

DESIGN AND IMPLEMENTATION OF SPREAD SPECTRUM ENCODER USING WALSH CODES

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Abstract:- The latest technology advancement in cellular mobile communication systems has become more demanding for better quality of service. It requires broad bandwidth for huge quanta of data transfer. CDMA communication system easily meets these requirements of cellular communications. To meet these requirements, the design of the relevant circuits is based on CDMA approach of direct sequence spread spectrum technology. This paper is in accordance with this increasingly important communication technology. The objective of paper is to design and implement Spread spectrum encoder using Walsh codes. Walsh codes are fixed length orthogonal codes possessing high auto correlation and low cross correlation properties. The spread spectrum encoder using Walsh code is designed in MATLAB and the same is implemented by carrying simulations using Field Programmable Gate Arrays (FPGA). The software program in Very High Speed Integrated Circuits Hardware Description Language (VHDL) on XILINX ISE is used for FPGA.

Index Terms:- Spread spectrum, CDMA, Orthogonal codes, Walsh codes, Channel bandwidth, Direct sequence Spread Spectrum, MATLAB, VHDL and FPGA.

I. Introduction

Spread-spectrum techniques are methods by which energy generated in a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference, jamming and to prevent detection. This is a technique in which a signal is transmitted on a bandwidth considerably larger than the frequency content of the original information.

The sequences which are used in CDMA should have the following properties:

- There should be a balance in the number of ones and zeroes.
- The autocorrelation must be a sharp two-valued function.
- The cross correlation must be as low as possible.

These code sets can be roughly divided into two classes: orthogonal codes and non-orthogonal codes. Walsh sequences fall in the first category, while the other group contains the so-called shift register sequences. Shift register sequences are not orthogonal, but they do have a narrow autocorrelation peak. These codes can be created using a shift register with feedback taps. Codes that can be found in practical Direct Sequence-systems are:

- Pseudo noise sequences (Maximal length sequences)
- Gold codes
- Walsh-Hadamard codes

- Barker codes
- Kasami codes etc.

II. Background

The task facing the designer of a digital communication system is that of providing a cost-effective system for transmitting information from a sender at a rate and a level of reliability acceptable to the user at the other end. The two key system parameters available to the designer are transmitted signal power and channel bandwidth. These two parameters, together with the power spectral density of receiver noise, determine the signal energy per bit-to-noise power spectral density ratio E_b/N_0 , which uniquely determines the bit error rate for a particular modulation scheme. Practical considerations place a limit on the value of E_b/N_0 . For a fixed E_b/N_0 , the only practical option available to change data quality from problematic to acceptable is to use coding.

Another practical motivation for the use of coding is to reduce the required E_b/N_0 for a fixed bit error rate. Coding accomplishes its purpose through the deliberate introduction of redundancy into messages. This enables the detection of the occurrence of an error, and sometimes even its correction. Coding has the usefulness that it allows us to increase the rate at which information may be transmitted over a channel while maintaining a fixed error rate. Alternatively, coding allows us to reduce the information bit error rate while maintaining a fixed transmission rate. More generally, coding allows us, in principle (up to the Shannon limit) to design a communication system in which both information bit rate and error rate are independently and arbitrarily specified but subject to a constraint on bandwidth.

Ideally, with ingenious enough coding and unlimited complexity we would be able to reach the Shannon limit. One measure of the efficiency of a code is precisely the extent to which it allows us to approach the Shannon limit. Error control for data integrity may be exercised by means of forward error correction. The channel encoder accepts message bits and adds redundancy according to a prescribed rule, thereby producing encoded data at a higher bit rate. The channel decoder exploits the redundancy to decide which message bit was actually transmitted.

The combined goal of the channel encoder and decoder is to minimize the effect of channel noise. The addition of redundancy in the coded messages implies the need for increased transmission bandwidth. Moreover, the use of coding adds complexity to the system, especially for the implementation of decoding operations in the receiver.

III Walsh Codes

The Walsh code is used to uniquely define individual communication channels. Walsh codes are mathematically orthogonal codes. These codes are also called as Walsh-Hadamard code as they are generated using Hadamard matrices. As such, if two Walsh codes are correlated, the result is intelligible only if these two codes are the same. As a result, a Walsh-encoded signal appears as random noise to a CDMA capable mobile terminal, unless that terminal uses the same code as the one used to encode the incoming signal.

Walsh codes are fixed length orthogonal codes possessing high auto correlation and low cross correlation properties. Walsh codes are linear phase and zero mean with unique number of zero crossings for each sequence within the set. Walsh codes are commonly used as spreading sequences in Direct Sequence Spread Spectrum (DS-SS) communications. These codes are the backbone of CDMA systems and are used to develop the individual channels in CDMA. Channelization by means of code multiplexing is a fundamental feature of advanced systems. In particular, channelization is accomplished using length-32 or more Walsh codes, which are assigned to different channels. Walsh codes can be generated recursively and indexed according to their row number in the M by M Walsh matrix. Their popularity is due to the ease of implementation. Among the former techniques for the generation of Walsh codes the popular method is based on the simple iterative scheme from the Hadamard matrices. The Walsh code is a linear code that maps binary strings of length n to binary codewords of length $2n$. Walsh codes can be produced from Hadamard matrices of orders which are a power of 2. The rows of the matrix having order $2N$ constitute the Walsh codes which encodes N bit sequences. As Walsh codes are linear codes, there exist a generator or a transformation matrix for the same.

As the Walsh codes are mutually orthogonal error correcting codes, they are widely used in multi-user CDMA communications. Walsh code is a group of spreading codes having good autocorrelation properties and poor cross-correlation properties. They have many interesting mathematical properties and vital applications in communication systems. These codes are defined as a set of N codes, denoted W_j , for $j = 0, 1, \dots, N - 1$, which have the following properties:

- W_j takes on the values $+1$ and -1 .
- $W_j[0] = 1$ for all j .
- W_j has exactly j zero crossings, for $j = 0, 1, \dots, N - 1$.
- Each code W_j is either even or odd with respect to its midpoint.

A. Parameters

- Code length: Integer scalar that is a power of 2 specifying the length of the output code.
- Code index: Integer scalar in the range $[0, 1, \dots, N - 1]$, where N is the Code length, specifying the number of zero crossings in the output code.
- Sample time: The time between each sample of the output signal. Specified as a nonnegative real scalar.
- Samples per frame: The number of samples in one column of the output signal. If Samples per frame is greater than the Code length, the code is cyclically repeated. Specified as a positive integer scalar.
- The time between output updates is equal to the product of Samples per frame and Sample time. For example, if Sample time and Samples per frame equal one, the block outputs a sample every second. If Samples per frame is increased to 10, then a 10-by-1 vector is output every 10 seconds. This ensures that the equivalent output rate is not dependent on the Samples per frame parameter.
- Output data type: The output type of the block can be specified as an int8 or double. By default, the block sets this to double

B. Generation of Walsh code using Hadamard Matrix

Walsh codes are defined using a Hadamard matrix of order N . The Walsh Code Generator block outputs a row of the Hadamard matrix specified by the Walsh code index, which must be an integer in the range $[0, \dots, N - 1]$. If you set Walsh code index equal to an integer j , the output code has exactly j zero crossings, for $j = 0, 1, \dots, N - 1$. Note, however, that the indexing in the Walsh Code Generator block is different than the indexing in the Hadamard Code Generator block. If you set the Walsh

code index in the Walsh Code Generator block and the Code index parameter in the Hadamard Code Generator block, the two blocks output different codes.

For Example denote $W(k, n)$ as Walsh code k in n -length Walsh matrix. It means the k -th row of $H(m)$ Hadamard matrix, where $n=2^m$. Here k could be $0, 1, \dots, n-1$. Walsh code can be represented as follows:

- $W(0,1) = 1$
- $W(0,2) = 1, 1$
- $W(1,2) = 1, -1$
- $W(0,4) = 1, 1, 1, 1$
- $W(1,4) = 1, -1, 1, -1$
- $W(2,4) = 1, 1, -1, -1$
- $W(3,4) = 1, -1, -1, 1$
- $W(0,8) = 1, 1, 1, 1, 1, 1, 1, 1$
- $W(1,8) = 1, -1, 1, -1, 1, -1, 1, -1$
- $W(2,8) = 1, 1, -1, -1, 1, 1, -1, -1$
- $W(3,8) = 1, -1, -1, 1, 1, -1, -1, 1$
- $W(4,8) = 1, 1, 1, 1, -1, -1, -1, -1$
- $W(5,8) = 1, -1, 1, -1, -1, 1, -1, 1$
- $W(6,8) = 1, 1, -1, -1, -1, -1, 1, 1$
- $W(7,8) = 1, -1, -1, 1, -1, 1, 1, -1$

Walsh codes are generated by applying Hadamard transform upon 0 repeatedly. Walsh codes can be generated recursively and indexed according to their row number in the M by M Walsh matrix. Their popularity is due to the ease of implementation. Among the former techniques for the generation of Walsh codes the popular method is based on the simple iterative scheme from the Hadamard matrices. In CDMA, Walsh-Hadamard matrices are used for user separation. In this paper we will be using Walsh codes generated by using Hadamard Matrices.

C. Generation of Walsh codes using spreading tree:

These codes can also be generated by using spreading tree. Two codes in the same level or codes in different branches (at different levels) are perfectly orthogonal (called OVFSF codes - Orthogonal Variable Spreading Factor Codes). The different levels of the tree correspond to different spreading factors (SF) for the code (which translates to different data rates - higher SF->higher data rates). If the code at a given level n is x (with SF $2^{(n-1)}$), the codes generated at the next level $n+1$ are $[x \ x]$ and $[x \ -x]$ (with SF 2^n).

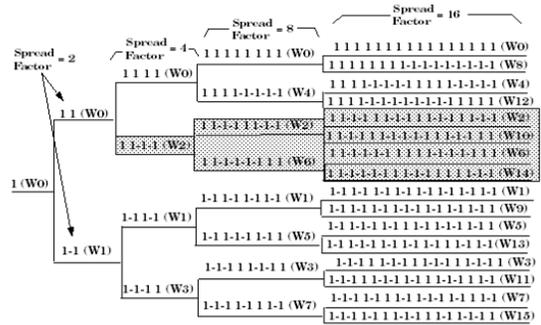


Figure 1 Spreading tree of Walsh code

IV. Spread spectrum encoder using Walsh codes

The encoding operation may be viewed as the discrete-time convolution of the input sequence with the impulse of the encoder. The duration of the impulse response equals the memory of the encoder. In a convolution encoder, unlike a block code, the channel encoder accepts message bits as a continuous sequence, and thereby generates a continuous sequence of encoded bits at a higher rate. This spreader employs convolution encoding. Walsh Codes are used for spreading operation.

In BPSK modulation, the phase of the RF carrier is shifted 180 degrees in accordance with a digital bit stream. The digital coding scheme used is called NRZ-M. A "one" causes a phase transition, and a "zero" does not produce a transition. Direct digital up converter (DUC) typically performs the modulation of a base band signal to an intermediate frequency signal more appropriate for driving a final analog up converter. The low sample rate base band signal is shaped, interpolated and then mixed with a local oscillator. In signal processing, the function of a filter is to remove unwanted parts of the signal, such as random noise, or to extract useful parts of the signal, such as the components lying within a certain frequency range.

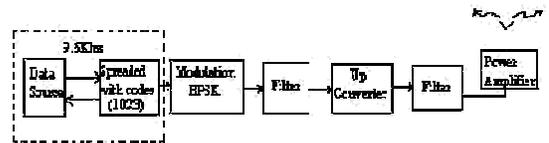


Figure 2 Spread Spectrum Encoder

V Results

V.I. Generation of 16-bits Walsh code in MATLAB:

- 16x16 Walsh code for $N=16$ has been generated by using Hadamard matrices and the program was executed in MATLAB. Table-1 shows the 16x16 Walsh matrix.

- Each row and column of 16x16 Walsh matrix is 16-bit Walsh code.

TABLE- I Walsh matrix 16x16

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
3	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1
4	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1
5	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	-1	-1	-1	-1
6	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1
7	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1
8	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	1
9	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1
10	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	-1
11	1	1	-1	-1	1	1	-1	-1	-1	1	1	-1	-1	1	1	-1	1
12	1	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	1	1	-1	1
13	1	1	1	1	-1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1
14	1	-1	1	-1	1	1	1	1	1	1	1	1	1	-1	-1	-1	-1
15	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	-1	-1
16	1	-1	-1	1	-1	1	-1	-1	1	-1	-1	1	-1	1	-1	1	-1

- Output of 16-bits Walsh code, Crosscorrelation and Autocorrelation in MATLAB is shown as below:

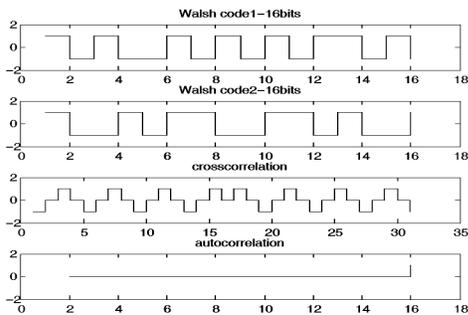


Figure 3 Output waveforms for 16-bit Walsh codes

In the output given above the Walshcode1 is 14th row of Walsh matrix and Walshcode 2 is 16th row. Crosscorrelation is the result between Walshcode1 and Walshcode2. Autocorrelation is overall autocorrelation of 16x16 Walshmatrix. We can consider any row or column for from 16x16 Walsh matrix as 16-bit Walsh code provided it should satisfy the properties of Walsh codes.

V. II. Generation of 32-bits Walsh code in MATLAB:

Similarly, by taking N=32 we have generated 32x32 Walsh code in MATLAB. The output waveforms of 32-bits Walsh code, Crosscorrelation and Autocorrelation in MATLAB is shown below:

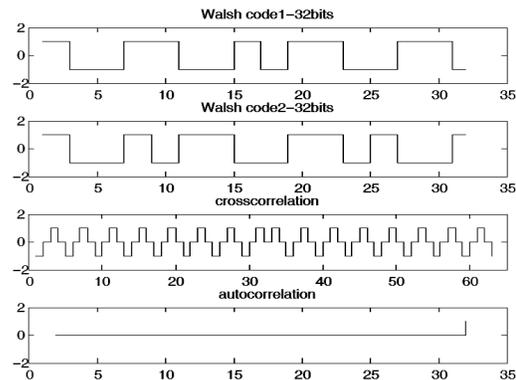


Figure 4 Output waveforms for 32-bit Walsh codes

V.III. Generation of 1024-bits Walsh code in MATLAB:

For the generation of 1024 bit Walsh code we have used 32bit Walsh code matrix. We can generate 1024 bit Walsh code by using any other Walsh matrix of length 16 bits, 32-bits etc. For example:

```
walshcode1=[walshcode(1,:) walshcode(2,) walshcode(3,) walshcode(4,) walshcode(5,) walshcode(6,) walshcode(7,) walshcode(8,) walshcode(9,) walshcode(10,) walshcode(11,) walshcode(12,) walshcode(13,) walshcode(14,) walshcode(15,) walshcode(16,) walshcode(17,) walshcode(18,) walshcode(19,) walshcode(20,) walshcode(21,) walshcode(22,) walshcode(23,) walshcode(24,) walshcode(25,) walshcode(26,) walshcode(27,) walshcode(28,) walshcode(29,) walshcode(30,) walshcode(31,) walshcode(32,);
```

```
walshcode2=[walshcode(10,) walshcode(2,) walshcode(8,) walshcode(15,) walshcode(21,) walshcode(3,) walshcode(26,) walshcode(20,) walshcode(16,) walshcode(6,) walshcode(11,) walshcode(19,) walshcode(24,) walshcode(14,) walshcode(27,) walshcode(4,) walshcode(30,) walshcode(28,) walshcode(22,) walshcode(12,) walshcode(17,) walshcode(25,) walshcode(31,);
```

```
walshcode(9,:) walshcode(32,:) walshcode(29,:)
walshcode(23,:) walshcode(5,:) walshcode(18,:)
walshcode(13,:) walshcode(7,:) walshcode(1,:);
```

In the above example we have generated two 1024 bit Walsh codes by using 32, 32-bit Walsh code. 32-bit Walsh codes used above are the rows of 32x32 Walsh matrix. We can make many combinations by using rows and columns of 32x32 matrix to generate 1024-bit Walsh code. The combinations of 32-bit code selected for generating 1024-bit Walsh code must satisfy the properties of Walsh codes. Output waveforms of 1024-bit Walsh code, Crosscorrelation and Autocorrelation in MATLAB are given as follows:

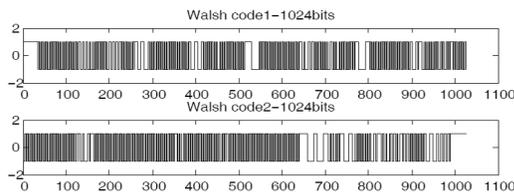


Figure 5 Output waveforms for 1024-bit Walsh codes

V.IV Implementation

The design of spread spectrum encoder using Walsh code was implemented in Artix-7 (Xilinx) FPGA by using VHDL programming and the final simulations observed on CRO are as follows:

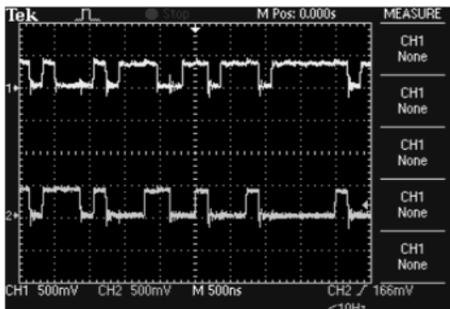


Figure 6 Output waveforms observed on CRO for spread spectrum encoder using Walsh codes

From the above simulations we have observed that the encoded signal was highly reliable and secured as the jamming effects has not degraded the quality of transmitted signal and the Walsh code established for CDMA communication is suitably encoded for retrieving the data at receiver end.

VI. Conclusion

In this paper the code used for the communication is Walsh code. It appears randomly, but is actually deterministic, so that the receiver can reconstruct the code for detection. The realization of the digital spread spectrum encoder for wireless data transfer that generates WALSH

CODES for encoding the digital signals using MATLAB & VHDL (Very High Speed Integrated Circuit Hardware Development Language) is done and the code is simulated, synthesized and implemented on FPGA (spartan3e). We transmitted 32 bits of Walsh code which spreaded the data. The code is generated by using Walsh – Hadamard matrices, the receiver knows how to generate the same code, and correlates the received signal with that code to extract the data. Original message has been encoded successfully and can be recovered even after about one-fourth of the bits have been corrupted. That makes Walsh codes more powerful when compared with other codes. The simulated results are placed in this paper.

With CDMA as the industry's single standard, carriers across the globe benefit from greater choice in equipment, lower prices, and the ability to deploy equipment and services faster than ever before. Next generation products can benefit from current products cost curves resulting in lower costs for both operators and consumers. We can extend this research to high ended data rate transmission. Walsh codes with good performance and flexible code length may help to improve the spread spectrum multiplexing capabilities of future wireless CDMA communication system. These codes will contribute effectively in the applications in which the security, low power transmission and high multiple access is a major concern.

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