International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Analysis of Convolutional Encoder System

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Accepted 14 April 2016, Available online 16 April 2016, **Vol.6, No.2 (April 2016)**

Abstract

This paper focuses on the analysis of convolutional encoder with different constraint lengths ,different modulation techniques, different circuit configurations till we find the best possible circuit. The analysis is performed using MATLAB &SIMULINK. Circuit is then designed using PSPICE Schematic design suite to operate as an non systematic, convolutional encoder a code rate of 0.5 and constraint length 3. Random errors in any communication system is the most concerning factor since it makes the system vulnerable to security threats. A system being designed to prevent such treats consisting of the proposed encoder with Viterbi decoding using MATLAB Programming.

Keywords: *PSPICE Schematic Design Suite; MATLAB &SIMULINK verR2013a; MATLAB Communication Tool box; Convolutional Encoder ;Code Rate; Constraint length; Generator Polynomial; Poly2trellis structure; State diagram; Trellis diagram ;Viterbi decoding;*

1. Introduction

Convolutional codes belong to the FEC(Forward Error Correcting) scheme which were invented by Peter Elias in the year 1955.Convolutional encoding is a process of channel coding. Later on Jack Wozencraft recognized that the tree structure of convolutional codes. Then in the year 1967,Andy Viterbi introduced Viterbi algorithm (VA) as an "asymptotically optimal" decoding algorithm for convolutional codes. Ever since then, Convolutional coding with Viterbi decoding has been the prominent forward error correction technique used in Satellite Communication, CDMA, Digital Mobile Application, Ultra wide band application.(P. Elias, *Coding for noisy channels,* Mar. 1955; *J.* M. Wozencraft and B. Reiffen, *Sequential Decoding,* 1961; Viterbi. A.J, *Convolution codes and their performance in communication systems,* October 1971)

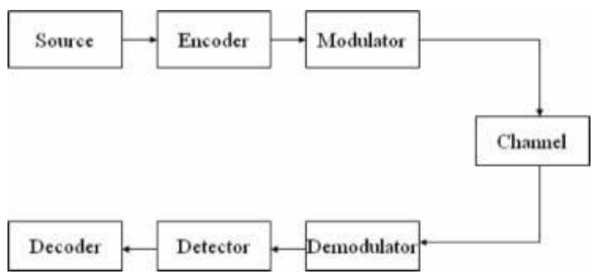

Fig1: Convolutional encoder/decoder position in a digital communication system

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1.1Convolutional Code

We know that (n,k) block code where code words are constructed independently of each other. Convolution code differ from block codes in the encoder output that is to say, it is not constructed from single input but by using, previous encoder input bits. Clearly memory registers are required to store the input for future use. Code rate of convolutional code, is calculated as k/n which also defines the efficiency of the code ,while quantity L is called the constraint length of code which is defined as no. of shifts over which a single message bit can influence the encoder outputs. calculated as L = m+1. where, 'm' denotes no. of memory elements used, 'n' denotes no. of outputs and 'k' denotes no. of inputs to the encoder. So, Fig 2 suggests a Code Rate of 0.5 & Constraint Length of 3.

1.2 Convolutional Encoder

The block diagram of convolution encoder is shown in Fig 2. is to generate the coded output, the encoder uses three values of the input signal. Present one and two previous input values. State is represented by the set of past values of input data. By EX-OR-ing a pattern of current and shifted values of input data each set of outputs is generated. Here (so,s1,s2) are memory states of the shift register. First coded bits and Second coded bits are outputs as (C1,C2).(Viterbi. A.J, *Convolution codes and their performance in communication systems,* October 1971).

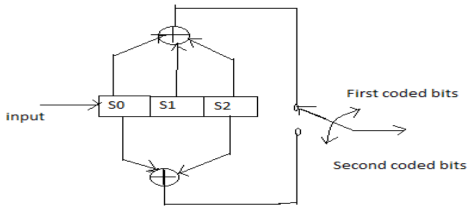

Fig 2: Block diagram of (2,1,3) convolutional encoder

1.3 Generator Polynomial

A polynomial forming the generator polynomial should be at most K degree and specifies the connections between the shift registers and the modulo-2 adders or EXOR gates. Two generator polynomials are g1(x) $=1+x^2$,g2(x) $=1+x+x^2$ which give g1(x) = (101) and g2(x) = (111).

1.4 Poly2trellis Structure

It converts convolutional code polynomials to trellis description and the format is: (L,[g2,g1]) where values of g1,g2 are in octal bases. So according to Figure2,we can say its poly2trellis(3,[7,5]) for the above configuration.

2.1 Impulse Response

An encoder can be accessed on the basis of its impulse response. Impulse response is that response of the encoder when a single '1' bit or '0' bit is passed through it. Consider the contents of the register shown in table as a '1' moves through it:

Table 2: Impulse Response of the (2,1,3) Encoder for a byte of information

Memory states Contents	Output(C1)	Output(C2)
1 0 0	1	1
0 1 0	1	0
1 0 1	0	0
0 1 0	1	0
1 0 1	0	0
0 1 0	1	0
1 0 1	0	0
0 1 0	1	0

A Byte of message bits is encoded by the encoder.

Input :10101010.
Output:11 10 00 10 00 10 00 10.

2.1 Encoder Operation

The encoding of the 8-bits input sequence [1 0 1 0 1 0 1 0], a byte of information for the 8 sequential time periods is as shown in **Fig 3.**

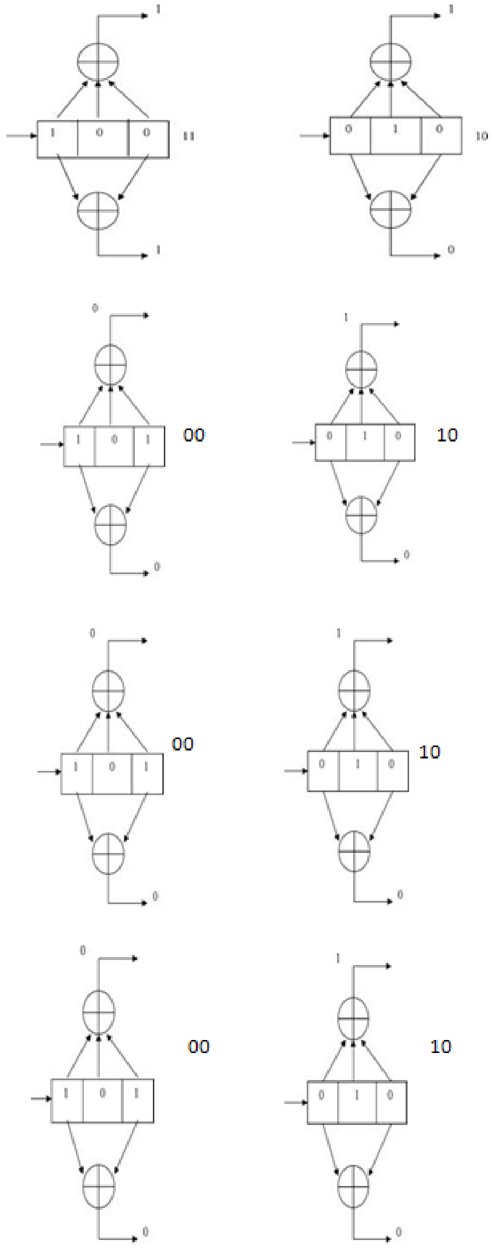

Fig.3 Encoding of the 8-bits input sequence

Table 3: Result showing the working of a (2, 1, 3) Convolutional Encoder for a byte of information

Time	Input Bits	Output Bits	Encoder Bits
0	1	1 1	0 0
1	0	1 0	1 0
2	1	0 0	0 1
3	0	1 0	1 0
4	1	0 0	0 1
5	0	1 0	1 0
6	1	0 0	0 1
7	0	1 0	1 0

A Byte of message bits is encoded by the encoder.

Input :10101010.
Output:11 10 00 10 00 10 00 10.

2.2 Different Encoder Configurations for the fixed Constraint length 3.

It has been observed that three different encoder circuits can be formed. We are differentiating them with poly2trellis structure.

i) Poly2trellis(3,[7,4]); implies g2(x)=111,g1(x)=100;
ii)Poly2trellis(3,[7,5]); implies g2(x)=111,g1(x)=101;
iii)Poly2trellis(3,[7,6]); implies g2(x)=111,g1(x)=110;

2.3 Program for the encoder operation

```
PROGRAM:
G1 = 7;% octal 7 corresponds to binary 111 n1 = m1 + m0 + m-1
G2 = 5; % octal 5 corresponds to binary 101 n1 = m1 + m-1
constLen = 3;   % Constraint length
% Create the trellis that represents the convolutional code
convCodeTrellis = poly2trellis(constLen, [ G1 G2 ]);
uncodedWord = [10 10 10 10];
codedWord2=convenc(uncodedWord,convCodeTrellis);


OUTPUT SCREEN:
codedWord2 = 11 10 00 10 00 10 00 10
```

"Matches with the theoretical value of Encoder Operation"

2.4 State Diagram Representation

The State is defined as the contents of the shift register of the encoder.

In state table shown in table 4 output symbol can be described as a function of input symbol and the state.

State diagram shows the transition between different states as shown in figure 4.

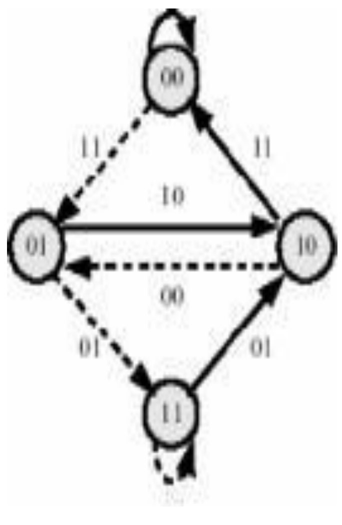

Fig 4: State Diagram

Table 4: State Table

Input	Present state State	Next state	Output
0	00	00	00
1	00	01	11
0	01	10	11
1	01	11	00
0	10	00	10
1	10	01	01
0	11	10	01
1	11	11	10

2.5 Trellis Diagram

The trellis diagram is drawn by lining up all the possible states in the vertical axis. Then we connect each state to the next by the allowable code words for that state. Since the code is binary there are only two choices possible at each state. These are determined by the arrival of either the bit 0 or the bit Trellis diagram is the description of state diagram of the encoder by a time line i.e. to represent each time unit with a separate state diagram as shown in figure 5.

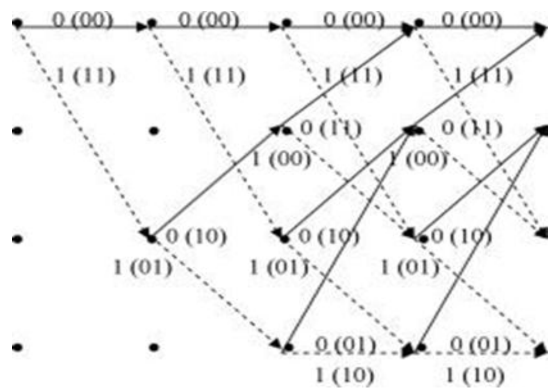

Fig 5: A trellis diagram for the (2, 1, 3) convolutional encoder

2.6 Decoding

Channel decoding is defined as the process of recovering the encoded input data stream, at the receiver, once transmitted through a channel. There are two major forms of channel decoding for convolutional codes: sequential decoding and the maximum likelihood decoding or Viterbi decoding Viterbi decoding, also often referred to as the maximum likelihood decoding was developed by Andrew J. Viterbi, entire received sequence of a given length. The decoder computes a metric for each path and makes a decision based on this metric. All paths are followed until two paths converge on one node. Henceforth based on a decision, discussed ahead, one of the two paths is chosen. The paths selected are called the survivors. (Viterbi. A.J, *Convolution codes and their performance in communication systems,* October 1971).

2.7 Viterbi Algorithm

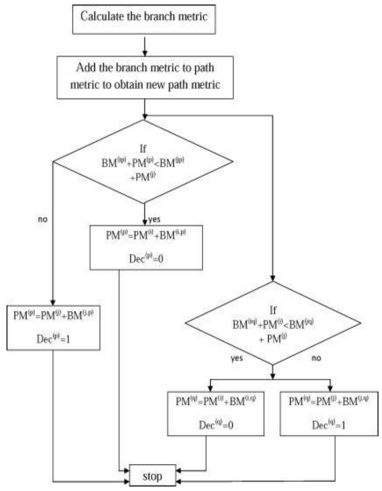

Fig.6:Viterbi algorithm

Branch Metric Unit

The branch metric is done with hamming distance and previous state path metric [BM = Pre. PM + hd]. Initially, at t=1 the branch metric is nothing but hamming distance because it is considered as previous path metric is zero. At each node of state there are two branch metrics. So, addrer1 and adder2 gives two branch metrics BM1 and BM2 respectively. (Viterbi. A.J, *Convolution codes and their performance in communication systems,* October 1971)

Path Metric Unit

The minimum of branch metrics is a path metric for each node [PM = min (BM1, BM2)]. In Viterbi decoder, the path metric is calculated for all state nodes as per constraints length which is further helpful during trace-back for that it is stored in path memory. If this path history memory is fixed amount, then the decoder can output the oldest bit on an arbitrary path each time it steps one level deeper into the trellis. (Viterbi. A.J, *Convolution codes and their performance in communication systems,* October 1971).

Survivor Memory Unit

The survivor memory stores the state having minimum path metric. And finally these states are used to get decoded bits, i.e. original data. The path comparisons made for paths entering each state require the calculation of the likelihood of each path involved for the particular received information. (Viterbi. A.J, *Convolution codes and their performance in communication systems,* October 1971)

3 BER (Bit Error Rate) Analysis

BER analysis is first done to obtain the best modulation type for the circuit. Then we have extended our analysis to find the best performing circuit so that hardware can be configured with it later analyzed with different constraint lengths.

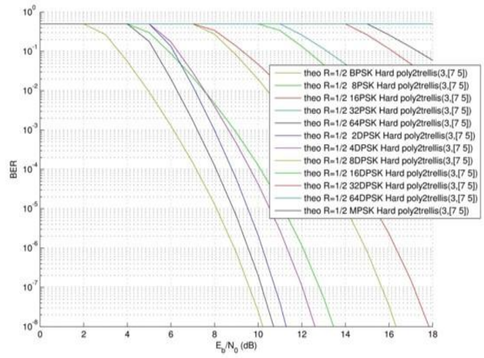

Fig.7: Comparison between different modulation techniques

It is found that for a constant BER, BPSK modulation technique performs best modulation process with lesser energy required to transmit the bits.

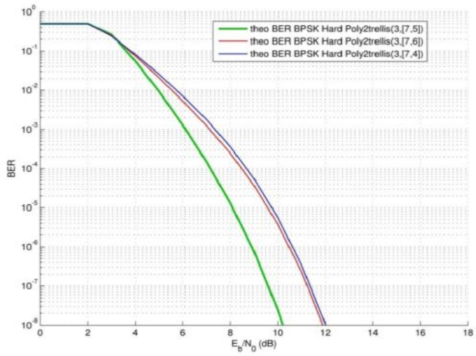

Fig 8: Comparison between different circuit configurations

Out of these circuits, for a constant BER, the circuit with poly2trellis(3,[7,5]) has the best performance. This indicates we need to have an encoder circuit with three memory elements and g2= (111) and g1= (101) as their impulse response.

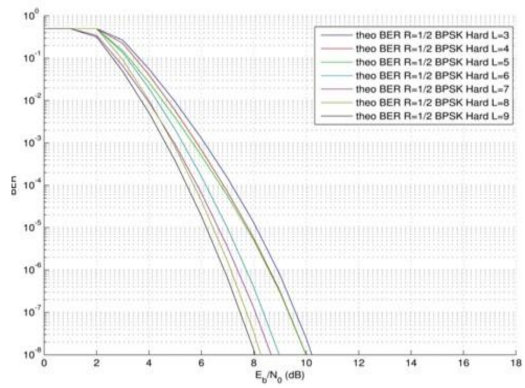

Fig.9:Comparison with different constraint lengths

It's found that for a constant BER, higher the constraint length less amount of energy is required to transmit the coded bits.

Now when we know that BPSK is the best modulation system we modeled a communication system with convolutional encoding and Viterbi decoding with MATLAB programming.

```
10/10/15 3:07 AM  E:\Program Files\MATLAB\R2013a\bin\m...   1 of 1

close all
clear all
trellis = poly2trellis(3, [7 5]);                  % Trellis structure
iteration = 1000;                                   % Number of simulations
n = 1000;                                           % Total block length
k =  500;                                         % Total number of message bits
rate = 0.5;                                          % Code rate
tbleng = 16;                                         % Traceback length
SNR = [];
ber = [];

for Ebn_dB = 0:1:8

    T_ber = 0;                                       % Total BER
    T_iteration = 0;                                 % Total iterations

    Esn_dB = Ebn_dB + 10*log10(rate);
    No = (10.^(-Esn_dB/10));
    for Nsimulation = 1:iteration

        %*************************** Encoding ****************************
        r_bit = (sign(randn(1,k))+1)/2;              % Random bits
        e_bit = convenc(r_bit,trellis);              % Encode the message.
        mod_bit = -2*e_bit+1;                        % BPSK modulation
        mod_bit=mod_bit+sqrt(No/2)*randn(1,n);       % AWGN Channel
        mod_bit=(1-sign(mod_bit))/2;                 % Hard decisions
        %*************************** Decoding ****************************
        deci = vitdec(mod_bit,trellis,tbleng,'cont','hard');
        [errors,ratio]=biterr(deci(tbleng+1:end),r_bit(1:end-tbleng));

        T_ber = T_ber + errors;
        T_iteration = T_iteration + k;
    end
    avgber = T_ber/T_iteration;                    % Find the avg BER
    ber = [ber avgber];                            % Total BER
    SNR = [SNR Ebn_dB];
    fprintf('%5.2f\t%e\t%6.0f\t%6.0f\n', Ebn_dB, avgber, T_ber, T_iteration);
end
semilogy (SNR,ber,'-b^');                           %Plot bit error rate
hold on
% Compare BER curve with that of uncoded BPSK modulation
semilogy ([SNR 8 9 10] ,qfunc(sqrt(2*10.^([SNR 8 9 10]/10))),'-r*');
axis tight
grid
hold on
title (' Plot of BER vs. Eb / No ')
xlabel (' Eb / No ')
ylabel (' Bit Error Rate(BER)')
legend('coderate = 1/2,m = 2,hard-decision tested','Uncoded BPSK')
```

Fig.10:MATLAB programming for convolutional encoding and Viterbi decoding

```
10/10/15 2:12 AM  MATLAB Command Window                    1 of 1

>> Program_BERanalysis_BPSK_Hard_uncodedBPSK
 0.00   1.900980e-01    95049  500000
 1.00   1.239480e-01    61974  500000
 2.00   6.924000e-02    34620  500000
 3.00   3.125200e-02    15626  500000
 4.00   1.108600e-02     5543  500000
 5.00   3.060000e-03     1530  500000
 6.00   4.920000e-04      246  500000
 7.00   8.800000e-05       44  500000
 8.00   4.000000e-06        2  500000
>>
```

Fig 11: MATLAB Command Window for the above Program.

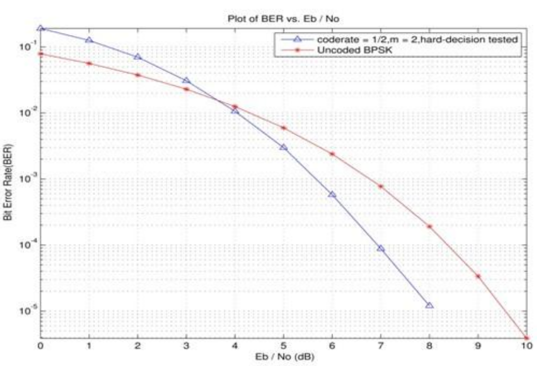

Fig 12: MATLAB Program Output

Thus, for the same BER, the encoded bits with hard decision requires less energy to transmit and are more error free.

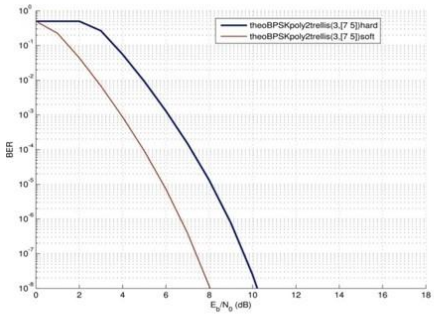

Fig.13: Comparison between hard and soft decision

It is found that for a constant BER, the performance of soft decoding is better than hard decoding.

4 Encoder Design

As we came to know about the circuit configuration we tried to implement it with PSPICE Schematic Design Suite.

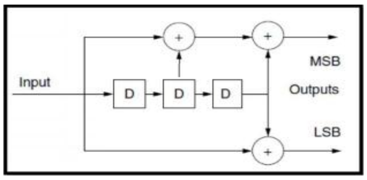

Fig14: Block diagram for the proposed design(Non-Recursive, Non Systematic Convolutional Encoder (2, 1, 3))

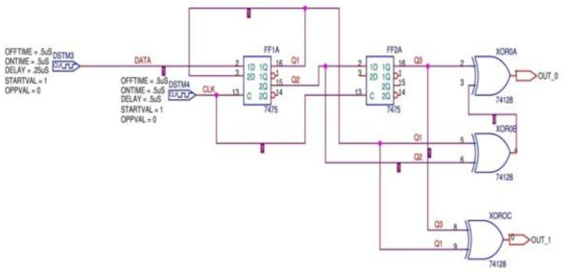

Fig 15: Proposed design implemented in PSPICE Schematic Design Suite

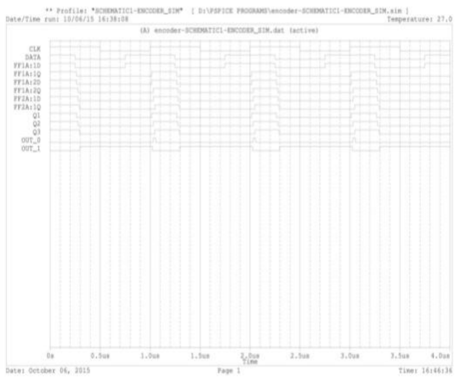

Fig.16:Output generated from Schematic

Conclusions

1) From BER (Bit Error Rate) analysis we have found that the BPSK modulation technique is the best modulation technique to transmit bits with lesser energy.
2) BER plot also showed us the best circuit to implement with the hardware i.e.Poly2trellis(3,[7,5]).
3) From BER plot it's found that for a constant BER, higher the constraint length less amount of energy is required to transmit the coded bits.
4) From the Matlab program output it's found that for the same BER, the encoded bits with hard decision requires less energy to transmit and are more error free.
5) It is found that for a constant BER, the performance of soft decoding is better than hard decoding.

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