorithm Optimization

OFDM OOB radiation may be a big interference with neighbouring transmissions. There exists a technique called cancellation carriers which can be used for OFDM side-lobe suppression. However, we do not know how good this technique works and how much improvement we can make for this cancellation carriers technique [1]. It is important to find an optimal solution.

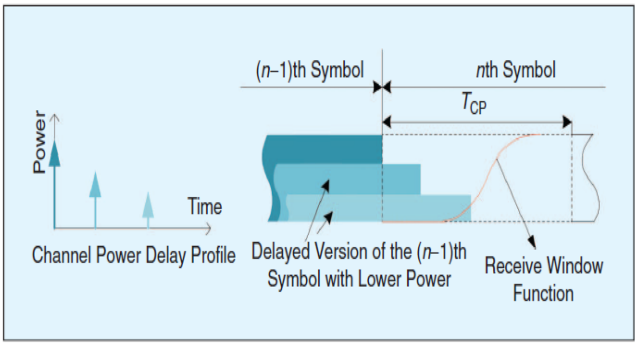

Figure 1: An illustration of ISI Contribution due to receive windowing

1.2 OFDM Sidelobe Suppression with Combined Modulated Filter Banks and Cancellation Carriers

Most OFDM sidelobe suppression techniques can only provide a reduction of about 15 dB, which is not enough. We must suppress the side lobes at least 60 dB to achieve a tolerable interference with neighbouring transmissions.

1.3 Unified Optimization for OfDM-Based Cognitive Radio Systems in Frequency Selective Fading Channel

Frequency selective channel will influence the performance of the system, including reducing signal to noise ratio, increasing bit error rate and reducing data throughput. In addition, as we talked before, out-of-band radiation is always a big problem which may interfere with the

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neighbouring transmissions. Therefore, we need to use different techniques to realize a unified optimization.

2. Block Diagram

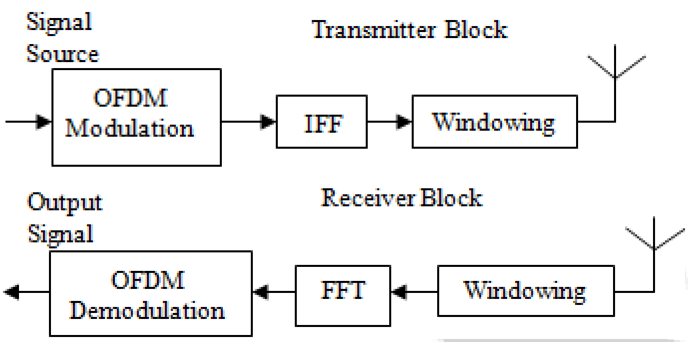
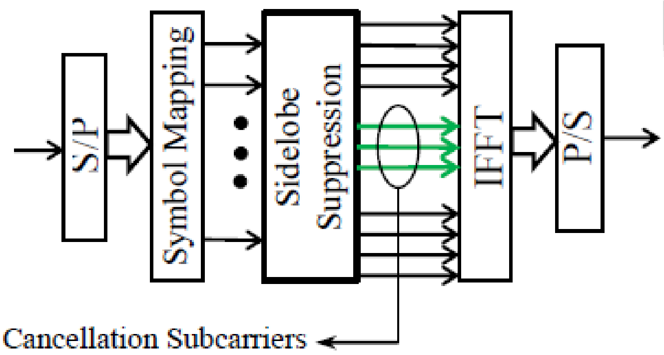


Figure 2: Main Block diagram - Transmitter and Receiver

3. Explanation of Main Block Diagram

OFDM is a multi-channel modulation system employing Frequency Division Multiplexing (FDM) of orthogonal sub-carriers, each modulating a low bit-rate digital stream. In older multi-channel systems using FDM, the total available bandwidth is divided into N *non-overlapping* frequency sub-channels. Each sub-channel is modulated with a separate symbol stream and the N sub-channels are frequency multiplexed [1]. Even though the prevention of spectral overlapping of sub-carriers reduces (or eliminates) Inter channel Interference, this leads to an inefficient use of spectrum. The guard bands on either side of each sub-channel are a waste of precious bandwidth.

To overcome the problem of bandwidth wastage, we can instead use N overlapping (but orthogonal) subcarriers, each carrying a baud rate of 1/T and spaced 1/T apart. Because of the frequency spacing selected, the sub-carriers are all mathematically orthogonal to each other. This permits the proper demodulation of the symbol streams without the requirement of non overlapping spectra. Another way of specifying the sub-carrier orthogonality condition is to require that each sub-carrier have exactly integer number of cycles in the interval T. It can be shown that the modulation of these orthogonal sub-carriers can be represented as an Inverse Fourier Transform.



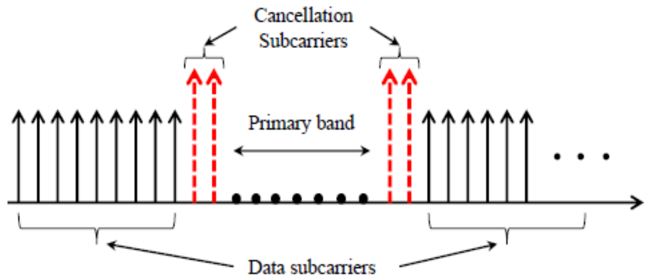


Figure 3: OFDM Cognitive transmitter for sidelobe Suppression

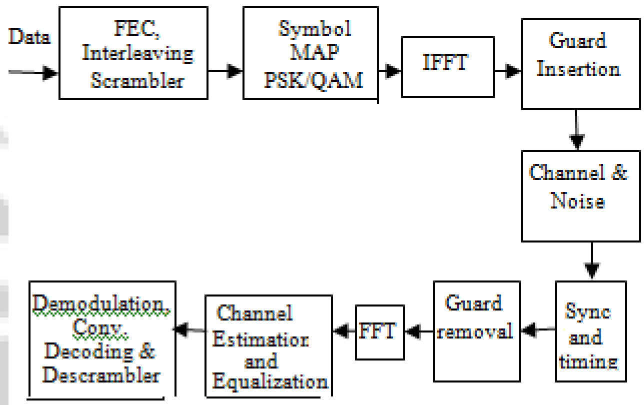
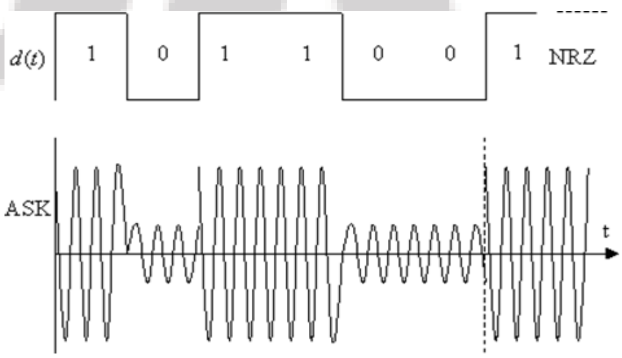


Figure 4: A generic OFDM transceiver

First, the *N* input complex symbols are padded with zeros to get *Ns* symbols that are used to calculate the IFFT. The output of the IFFT is the basic OFDM symbol. Based on the delay spread of the multi-path channel, a specific guard-time must be chosen Tg. A number of samples corresponding to this guard time must be taken from the beginning of the OFDM symbol and appended at the end of the symbol. Likewise, the same number of samples must be taken from the end of the OFDM symbol and must be inserted at the beginning [2]. The OFDM symbol must be multiplied with the Blackman window to remove the power of the out-of-band sub-carriers. The windowed OFDM symbol is then added to the output of the previous OFDM symbol with a delay of Tr, so that there is an overlap region of βTr between each symbol.

A. Modulation Types (Binary ASK, FSK & PSK)



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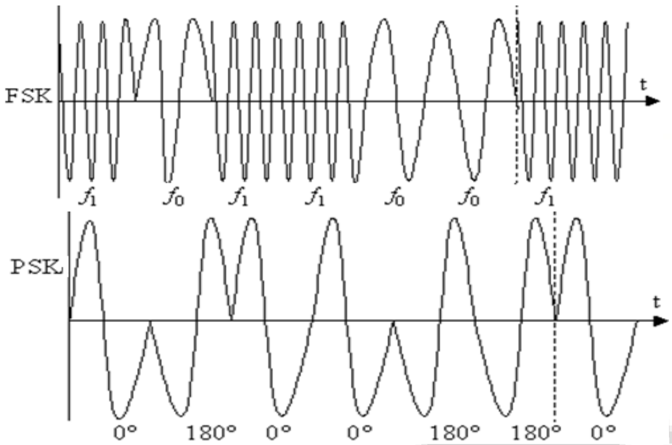

Figure 5: Modulation Types (Binary ASK, FSK & PSK)

The most common tools used to perform Fourier analysis and synthesis is called the fast Fourier transform (FFT) and the inverse fast Fourier transforms (IFFT). The FFT and IFFT are optimized (very fast) computer-based algorithms that perform a generalized mathematical process called the *discrete Fourier transform* (DFT). The DFT is the actual mathematical transformation that the data go through when converted from one domain to another (time to frequency). Basically, the DFT is just a slow version of the FFT—too slow for our impatient ears and brains.

FFTs, IFFTs, and DFTs became really important to a lot of disciplines when engineers figured out how to take samples quickly enough to generate enough data to re-create sound and other analog phenomena digitally. Remember, they don’t just work on sounds; they work on any continuous signal (images, radio waves, seismographic data, etc.)

B. Advantages of OFDM

OFDM possesses some inherent advantages for Wireless Communications. This section glances on few of the most important reasons on why OFDM is becoming more popular in the Wireless Industry today.

- Multi-path Delay Spread Tolerance.
- Effectiveness against Channel Distortion.
- Throughput Maximization (Transmission at Capacity).
- Robustness against Impulse Noise.
- Frequency Diversity.

4. System Model

A. OFDM Based Cognitive Radio System

Flexible pooling of the spectral resources is made possible by the cognitive radio (CR), an extension of software-defined radio (SDR), where the radio platform not only rapidly reconfigures its operating parameters and functions but also senses its environment, tracks changes, and reacts upon its findings [3]. A CR is an autonomous unit in a communications environment that can determines the appropriate transceiver parameters based on its interaction with the environment, to enable secondary utilization of the spectrum. In order to use the spectral resource most efficiently, the CR has to be aware of its location, be interference sensitive, comply with some communications etiquette, be fair against other users and keep its owner informed. In order to handle these tasks, a CR carries location sensors in order to determine its own location. It has to monitor its spectral environment, e.g. by employing a broadband fast Fourier transform (FFT). To track its location or the spectral environment's development, it has to use appropriate learning and reasoning algorithms. Most important, CRs should respect the rights of other spectrum users, especially incumbent license holders, i.e. it has to compromise its own demands with the demands of other users. In this way we can solve an important problem that makes the coexistence of legacy and rental systems a practical solution to the existing under-utilization of the radio spectrum.

A high speed data stream is split into N slower data streams using a serial-to-parallel (S/P) converter. In the presence of primary user transmissions, which are detected using dynamic spectrum access (DSA) and channel estimation techniques, the secondary OFDM user turns off the subcarriers in their vicinity resulting in a non-contiguous transmission. The inverse fast Fourier transform (IFFT) is then applied to these modulated signals. A cyclic prefix (CP) whose length is greater than the delay spread of the channel is inserted to mitigate the effects of the inter symbol interference (ISI)[4]. Following the parallel-to-serial (P/S) conversion, the baseband OFDM signal is passed through the transmitter's RF chain, to amplify the signal and up convert it to the desired frequency. At the receiver, the reverse operations are performed, namely, mixing the band pass signal to down convert it to a baseband signal, and then applying S/P conversion, discarding the CP and applying fast Fourier transform (FFT) to transform the time domain signal to frequency domain [4]. After performing channel equalization and P/S conversion, the symbol stream is demodulated to recover the original high-speed input signal.

B. Software Defined Ratio

The term software radio was first coined by Joseph Mitola in 1991 as a “class of reprogrammable or reconfigurable radios.” According to Dr. Jeffrey Reed, a professor at Virginia Tech and author of “Software Radio: A Modern Approach to Radio Engineering” (2002), a software radio is a flexible radio that can accommodate formats and protocols yet to be determined.

C. GNU Radio

GNU Radio2 is a free collection of signal processing blocks that can be used for RF real-time applications. GNU Radio can act as a stand-alone software package or as a backend to a hardware device. GNU Radio is written in both C++ and Python, and programs are compiled and run on most general purpose processors (GPP’s) and operating systems (e.g. Linux, Mac OSX, and Windows XP). Typically, the highest level of programming done in GNU Radio is written in Python (i.e. initialization and control for the signal processing components), and any time sensitive processing is done in C++. Currently, GNU Radio is the primary software platform supporting the drivers for the USRP on a personal computer [5]. The Blade RFx40 SDR software defined parameters (e.g. center frequency, PGA gain, interpolation factor, decimation factor, and some transmit and receive path multiplex options) can only be controlled using Python.

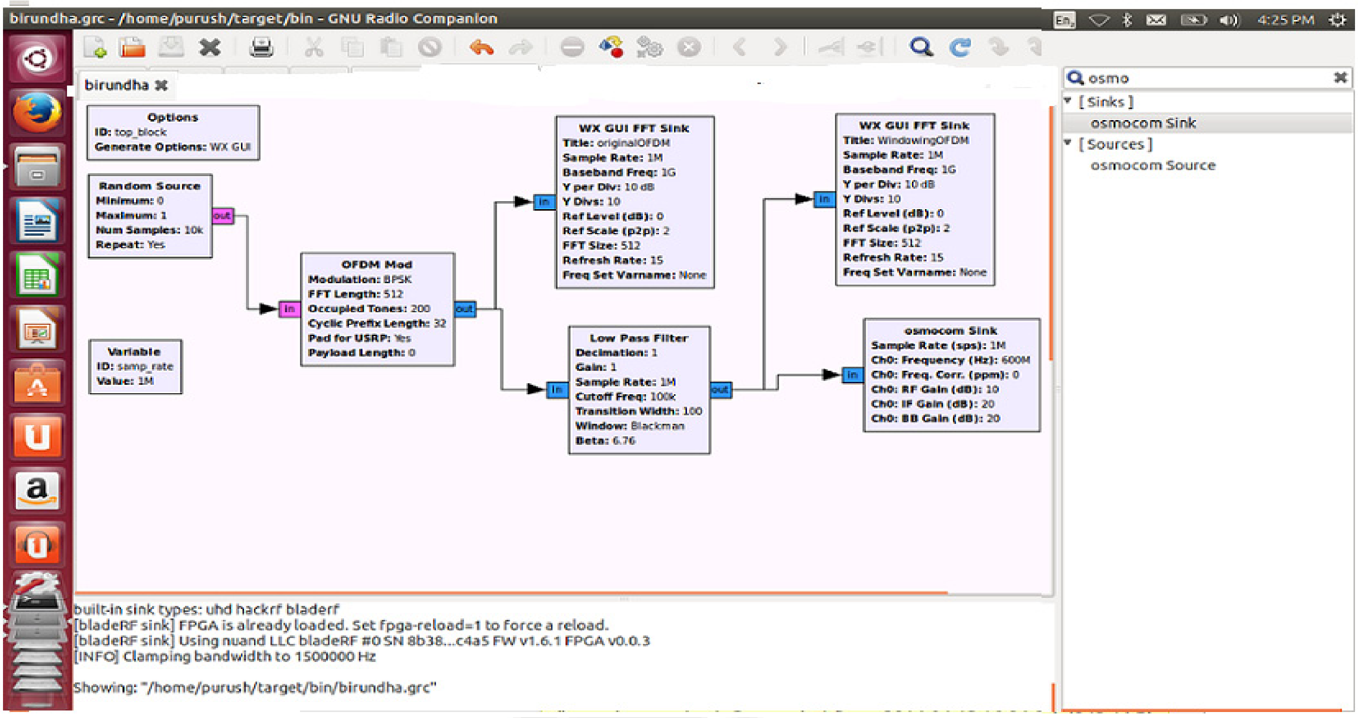

Figure 6: Transmitter Block executed in SDR Platform – Screenshot.

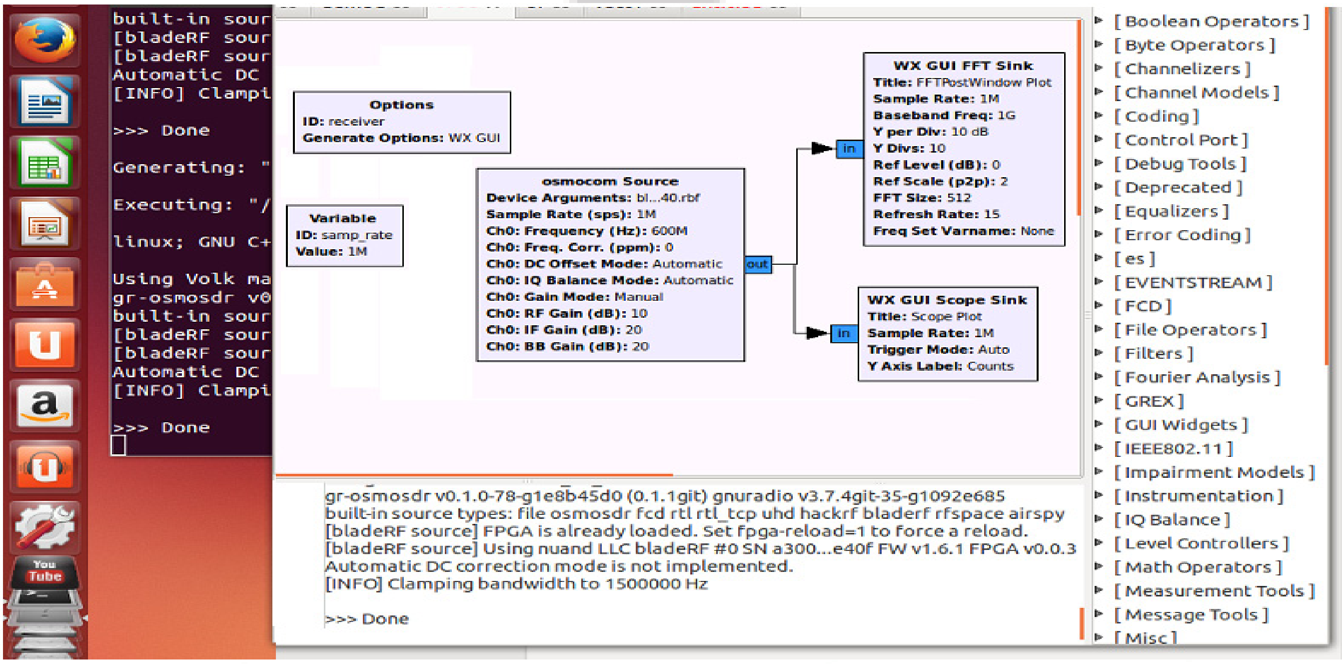

Figure 7: Receiver Block executed in SDR Platform – Screenshot

D. Blackman Windowing

The following equation defines the Blackman window of length *N*:

$$W(n) = 0.42 - 0.5\cos(2\pi n/(N-1)) + 0.08\cos(4\pi n/(N-1))$$

$$0 \le n \le M-1$$

Where M is $N/2$ for N even and $(N+1)/2$ for N odd. In the symmetric case, the second half of the Blackman window $M \le n \le N-1$ is obtained by flipping the first half around the midpoint. The symmetric option is the preferred method when using a Blackman window in FIR filter design [1].

The periodic Blackman window is constructed by extending the desired window length by one sample to $N+1$, constructing a symmetric window, and removing the last sample. The periodic version is the preferred method when using a Blackman window in spectral analysis because the discrete Fourier transform assumes periodic extension of the input vector.

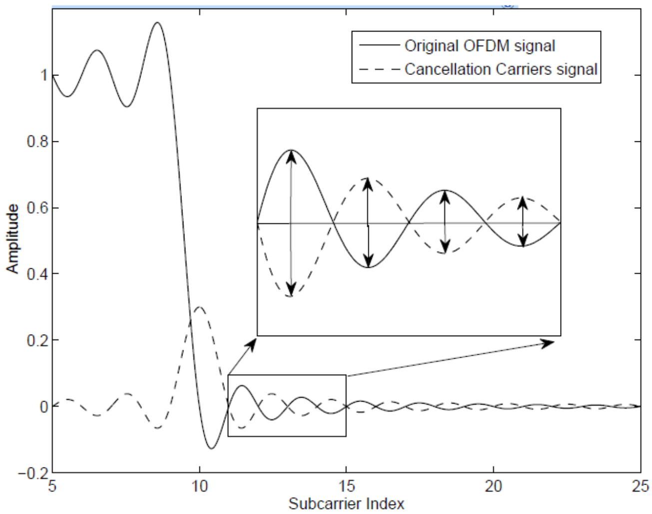

Figure 8: An illustration of the cancellation carrier's technique

Another well known technique is called transmit windowing. The sharp transitions between consecutive OFDM symbols cause significant OOB radiation. To smooth these transitions, the time domain signal can be multiplied with a windowing function. In contrast to the conventional rectangular window, the edges of the windowing function are less steep. As a result, the spectrum of each OFDM subcarriers has lower side lobes than the sinc-pulse obtained with conventional rectangular windowing. A raised cosine window is a commonly used window type with straight-forward implementation. The OFDM signal in time-domain with a raised cosine window in trapezoid shapes applied to it for the purpose of smoothing the transition. We can see that the postfix needs to be longer than βT to maintain the orthogonality within the OFDM signal. That is, the application of windowing to reduce the OOB radiation of the OFDM signal has the adverse effect of expanding the temporal symbol duration by $(1+\beta)$, resulting in a lowered system throughput for the unlicensed user.

Analysis has shown that the benefit of this windowing approach with respect to interference reduction is fairly low [6]. Nevertheless, windowing can be conveniently combined with any other sidelobe suppression technique as an additional means to suppress the high OOB radiation.

E. Hardware - BLADERF X40

The bladeRF x40 is a low-cost USB 3.0 Software Defined Radio. The 40KLE option makes the bladeRF the essential low-cost RF transceiver kit for both hobbyists, and RF enthusiasts.

Figure 9: Hardware – Blade RF x40

A. Kit Includes

- bladeRF x40 (40KLE Cyclone 4 FPGA)
- USB 3.0 SS cable
- 2x SMA cables

Out of the box the bladeRF can tune from 300MHz to 3.8GHz without the need for extra boards. The current open source drivers provide support for GNU Radio among other things, allowing the bladeRF to be placed into immediate use. This gives the bladeRF the flexibility to act as a custom RF modem, a GSM and LTE picocell, a GPS receiver, an ATSC transmitter or a combination Bluetooth/ WiFi client without the need for any expansion cards.

B. Technical Specifications

- Fully bus-powered USB 3.0 SuperSpeed Software Defined Radio
- Portable, handheld form factor: 5" by 3.5"
- Extensible gold plated RF SMA connectors
- 300MHz - 3.8GHz RF frequency range
- Independent RX/TX 12-bit 40MSPS quadrature sampling
- Capable of achieving full-duplex 28MHz channels
- 16-bit DAC factory calibrated 38.4MHz +/-1ppm VCTCXO
- On-board 200MHz ARM9 with 512KB embedded SRAM (JTAG port available)
- On-board 40KLE Altera Cyclone 4 E FPGA (JTAG port available)
- 2x2 MIMO configurable with SMB cable, expandable up to 4x4
- Modular expansion board design for adding GPIO, Ethernet, and 1PPS sync signal and expanding frequency range, and power limits
- DC power jack for running headless
- Highly efficient, low noise power architecture
- Stable Linux, Windows, Mac and GNU Radio software support.
- Hardware capable of operating as a spectrum analyzer, vector signal analyzer, and vector signal generator

5. OFDM Based Cognitive Radio System Using Blade RFX40 SDR Platform Block Diagram Transmitter and Receiver

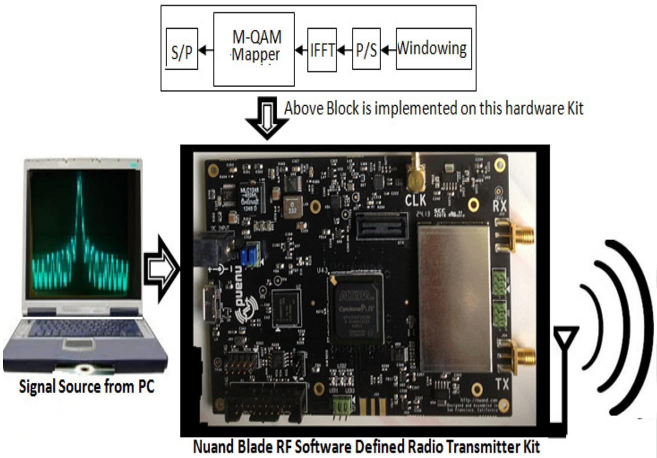

Figure 10: Picture of OFDM based Cognitive Radio system using Blade RFx40 SDR platform Block Diagram Transmitter

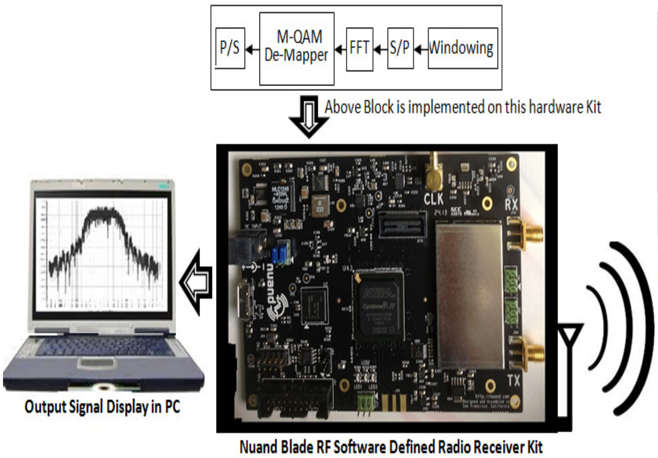

Figure 11: Picture of OFDM based Cognitive Radio system using Blade RFx40 SDR platform Block Diagram Receiver.

6. Results

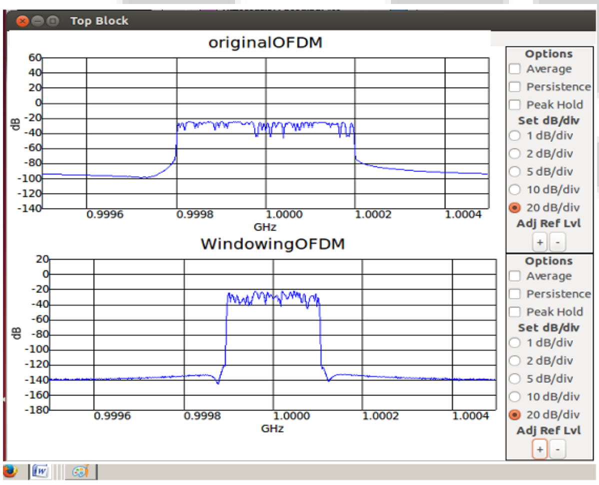

Figure 12: Picture of Simulation results – Transmitter

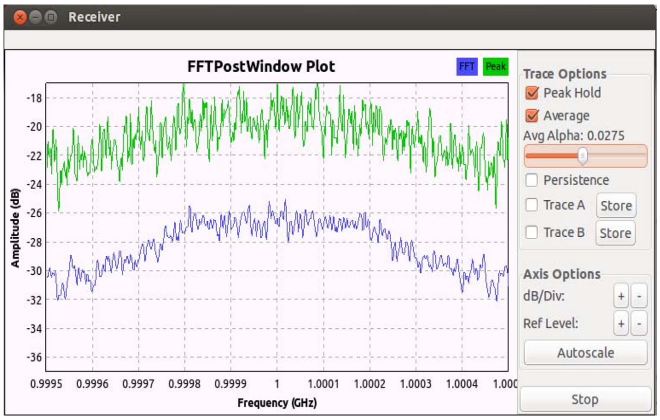

Figure 13: Picture of Simulation results – Receiver

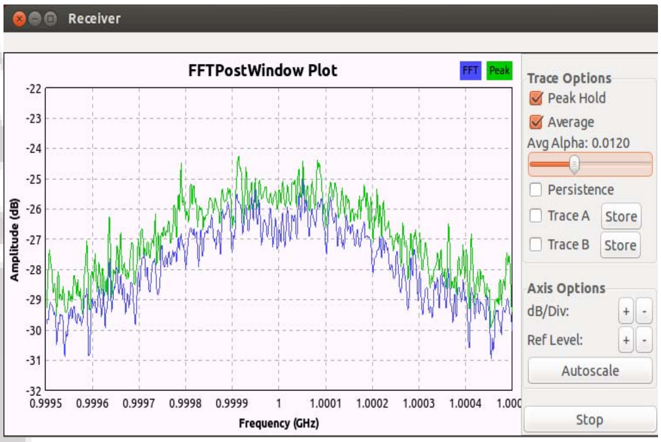

Figure 14: Picture of Simulation results – Receiver

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