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Single & Multicarrier Daubechie Scaling Function Signals for Modulation of Digital Communication Signals

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Abstract— Digital modulation schemes use phase shifted sine wave segments to encode data symbols. Reception is based on phase detection. In this paper, a different scheme of encoding digital data using wavelet functions instead of sinusoidal waves is explained. We consider the use of Wavelet scaling functions of Daubechie (DB4 to DB24). They provide several clues for identification of the data symbol instead of just by one criterion viz., the phase of the carrier as in the PSK schemes. So, this method is found to be better in bit errors due to noise. Several schemes are developed, from 1 bit to 8 bits per symbol, using two to 16 wavelet based waveforms and additional amplitude and shift modulations, offering improved bit error ratio. It can also be proved mathematically to be superior to the normal sine modulation schemes. Further, the method has been extended to multi carrier modulation schemes similar to IEEE802.1x. Spectral method of demodulation has been tried and found successful in receiver decoding.

Index Terms— Minimum 7 keywords are mandatory, Keywords should closely reflect the topic and should optimally characterize the paper. Use about four key words or phrases in alphabetical order, separated by commas. Data Encoding, PSK Modem, Wavelet functions, Daubechie Wavelet, Multi- carrier modulation, Bit Errors.

1 INTRODUCTION

SINE wave based modulation methods are the only available techniques in digital communication today. The sine function is a continuous time function existing for all time. This is the essence of the Fourier method of treating any signal by such continuous sine waves of various frequencies and phases. The two properties of a sine wave have all been fully used up in digital modulation schemes. They are the magnitude, phase [1]. Multi carrier techniques make use of the same sine wave phase and amplitude variations with subcarrier modulation on multiple frequencies.

Wavelets are functions which are having compact support and possess similar expansion and reconstruction feasibleness like the Fourier series and its inverse [2]. There will be no discontinuities as the data bits are modulated and sent from time to time. We could use specific wavelet functions, one for each symbol pattern. The functionally specific nature of the signal preserves its functional property even with noise added. Amplitude and phase variations are not able to affect very much the decision of the received symbol data pattern. In this paper, we provide a scheme of encoding, not using pure sinusoidal carrier, but using standard mathematically defined Wavelet bases as the symbol carriers. Since these waves are well defined with many properties determining their shape and time course, they provide multiple clues to the assessment problem in solving ambiguous symbols received. Therefore, bit errors are definitely less. Further we have also shown how the scheme is easily realized for multi carrier modulation as well. We give some examples of hardware implementation using Xilinx Spartan 6 and fast ADC, DACs.

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2 DAUBECHIE WAVELET SCALING FUNCTIONS FOR SYMBOL ENCODING

Wavelets are expansions of time functions similar to the Fourier series, but have characteristics which make them suited for analysis of data through wavelet scales rather than frequencies [3]. In order to utilize waveforms for the symbol audio frequency carrier for encoding, it is necessary that the wavelet should satisfy the properties of standard wavelets, such as dilation and scaling. The Daubechies Series [4] wavelets are standard functions with mathematically defined functions, satisfying continuity and compact support. These waveforms can be identified mathematically by a computer algorithm perfectly and provide several criteria for their detection.

Wavelets have two associated waveforms, one of which is the scaling function and another is the wavelet function. The scaling function is more compact and is useful for modulation of symbols. The waveforms of some of the scaling functions are given in fig. 1 for four wavelets DB 4 to DB10. As with QPSK, we use one wavelet in the time slot for the symbol.

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For e.g., the two digital bits encoded will take values 00,01,10 and 11 and these are encoded as the four waves shown in fig.1. In this Daubechie method (DbSK), the probability of getting a wrong symbol instead of the correct symbol at any instant depends on the probability of nearness to the right symbol. The root mean square criterion of the autocorrelation function of the received symbol has the values which decrease from DB4 to DB32 monotonically. These values are stored by a priori calculations. The probability of the value deviating far from the right symbol's value depends on the noise. The integral of the probability function of this Gaussian random variable is a definite integral between the two fixed values only (such as between 82 and 115 for DB8 and DB10 ambiguity) and not from 0 to infinity as in the derivation of the QPSK bit error probability.

Mathematically, we can obtain values of the parameters distinguishing these waves, for instance, through their maxima and minima positions, zero crossings and their distances, rates of changes at zero crossings, ratios of peaks for successive peaks and troughs and in addition several other statistical parameters as RMS value of autocorrelation value, ratio of peak areas on positive to negative course and so on. Thus, if we use these wavelets as the symbols carrying the digital bits, it should provide a convenient method for assessment of the received data even in a highly noisy SNR environment on the RF channel.

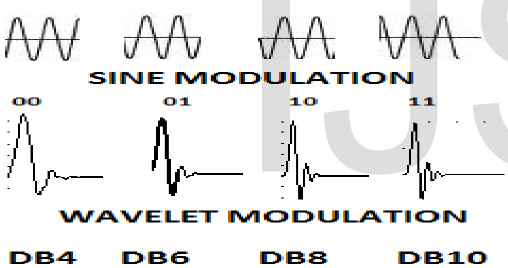

Fig.1. Comparison between existing sine wave QPSK modulation and proposed wavelet modulation

In the usual sine phase modulation method, there is one and only one parameter, viz., the phase which is used. The decoding of the signal at the receiver end is performed by correlating (i.e., by multiplication) with a reference sine signal. The product of two same frequency sine waves gives sum and difference frequency components. The product is integrated over a cycle of the wave and its mean found. This gives the Cosine of the phase φ. Thus it is known which symbol has been received in that time slot. While decoding, phase errors occur due to noise and phase shifts in the channel. For e.g., even in the 2 bit QPSK, the possible phase positions on an average noisy channel will look like in fig.2. The higher density modulation schemes like the 16QAM, 64QAM (fig.3) have very limited regions of phase and noise based variations usually resulting in symbols being erroneously decoded.

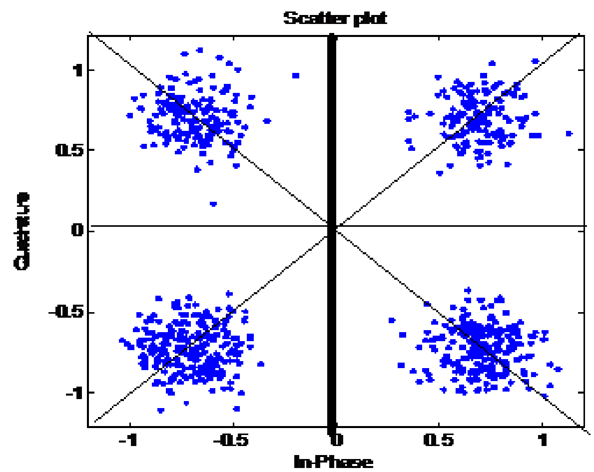

Fig.2 This is a QPSK data chunk plotted on a phase plot showing how the received data phase varies from the nominal value. If points are not easily allotted to a definite phase point, there will be symbol error.

For eg., the two bits per symbol modulation uses four DB scaling functions. The scaling functions possess a constant mean value. Since D.C. values cannot be transmitted, the mean value is subtracted from the function data and the zero mean functions are alone used for the encoding . The bit error graph appears in fig.4 which is much better than the standard sine modulation using QPSK. Further, the wavelet scaling functions are such that their correlation among themselves is zero, i.e., these waveforms are orthogonal, like sinusoids of integral multiple frequencies. That is an advantage because this reduces the errors due to multiple path reception, where time differences of the paths might cause inter-symbol interference (ISI).

3. The QPSK Standard Method and the Twin Bit Encoding Using Wavelet Scaling Functions

Most of the communication schemes employ the QPSK encoding in the standard sine modulation. With scaling functions, chosen among the range DB4 to DB16, with gaps in between, we can conveniently select four functions to match the four symbols in a quaternary scheme of modulation. If there is gap between the scaling functions chosen, such as DB4 for 00, DB8 for 01, DB12 for 10, DB16 for 11, there is good decoding criteria separation. Therefore the error performance of the same is superior to that of the standard QPSK.

In our scheme, as described in a later section, the possibilities of errors (fig.3) are much less in view of the better distinguishing features of the four waveforms in fig.1.

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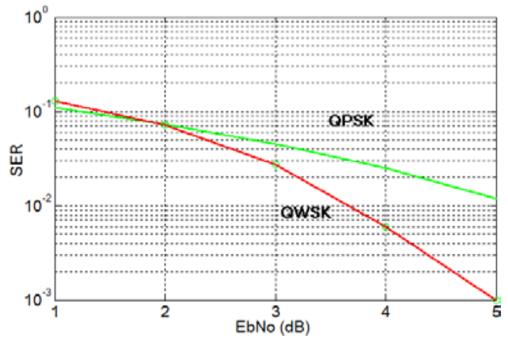

Fig.3. Showing the performance of the wavelet based scheme in symbol errors (SER) versus QPSK scheme with respect to Signal to noise level.

4. Reception of the Signal, Synchronisation of Symbols, Decoding Data

In this section, the received signal after transmission is considered for data retrieval by decoding the analog signal waveform obtained from the radio receiver. The radio receiver receives the high frequency signal which has the modulated data in it and through an usual intermediate frequency conversion stage, amplifies the signal and rectifies the amplitude modulated intermediate frequency to obtain the original baseband frequency signal. That signal will be the same as sent at the transmitter end except that noise and interference might have corrupted it en route.

The received signal at the baseband frequency range is to be processed only digitally and hence the same is converted to digital samples through an ADC which is clocked at the same rate as the original sample rate. If the original signal was as in fig.7, the received signal might appear due to noise as fig.8.

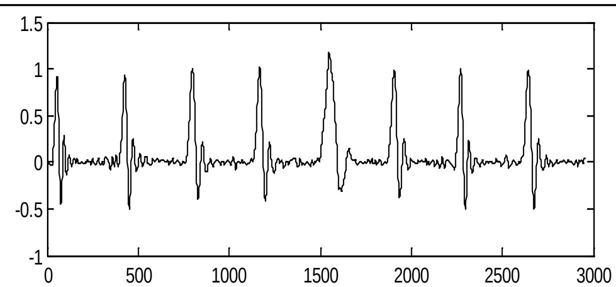

Fig.4 A set of eight data symbols encoded as scaling functions for a 2 bit encoding scheme.

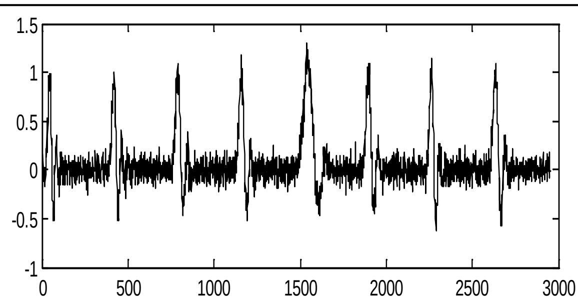

Fig.5. The same data as received and sampled by the receiver – demodulator ADC and plotted.

The same thing happens even in the usual sine modulation schemes. For example, a 16 QAM signal as transmitted and received with noise are shown in figs.6 and 7.

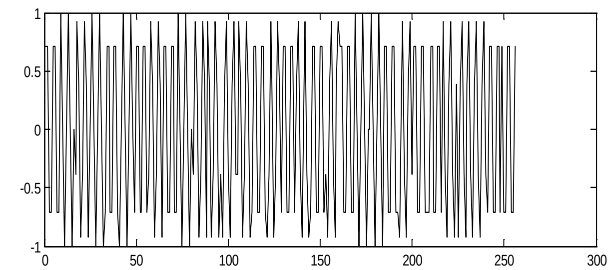

Fig.6 The data for eight symbols in a 16QAM sine modulation scheme

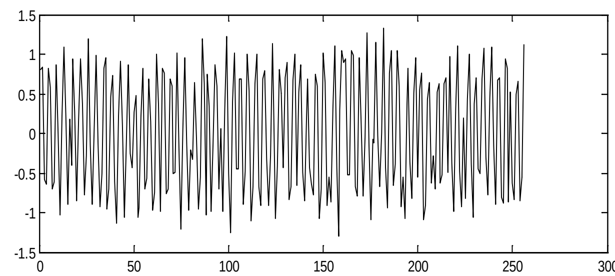

Fig.7 The noisy received signal with a small amount AWGN added.

In the sine modulated method, the decoding of the signal at the receiver end is performed by correlating (i.e., by multiplication) with a reference sine signal.

The product of two same frequency sine waves gives sum and difference frequency components. The product is integrated over a cycle of the wave and its mean found. This gives the Cosine of the phase φ. Thus it is known which symbol has been received in that time slot. When using more than one frequency for the carrier, the product integrated and averaged will give a zero result.

If we multiply by a sine waveform and also by a cosine waveform, we get two results after integration and averaging, which are called as the in-phase and quadrature signals, viz., I (In-phase) and Q (Quadrature). The above multiplication and averaging is also possible by a cross correlation of the signal received with the reference sine or cosine wave.

V Multi Carrier Modulation

For multicarrier schemes, the N-subcarriers are demodulated with thesimilar functions and the total time signal for one time slot obtained. Because the subcarriers are spaced with Δf = N/T,, the subcarriers are orthogonal to each other and eliminate ISI. In addition, the modulating wavelet based scaling function waveforms are themselves orthogonal.

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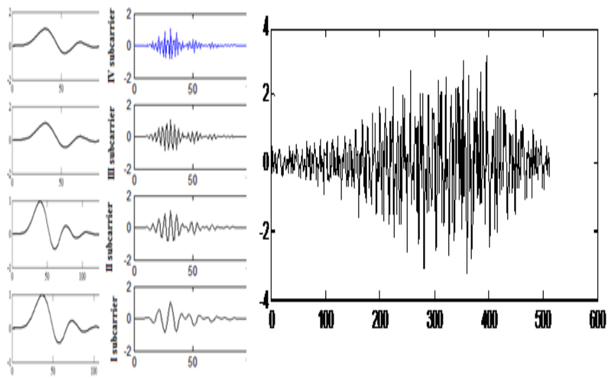

i) Encoded wavelets ii) Modulated on Subcarriers

iii) Total MCM signal in one symbol time.

Fig. 8. Showing the subcarriers (1 -4) modulated by a wavelet scaling function

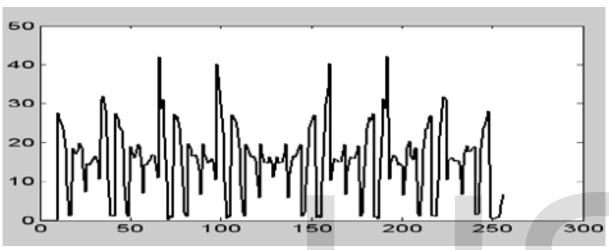

Fig.9.When we add the spectra of all the subcarriers, we get this total spectrum of the symbol time signal

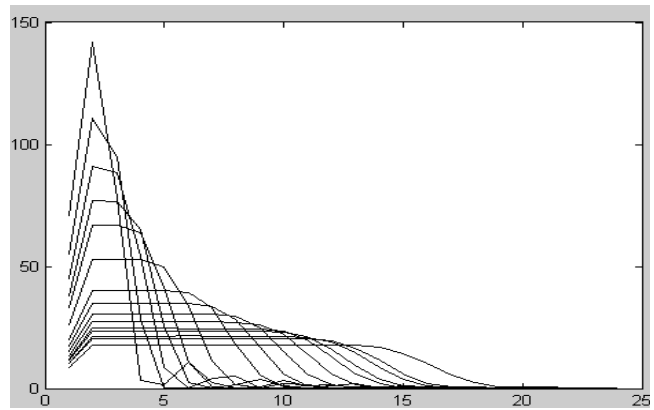

Fig. 10 Shows the encoding waveforms' spectra (showing the first significant part of 20 samples.

It is seen that at the bottom of these waves, the higher end DB signals have very small differences in their peaks. But their bandwidth increases upto 18 samples.

Thus, there may be some difficulty in decision of received signal from the spectral peak if much noise adds to the spectrum.

So, when we use the top four spectra, and just use four wavelets for encoding, we get much better results with noise.

Then, we can use four wavelets, with shifted and sign reversed versions to yield totally four data bits for one symbol per carrier. Since the four upper wavelets (i.e., in fig.10) are for db4 to db10, there samples can also be confined to much less sample space. Thus, instead of usign a 512 sample space, we can use just 256 and even 128 sample space. Sending 4 bits at 128 samples or 7 bits at 256 samples makes not much difference in the data rate.

The method for detecting the shifted and sign reversed versions of the waves has also been dealt with using the spectral segment of the subcarrier itself.

6. Spectral Decoding

Now it appears to us that the process of the inverse fourier transform of all the 15 subcarrier spectra may be somewhat laborious. In fact, in the IEEE 802.15 and all, they do not retrieve the phase shift (and amplitude modulated) time signals and then decode the data. They simply compare the spectral co-efficients at the several freqeuncy spaces and by a plot of the phase in Argand diagram (complex plot), they decide the symbol.

Here too, that method could be adopted. We have separately found the several spectra for each of the 15 subcarriers. Fig.10 shows it for the subcarrier 1.

If we compare this spectrum with the spectrum of all the DB waveform spectra we used for encoding the symbols, (0 to 15), then we can find out which is which. For that two criteria can be adopted.

One criteria is the peak of the spectrum. Another is its bandwidth.

When we plot the spectra of the several wavelets used, we will get an idea of how the peaks start diminishing little by little and the bandwidth increases little by little.

7. Implementing with low level FPGA

A simulation with added white Gaussian noise was demodulated by separating the subcarriers and found to be reliable. Both the single carrier and multi carrier schemes were also tested in the baseband signal by communicating between two computers using the sound card for the modulated audio signal. For higher frequency sampling rates, a SPARTAN 6 with high speed ADC and DAC was programmed with MATLAB using the "system Generator" linking Simulink Code with Verilog Code downloaded into the FPGA. A 2.5GHz R.F. Transceiver attached to the DAC output from the FPGA. The received signal demodulated by this module was taken through the ADC input of the FPGA board and processed to decode the data.

The Spartan 3E kit is one usually available in laboratories of institutions.

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VLSI Implementation and Design of Digital Modulation Using Xilinx has been investigated by many; Sareka Jeevane Dowrla, K. Jhansi Ranihave [4] designed 16-bit digital sine wave with required frequency and phase shifts for PSK modulation.

Anton S. Rodriguez, Michael C. Mensinger, Jr from Bradley University, Peoria IL using the Simulink tool, [5] have implemented QPSK modulation on the Virtex-II Field rogrammable Gate Array (FPGA) development kit. They state that in the QPSK application, the multi-path and relative motion between the transmitter and receiver cause amplitude attenuation, Doppler frequency shift, and phase shift in the constellation data points, as seen in Fig.4.1. The Doppler frequency shift and coarse carrier synchronization cause the QPSK constellation to rotate and thus, decoding of the data is a real challenge. In order to lock onto the correct QPSK constellation and correctly recover the transmitted data, coarse and fine carrier synchronization is required.

An example of the development of the program for WSK_2bit (similar to QPSK) in System Generator is shown in fig.11.

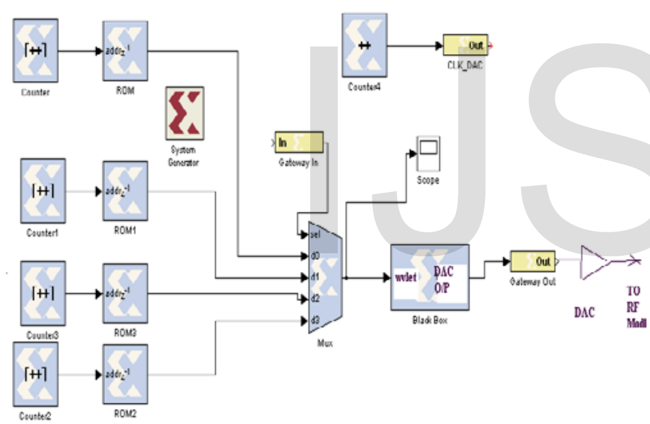

Fig.11 QWSK Modulator for FPGA in Simulink with ISE System Generator

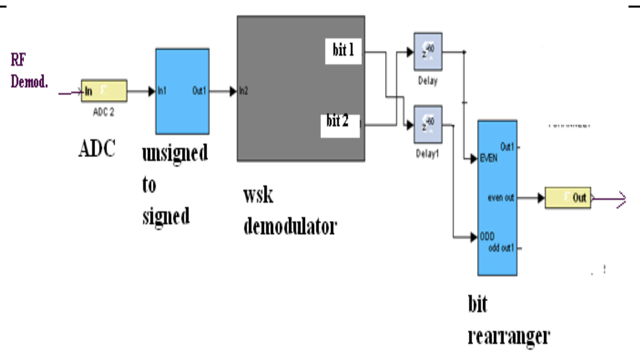

Fig.12. QWSK Demodulator for above

The demodulator version uses a separate black box m code version of the functions used for decoding, using the features of the wavelet patterns.

One advantage of our scheme over and above the reception simplicity is the absence of involved synchronization schemes. Synchronisation at symbol level is easy by looking up the DAC data and isolating the peak point of the first few samples of data, Since the sample rate at the receiver is same as that of transmitter, the symbols are then identified for every set of 256 samples. The data pattern in these 256 are used to determine which wavelet is received in a symbol time.

For multi carrier modulation and demodulation, spectral decoding is easy. It needs IFFT and FFT to be performed on transmitter and receiver. Though FFT programs for specific FPGA devices are available, they are huge and need high end devices. So, our realizations were limited to single carrier QPSK. In our studies, we could make use of an FPGA Spartan 6. This had an associated PROM for downloading code from the Xilinx System Manager. The FPGA has input output ports assigned from out of its several pins. The high speed Analog Devices ADC and TI's DAC are wired to 12 bit ports.

Inputs are assigned to pins to which serial interface and JTAG interface ICs are attached. Additionally, an USB interface is also attached. Thus, this system provides a convenient method for developing programs and downloading to the FPGA. The system also has an attached RF transmitter and receiver using two EV kits of Maxim 2830 chips. The unit was amenable for verification even at R.F. level.

8 Conclusion

The wavelet functions used for the symbols are such that the correlation of these functions among themselves is small. That is an advantage because that reduces the errors due to multiple path reception. Time differences of the paths cause inter-symbol interference. But the combination of the signals of different wavelet functions does not contribute to considerable errors because of the above reason. A simulation with added white Gaussian noise was demodulated by separating the subcarriers and found to be reliable. Both the single carrier and multi carrier schemes were also tested in the baseband signal by communicating between two computers using the sound card for the modulated audio signal. For higher frequency sampling rates, a SPARTAN 6 with high speed ADC and DAC was programmed with MATLAB using the "system Generator" linking Simulink Code with Verilog Code downloaded into the FPGA For multicarrier schemes, the simulation was done based on the addition of a white Gaussian noise to the received total time signal. The resulting separated time signals are able to differentiate between the several symbols. Thus noise performance on simulation was tested and found to be reliable.

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