# A method for decreasing the multipath interference in digital data transmission over wireless radio channels and its implementation on single chip microcontroller as a wireless data encoder

Boris Ribov

***Abstract:*** *Frequency division multiplexing (FDM) is a technology that transmits multiple signals simultaneously over a single transmission path, such as a cable or wireless system. Each signal travels within its own unique frequency range (carrier), which is modulated by the data (text, voice, video, etc.). For multimedia implementations, consider the more efficient and robust OFDM (orthogonal frequency division multiplexing). OFDM, sometimes referred to as multi-carrier or discrete multi-tone modulation, utilizes multiple sub-carriers to transport information in from one particular user to another. In this publication we present a digital OFDM wireless encoder based on single chip microcontroller. The benefits of OFDM are high spectral efficiency, resiliency to RF interference, and lower multi-path distortion. The orthogonal nature of OFDM allows sub-channels to overlap, having a positive affect on spectral efficiency.*

***Key words:*** *OFDM, DSSS, CCK, Spread Spectrum, RF transmission encoder, IEEE 802.11*

## INTRODUCTION

Orthogonal FDM's (OFDM) spread spectrum technique distributes the data over a large number of carriers that are spaced apart at precise frequencies. This spacing provides the "orthogonality" in this technique, which prevents the demodulators from seeing frequencies other than their own. The benefits of OFDM [5] are high spectral efficiency, resiliency to RF interference, and lower multi-path distortion. This is useful because in a typical terrestrial broadcasting scenario there are multipath-channels (i.e. the transmitted signal arrives at the receiver using various paths of different length). Since multiple versions of the signal interfere with each other (inter symbol interference - ISI) it becomes very hard to extract the original information.

OFDM exhibits lower multi-path distortion (delay spread) due to sending the high-speed composite's "sub-signals" at lower data rates. Because of the lower data rate transmissions, multi-path-based delays are not nearly as significant as they would be with a single channel high rate system. For example, a narrowband signal sent at a high rate over a single channel would likely experience greater negative effects from delay spread because the transmitted symbols are closer together. In fact, the information content of a narrowband signal can be completely lost at the receiver if the multi-path distortion causes the frequency response to have a null at the transmission frequency. The use of the multi-carrier OFDM significantly reduces this problem.

There exist other techniques applicable for transmission in multipath environments based on a single carrier. One of them is CCK [4]. In the CCK there is no information redundancy in the output stream but some of the methods are based on adding additional information to the output stream. DSSS [3] has better multipath performance than the traditional digital transmission over wireless channels. DSSS is based on the autocorrelation functions. It is a spread spectrum method and the speed of the output stream is higher than the speed of the effective data.


**FIGURE 1. Single carrier system**

OFDM was first implemented by using banks of sinusoidal generators, so basically just placing up a whole lot of single carriers in parallel. (See FIGURE 1, FIGURE 2). The use of the discrete Fourier transform (DFT) was first suggested in 1971 by Weinstein and Ebert, which significantly reduce the implementation complexity of OFDM modems. This was further reduced by the introduction of the Fast Fourier Transform (FFT). After this an equalisation algorithm was suggested in order to suppress both ISI and inter-subcarrier-interference caused by the channel impulse response or timing and frequency errors.

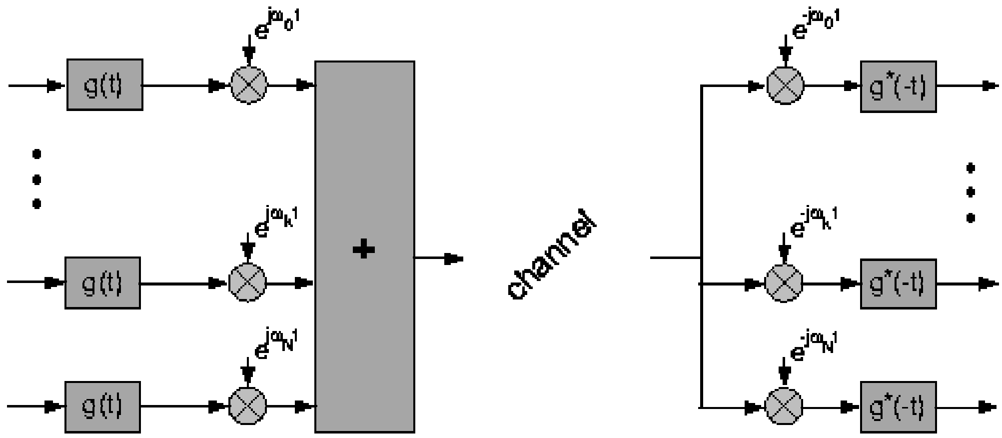
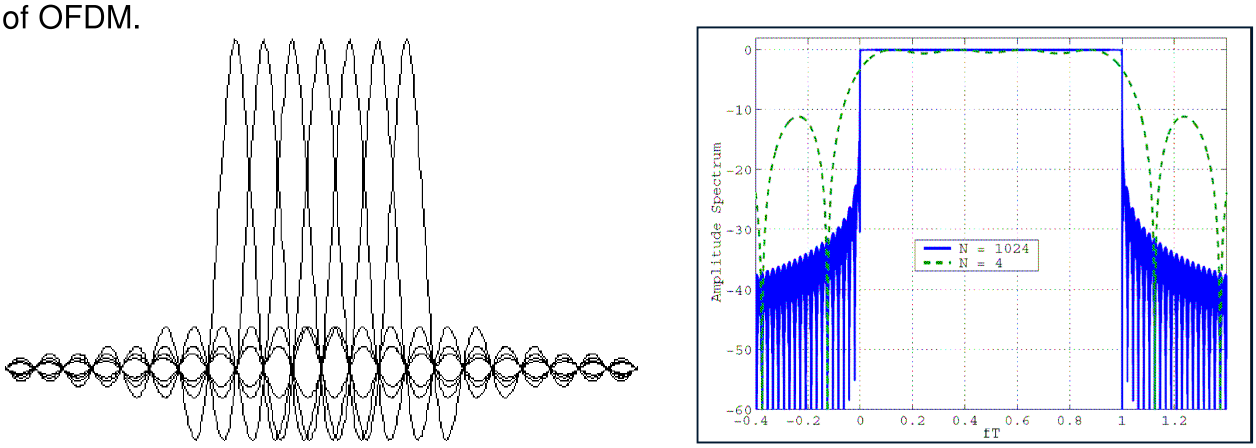



**FIGURE 2. Multi Carrier System**

**PRINCIPLE**

In OFDM the sub-carrier pulse used for transmission is chosen to be rectangular. This is why the task of pulse forming and modulation can be performed by a (IDFT), which can be implemented very efficiently as a (IFFT). Accordingly in the receiver we only need a FFT to reverse this operation. According to the theorems of the Fourier Transform the rectangular pulse shape will lead to a sin(x)/x type of spectrum of the sub-carriers. In conventional FDM the sub-channels are not orthogonal therefore must be separated by guard bands, which wastes precious spectrum. In OFDM, by using an IFFT for modulation we implicitly chose the spacing of the sub-carriers in such a way that at the frequency where we evaluate the received signal all other signals are zero thus allowing the sub-channels to overlap (See FIGURE 3a). However For an OFDM system to work in this way, the receiver and the transmitter must be perfectly synchronized, and there should be no multipath fading, which sounds unusual since conquering this is one of the main goals of OFDM.




a) b)

**FIGURE 3. Sin(x)/x spectrum with orthogonality**

Fortunately there is a simple way to solve the latter problem. If we implement a guard interval larger than the expected delay spread by artificially prolonging the symbol time and then removing this extension at the receiver the problem is solved but with a slight loss in bandwidth.

**MATHEMATICAL MODEL**

In this publication we show a method for digital OFDM encoder different from traditional Inverse Fast Fourier Transformation (IFFT) to make OFDM channels. It is based on orthogonal matrices.

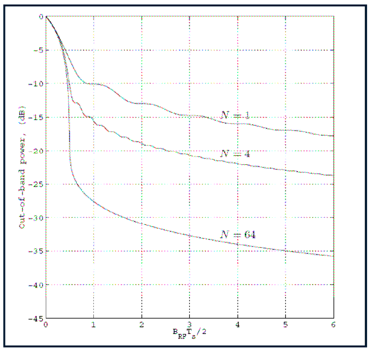
A square matrix A is called an orthogonal matrix if it is equal to the inverse of its transpose, i.e. if $A=(A^T)^{-1}$. If an orthogonal matrix is real, then it is also a normal matrix. Walsh codes are subset of orthogonal codes based on orthogonal matrix.

Walsh codes can be obtained performing simple operations as it is illustrated in Figure 4a. For the 2-ary case, taking a 2x2 matrix of 1s and inverting the lower right quadrant of the matrix form the basic symbols. To form the 4-ary case, take 4 of the 2x2 matrices and make a 4x4 matrix with the lower right hand quadrant again inverted. The procedure is repeated for the 8-ary case and beyond:

```
                          11 11 11 11
                          10 10 10 10
               11 11      11 00 11 00
1 1            10 10      10 01 10 01
1 0            11 00
               10 01      11 11 00 00
                          10 10 01 01
                          11 00 00 11
                          10 01 01 10

2              4          8
```

a)




b)

**FIGURE 4. Walsh matrix**

Walsh functions have a regular structure and at least one member that have a substantial DC bias. In this case it is the first row with all 1s. All the rest are half 1s and half 0s. The DC bias can be reduced on the worst member of the set by multiplying all members with a cover code. This, however, introduces a (smaller) bias in half of the members.

**ENCODER IMPLEMENTATION**

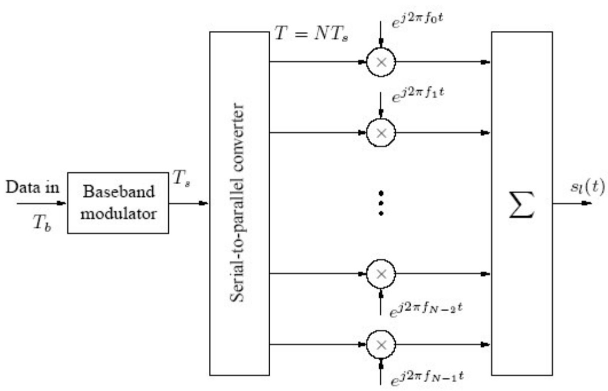



**FIGURE 5. ENCODER**

The OFDM encoder presented in this publication use 128 sub channels. Thus it uses Walsh code based on orthogonal matrix with dimension 128x128. The encoder splits input bit stream on a symbols of 128 bits. Every bit of the symbol acts as a data source for every individual channel. Thus we transmit 128 channels at the same time.

This encoder is low-cost but the main disadvantage is that the data throughput is limited by the microcontroller [7] speed. Some of the application required low-speed data stream over multipath environment. Typical example of that kind of applications is remote control unit for controlling SOHO (Small Office, Home use) devices. There exist low-cost methods for increasing the stability of the RCU protocol [2] but the OFDM is a contemporary method of approach to control SOHO devices remotely.

RCU uses typical multipath environment. So the use of OFDM is excusable for that kind of applications. Figure 6 shows the schematic diagram of the encoder. The use of PIC based microcontroller is forced by the low-cost of the microcontroller. For high-speed applications high-speed programmable logic devices can replace this microcontroller. This approach significant increases the bandwidth of the encoder.

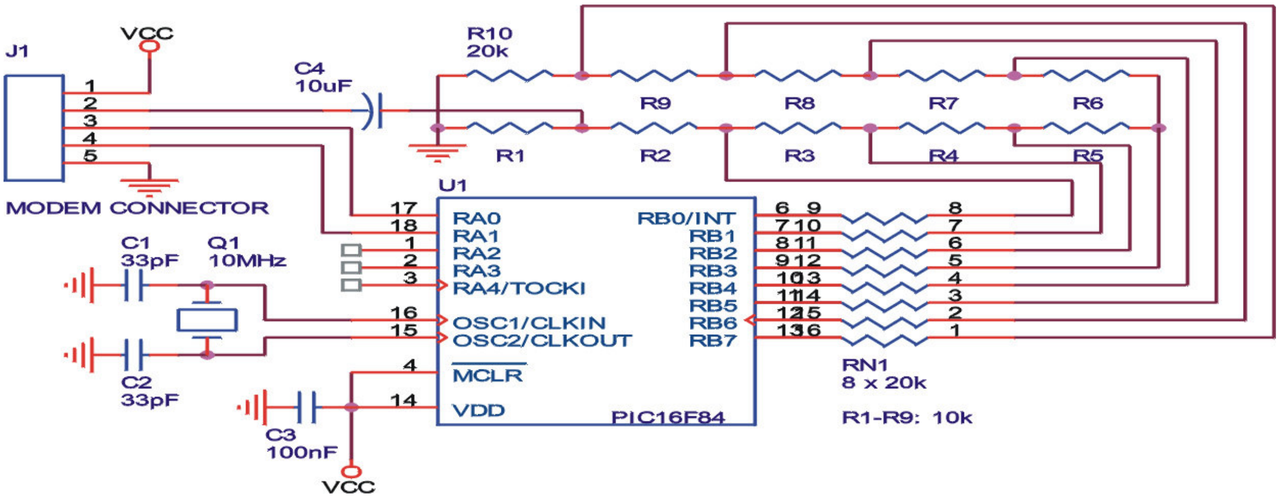



**FIGURE 6. Circuit diagram of the encoder**

We have a low-cost external DAC made with RN1 and R1-R10. The analogue output is DC filtered by C4. The value of C4 depends on input resistance of the up-converter. At the output of the encoder (pin 2 on J1) we have analogue baseband signal. Up-converter moves the spectrum of the baseband signal to the RF. Baseband spectrum depend on the transmission data rate. Input binary data feeds to synchronous interface. Pin 17 of the CPU is data input pin, while pin 18 is clock input.

The encoder works in slave mode. Clock signal is generated by external master device. The CPU waits to receive the whole data symbol (8 serial data bits) and buffer 16 symbols to generate 128 parallel one-bit serial sub-channels.

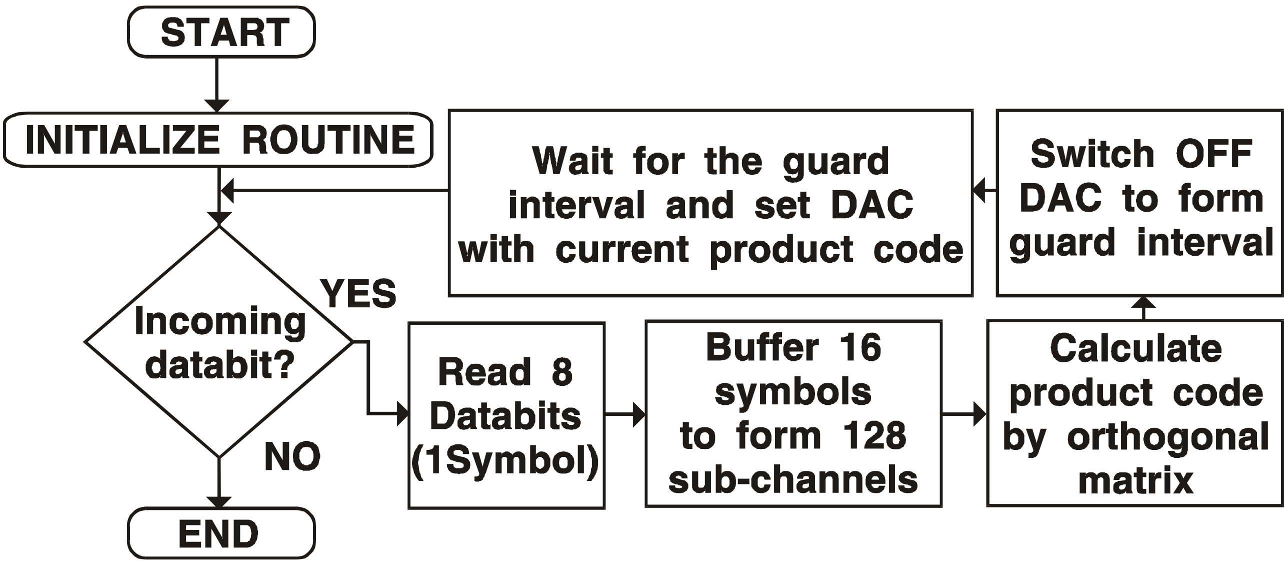


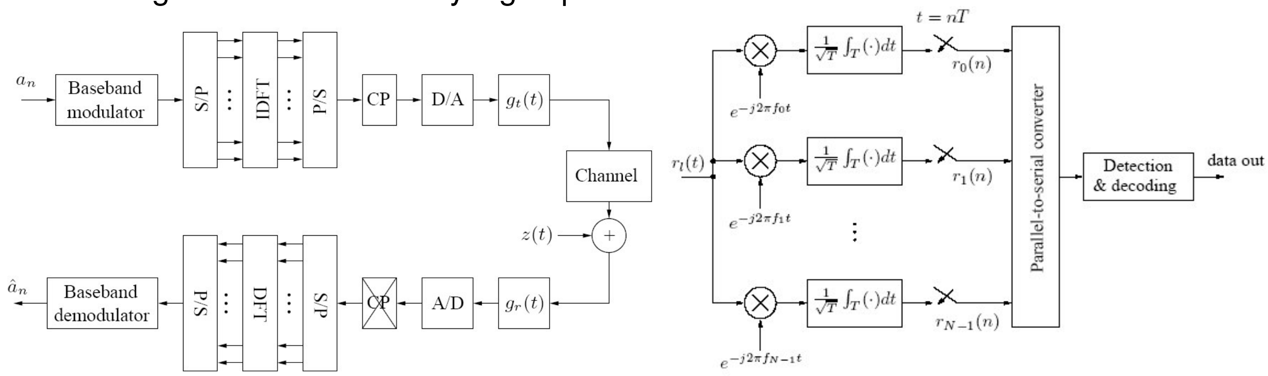

**FIGURE 7. Block diagram**

Figure 7 illustrates the block diagram of the encoder's program. After the initialisation subroutine the program expect to receive data from the master device. Incoming data forms an 8-bit symbol from incoming data bits. A portion of 16 symbols is required to form

128 parallel one-bit sub-channels. After forming the channels a subroutine calculates the overall product code by multiplexing the bit of every sub-channel with the value from the orthogonal code generator. Orthogonal code generator is performed with a dataset of an orthogonal matrix with dimension 128x128. The matrix is static and is stored in the ROM memory. All data bits from the parallel sub-channels are summed in one 8-bit register. This sum is the DAC's product code. A time delay subroutine makes the multipath guard protection. The process is finishing with scan for incoming data bit from the master device.

**RECEIVER**

In typical designs the receiver consist of a high-speed analogue-to-digital converter and DSP for the Fast Fourier Transformation (FFT) as shown on FIGURE 8a. Both ADC and DSP are costly parts of the front-end of the communication equipments. Also they have speed limits. Instead of the traditional design we can develop OFDM receiver based on high-speed flexible programmable logics (FPGA). That is illustrated on FIGURE 8b, where multiple phase detectors compares the input digital signal with each individual code calculated from the rows of orthogonal matrix. Simple filtering and parallel to serial converting will cover the whole process of the OFDM demodulation. That kind of approach allows using this structure in very high-speed communication flows.




a) b)

**FIGURE 8. Receiver structure**

**CONCLUSION AND FUTURE WORK**

Interferences in wireless communications are common problem. A research [1] shows that simultaneously work of Bluetooth and IEEE 802.11 [6] gives significant packet loss of the devices worked on IEEE 802.11. That is why DSSS and CCK modulations are not steady enough than GFSK used in Bluetooth. The alternative for reducing the multipath interference is OFDM technique. OFDM's high degree of spectral efficiency (Figure 3b), resiliency to interference and multi-path distortion, and existing inclusions in the leading higher rate wireless LAN standards, provides a strong based for the development of newer broadband wireless networks. The technology is certainly proven; however, the future unification of a single standard is causing some grief among those deciding which version of OFDM to implement in their products. In addition, the non-conformance to a single standard is hampering the benefits of economies of scale as companies utilize dissimilar components based on their chosen version of OFDM. Regardless, the future for OFDM is very bright as it gains significant momentum in the industry. In this publication we present the results from our test bench at figures 3b and 4b. Figure 3b illustrates spectrum as function of subcarriers (for 4 and 1024 subcarriers). Figure 4b shows out-of-band spectrum performance diagram based on a simulation of our model. Still there exist two major problems to solve: One of the problems with OFDM is that the signal has a high peak power compared with its average power. When an RF carrier is modulated with an OFDM signal it results in a similar variation in power of the carrier envelope. This results in the requirement that the signal is amplified and transmitted in a linear way.

Other significant problem with OFDM is its sensitivity to frequency offsets affecting the performance. The demodulation of an OFDM signal with an offset in the frequency can lead to a high bit error rate. This is caused by the loss of orthogonality between the subcarriers resulting in inter-carrier interference (ICI), and a lack of correction for phase rotation of the received data vectors. Frequency errors will tend to occur from two main sources. These are local oscillator errors and Doppler spread. Any difference between transmitter and receiver local oscillators will result in a frequency offset. This offset is usually compensated for by using frequency tracking, however any residual errors result in a degraded system performance.

Movement of the transmitter or receiver results in Doppler shift in the signal. This appears as a frequency offset for free space propagation. This offset is usually corrected for as part of the local oscillator compensation. A much more serious problem is that of Doppler spread, which is caused by movement of the transmitter or receiver in a multipath environment. Doppler spread is caused by the different relative velocity of each of the reflected multipath components, resulting in the signal being Frequency Modulated. This FM modulation on the subcarriers tends to be random due to the large number of multipath reflections that occur in typical environments. This Doppler spread is typically poorly compensated for and results in degradation of the signal.

In a mobile multi-user environment the problem is worse, as the transmission from each user can have a different frequency offset. Even if each user is synchronized to the base station perfectly, there will still be significant different frequency offsets for each user due to Doppler shift. Frequency offset in a single user OFDM link isn't a significant problem as it can be compensated for with minimal increased receiver complexity. However in a multi-user case there is no easy way of correcting the frequency errors.

Future work of this project is intended to investigate methods for compensating the frequency errors in multipath and mobile environment.

**REFERENCES**

[1] Grozev, D., Kakanakov, N., Spasov, G., Ribov, B., *"Investigation of interference between Bluetooth and wireless LAN working on 802.11"*, Scientific Session "Technics, Agrarian Sciences and Technologies", Plovdiv, Bulgaria, ISSN 1311-9192, pp.52-57, 2005

[2] Vasilev V. and Ribov B., *"Software state machine decoder for the infrared remote control units using Bi-phase coding scheme"*, 13th International Scientific and Applied Science Conference, *"ELECTRONICS ET'2004"*, Sozopol, September 22-24, Bulgaria, book 2, ISBN 954-438-446-4, pp.122-128, 2004

[3] Spasov, G.V. and Ribov, B.Y., *"Spread Spectrum for Wireless Systems using PIC based micro-controllers as a Spreader"*, 11th International Scientific and Applied Science Conference, *"ELECTRONICS ET'2002"*, Sozopol, September 25-27, Bulgaria, book 2, ISBN 954-438-327-1, pp.89-94, 2002

[4] Ribov, B.Y. and Spasov, G., "Complementary code keying with PIC based microcontrollers for the wireless radio communications", Rouse, Bulgaria, ACM Press, New York, NY, USA, ISBN 954-9641-33-3, pp. 66-70, 2003

[5] R.V. Nee and R. Prasad, "*OFDM Wireless Multimedia Communications",* Norwood, MA: Artech House, 2000

[6] Juha Heiskala, John Terry, "*OFDM Wireless LANs - A Theoretical and Practical Guide*", Sams Publishing, ISBN: 0-672-32157-2, 2002

[7] Microchip PIC16F8X Data Sheet, Microchip Technology Inc., 1998

**ABOUT THE AUTHOR**

Boris Ribov, LZ1BJR, Ph.D. student, Space Research Institute, Bulgarian Academy of Sciences, Phone: +359 887/261-866, E-mail: ribov@developer.bg