



**LDPC and Polar Codes in 5G Standard**  
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**Simulation of (7,4) Hamming Code in MATLAB**

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**Example: (7,4) Hamming Code**

```

    graph LR
      r["r = [r1 r2 ... rn]"] --> HD["Hard Decision"]
      HD -- "If r1 > 0, b1 = 0" --> b["b = [b1 b2 ... bn]"]
      HD -- "If r1 < 0, b1 = 1." --> b
      b --> F["Find c that minimizes dH(c, b)"]
      F --> c["c"]
  
```

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

- $b = [1010101]$ ,  $\hat{c} = ?$
- $b = [0110110]$ ,  $\hat{c} = ?$

[PROF ANDREW THANGARAJ] IIT MADRAS Simulation of (7,4) Hamming Code in MATLAB

Hello, so in this lecture we will be looking at building decoders for the 7 4 Hamming code. You remember in the previous Matlab coding lectures we saw how to build decoders for the repetition code. We built both the soft decision decoder and the hard decision decoder. We ran them and saw what the output was and compared it with some plots and we got good answers.

We will do the same for the Hamming code. I will build it very quickly and show you. But a couple of things I want to point out once again, remind you. The code I write primarily using Matlab for the demonstrations, you can use Octave as well, and the same code that we provide for you should work on Octave also, Ok.

So let us get started. So this is the Hamming code, the 7 4 Hamming code. So, I mentioned that this is a linear code as well and one can write down the generator matrix for this linear code. So this would come out like this. So you have G equals, remember it is a 7 4 code so it will be 4 by 7 generator matrix,

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**Example: (7,4) Hamming Code**

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  | 000101  
 •  $b = [0110110]$ ,  $\hat{c} = ?$

$H = \begin{bmatrix} & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \end{bmatrix}$

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Simulation of (7,4) Hamming Code in MATLAB

Ok. So it turns out since, since this encoding is systematic you can quickly write down the generator matrix. So the generator matrix will look like this.

1 0 1

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**Example: (7,4) Hamming Code**

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  | 000101  
 •  $b = [0110110]$ ,  $\hat{c} = ?$

$H = \begin{bmatrix} & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \end{bmatrix}$

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Simulation of (7,4) Hamming Code in MATLAB

and 1 1 1



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**Example: (7,4) Hamming Code**

NPTEL

Hard Decision

$r = [r_1 \ r_2 \ \dots \ r_n]$

If  $r_i > 0$ ,  $b_i = 0$   
If  $r_i < 0$ ,  $b_i = 1$ .

$b = [b_1 \ b_2 \ \dots \ b_n]$

Find  $c$  that minimizes  $d_H(c, b)$

$\hat{c}$

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  1000101

•  $b = [0110110]$ ,  $\hat{c} = ?$

$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix}$

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Simulation of (7,4) Hamming Code in MATLAB

and then you have 0 0 1 0 and 1 1 0

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**Example: (7,4) Hamming Code**

NPTEL

Hard Decision

$r = [r_1 \ r_2 \ \dots \ r_n]$

If  $r_i > 0$ ,  $b_i = 0$   
If  $r_i < 0$ ,  $b_i = 1$ .

$b = [b_1 \ b_2 \ \dots \ b_n]$

Find  $c$  that minimizes  $d_H(c, b)$

$\hat{c}$

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  1000101

•  $b = [0110110]$ ,  $\hat{c} = ?$


$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix}$


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Simulation of (7,4) Hamming Code in MATLAB

and 0 0 0 1, 0 1 1. Ok

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### Example: (7,4) Hamming Code

$r = [r_1 \ r_2 \ \dots \ r_n]$ 
Hard Decision
 $b = [b_1 \ b_2 \ \dots \ b_n]$ 
Find  $c$  that minimizes  $d_H(c, b)$ 
 $\rightarrow \hat{c}$


If  $r_i > 0$ ,  $b_i = 0$   
 If  $r_i < 0$ ,  $b_i = 1$ .

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

$\bullet b = [1010101], \hat{c} = ? 1000101$   
 $\bullet b = [0110110], \hat{c} = ?$

$G = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$



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Simulation of (7,4) Hamming Code in MATLAB

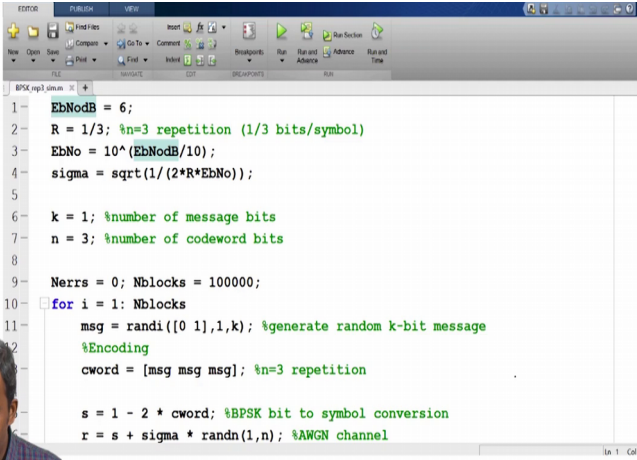


so this is the generator matrix for this 7 4 Hamming code. So you have, when you multiply  $m$  with  $G$  with the message bits appearing in the first 4 locations and then the first parity will be  $m_0$  plus  $m_1$  plus  $m_2$ . The second parity will be  $m_1$  plus  $m_2$  plus  $m_3$ . And the third parity is  $m_1$  plus  $m_2$  plus  $m_4$ , Ok.

So this is the generator matrix. One can write down the parity check matrix as well for this, for this code so that will be just  $p$  transpose and  $I_3$  ( $()$ ). And one can use it, Ok.

So, so I am giving you this just for, just for completing the previous lecture but this you may want to use it in the, in your coding for instance when you want to do encoding this is a good thing to use, Ok.

So let us move over to Matlab.

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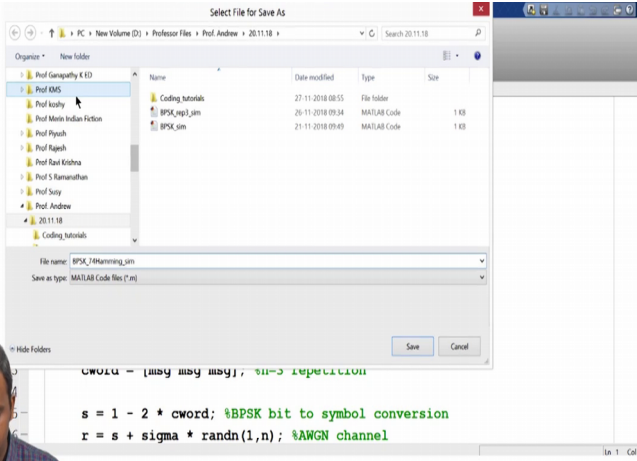


```
1 EbNodB = 6;
2 R = 1/3; %n=3 repetition (1/3 bits/symbol)
3 EbNo = 10^(EbNodB/10);
4 sigma = sqrt(1/(2*R*EbNo));
5
6 k = 1; %number of message bits
7 n = 3; %number of codeword bits
8
9 Nerrs = 0; Nblocks = 100000;
10 for i = 1: Nblocks
11     msg = randi([0 1],1,k); %generate random k-bit message
12     %Encoding
13     cword = [msg msg msg]; %n=3 repetition
14
15     s = 1 - 2 * cword; %BPSK bit to symbol conversion
16     r = s + sigma * randn(1,n); %AWGN channel
```

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Simulation of (7,4) Hamming Code in MATLAB

So I am going to save this as 7 4 Hamming

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Select File for Save As

File name: BPSK\_74Hamming\_sim  
Save as type: MATLAB Code File (\*.m)

Save Cancel

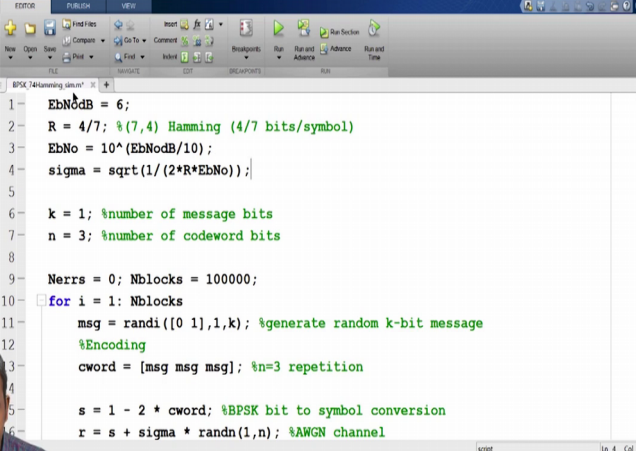


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Simulation of (7,4) Hamming Code in MATLAB

Ok so we will use the same 6 dB, remember the rate is 4 by 7 Ok so let us make a few quick changes here.

This part

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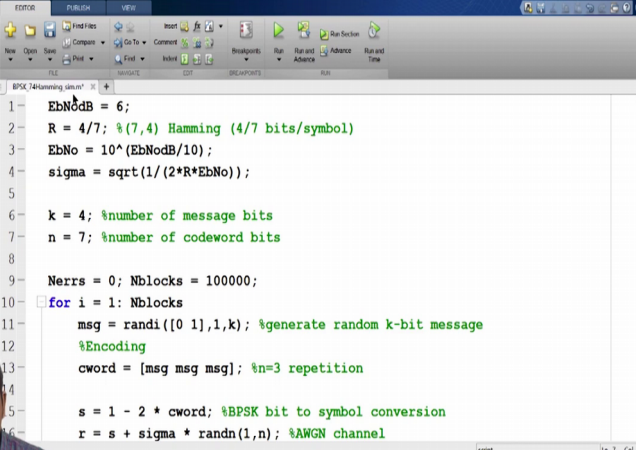


```
1 EbNodB = 6;
2 R = 4/7; % (7,4) Hamming (4/7 bits/symbol)
3 EbNo = 10^(EbNodB/10);
4 sigma = sqrt(1/(2*R*EbNo));
5
6 k = 1; %number of message bits
7 n = 3; %number of codeword bits
8
9 Nerrs = 0; Nblocks = 100000;
10 for i = 1: Nblocks
11     msg = randi([0 1],1,k); %generate random k-bit message
12     %Encoding
13     cword = [msg msg msg]; %n=3 repetition
14
15     s = 1 - 2 * cword; %BPSK bit to symbol conversion
16     r = s + sigma * randn(1,n); %AWGN channel
```

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Simulation of (7,4) Hamming Code in MATLAB

does not change, k equals 4, n equals 7.

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```
1 EbNodB = 6;
2 R = 4/7; % (7,4) Hamming (4/7 bits/symbol)
3 EbNo = 10^(EbNodB/10);
4 sigma = sqrt(1/(2*R*EbNo));
5
6 k = 4; %number of message bits
7 n = 7; %number of codeword bits
8
9 Nerrs = 0; Nblocks = 100000;
10 for i = 1: Nblocks
11     msg = randi([0 1],1,k); %generate random k-bit message
12     %Encoding
13     cword = [msg msg msg]; %n=3 repetition
14
15     s = 1 - 2 * cword; %BPSK bit to symbol conversion
16     r = s + sigma * randn(1,n); %AWGN channel
```

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Simulation of (7,4) Hamming Code in MATLAB

The number of blocks maybe we want to keep it at some low number

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```

1- EbNodB = 6;
2- R = 4/7; % (7,4) Hamming (4/7 bits/symbol)
3- EbNo = 10^(EbNodB/10);
4- sigma = sqrt(1/(2*R*EbNo));
5-
6- k = 4; %number of message bits
7- n = 7; %number of codeword bits
8-
9- Nerrs = 0; Nblocks = 1000;
10- for i = 1: Nblocks
11-     msg = randi([0 1],1,k); %generate random k-bit message
12-     %Encoding
13-     cword = [msg msg msg]; %n=3 repetition
14-
15-     s = 1 - 2 * cword; %BPSK bit to symbol conversion
16-     r = s + sigma * randn(1,n); %AWGN channel

```


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Simulation of (7,4) Hamming Code in MATLAB

just for simulation. This part is Ok. The message is k bits. Now the codeword I have to change, right.

So I have to have the message appearing by itself, Ok and then remember from my encoding, my

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### Example: (7,4) Hamming Code

$r = [r_1 \ r_2 \ \dots \ r_n]$  → Hard Decision →  $b = [b_1 \ b_2 \ \dots \ b_n]$  → Find  $c$  that minimizes  $d_H(c, b)$  →  $\hat{c}$

If  $r_i > 0$ ,  $b_i = 0$   
 If  $r_i < 0$ ,  $b_i = 1$ .

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  | 000101  
 •  $b = [0110110]$ ,  $\hat{c} = ?$

$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$

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Simulation of (7,4) Hamming Code in MATLAB

message will come here by itself. The 4 bits of the message will come here. What about the first parity? It is the first bit of the message XORed with the second bit of the message XORed with the third bit of the message. Ok

So that is my first parity, so I can write that down here. So it is going to be message of 1 plus message of 2 plus message of 3 and then I have to do modulo 2 and that you can do in this fashion, Ok. So this is for the 7,4 Hamming, Ok.

Now just to make the writing a bit clear I will use this dot dot dot which gives me the ability to write over multiple lines.

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```

6- k = 4; %number of message bits
7- n = 7; %number of codeword bits
8-
9- Nerrs = 0; Nblocks = 1000;
10- for i = 1:Nblocks
11-     msg = randi([0 1],1,k); %generate random k-bit message
12-     %Encoding
13-     cword = [msg mod(msg(1)+msg(2)+msg(3),2)...
14-             mod(... % (7,4) Hamming
15-
16-     s = 1 - 2 * cword; %BPSK bit to symbol conversion
17-     r = s + sigma * randn(1,n); %AWGN channel
18-
19-     %Hard-decision decoding
20-     b = (r > 0); %threshold at zero
21-     if sum(b) > 1


```

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Simulation of (7,4) Hamming Code in MATLAB

The second message, if you, the second parity bit if you look at it

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### Example: (7,4) Hamming Code

$r = [r_1 \ r_2 \ \dots \ r_n]$  → Hard Decision →  $b = [b_1 \ b_2 \ \dots \ b_n]$  → Find  $c$  that minimizes  $d_H(c, b)$  →  $\hat{c}$

If  $r_i > 0$ ,  $b_i = 0$   
 If  $r_i < 0$ ,  $b_i = 1$ .

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

$\bullet b = [1010101], \hat{c} = ?$   
 $\bullet b = [0110110], \hat{c} = ?$

$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$

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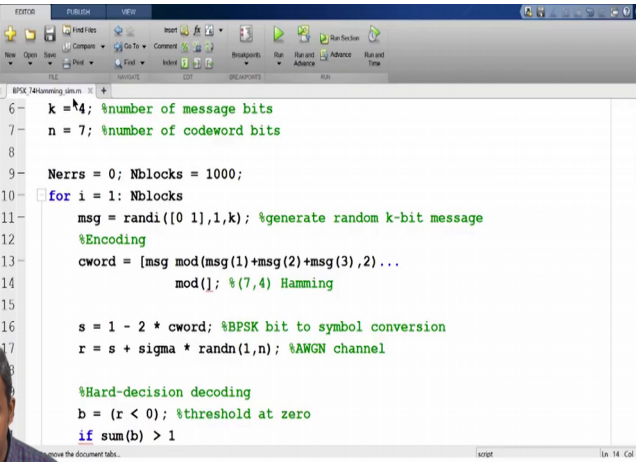


Simulation of (7,4) Hamming Code in MATLAB

is actually message, message the second message bit XORed with the third message bit XORed with the fourth message bit, right?



So I can

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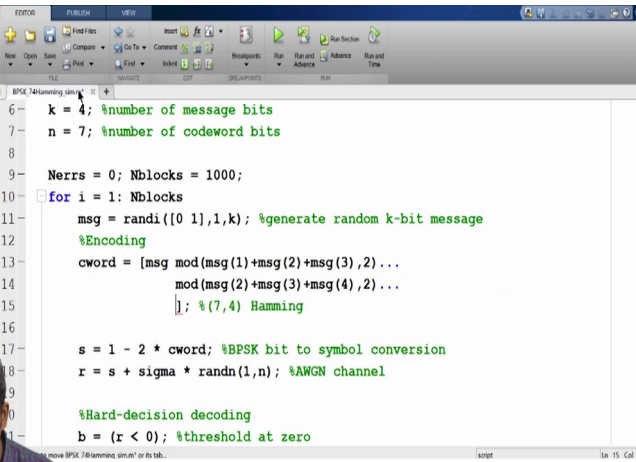


```
6 k = 4; %number of message bits
7 n = 7; %number of codeword bits
8
9 Nerrs = 0; Nblocks = 1000;
10 for i = 1: Nblocks
11     msg = randi([0 1],1,k); %generate random k-bit message
12     %Encoding
13     cword = [msg mod(msg(1)+msg(2)+msg(3),2)...
14             mod(, % (7,4) Hamming
15
16     s = 1 - 2 * cword; %BPSK bit to symbol conversion
17     r = s + sigma * randn(1,n); %AWGN channel
18
19     %Hard-decision decoding
20     b = (r < 0); %threshold at zero
21     if sum(b) > 1
```

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Simulation of (7,4) Hamming Code in MATLAB

write that down. Remember this mod 2 you have to keep doing, Ok

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```
6 k = 4; %number of message bits
7 n = 7; %number of codeword bits
8
9 Nerrs = 0; Nblocks = 1000;
10 for i = 1: Nblocks
11     msg = randi([0 1],1,k); %generate random k-bit message
12     %Encoding
13     cword = [msg mod(msg(1)+msg(2)+msg(3),2)...
14             mod(msg(2)+msg(3)+msg(4),2)...
15             ]; % (7,4) Hamming
16
17     s = 1 - 2 * cword; %BPSK bit to symbol conversion
18     r = s + sigma * randn(1,n); %AWGN channel
19
20     %Hard-decision decoding
21     b = (r < 0); %threshold at zero
```

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Simulation of (7,4) Hamming Code in MATLAB

and the third parity bit, oops sorry, (( )) the third parity bit if you look at the

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### Example: (7,4) Hamming Code

$r = [r_1 \ r_2 \ \dots \ r_n]$ 

Hard Decision  
 If  $r_i > 0$ ,  $b_i = 0$   
 If  $r_i < 0$ ,  $b_i = 1$ .

 $b = [b_1 \ b_2 \ \dots \ b_n]$ 

Find  $c$  that minimizes  $d_H(c, b)$

 $\hat{c}$

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  | 000101

•  $b = [0110110]$ ,  $\hat{c} = ?$

$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$


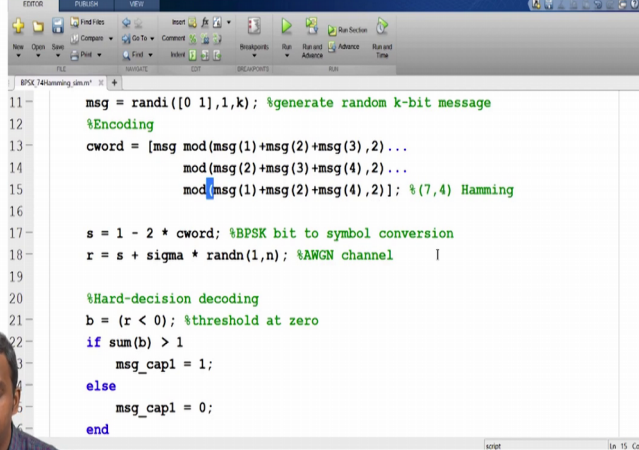
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Simulation of (7,4) Hamming Code in MATLAB

equation once again, it is the first message bit XORed with the second message bit and XORed with the fourth message bit, Ok.

So one can write this down as msg of 1 plus msg of 2 plus msg of 4 and comma 2 that is it.

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```


11- msg = randi([0 1],1,k); %generate random k-bit message
12- %Encoding
13- cword = [msg mod(msg(1)+msg(2)+msg(3),2) ...
14-          mod(msg(2)+msg(3)+msg(4),2) ...
15-          mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
16-
17- s = 1 - 2 * cword; %BPSK bit to symbol conversion
18- r = s + sigma * randn(1,n); %AWGN channel
19-
20- %Hard-decision decoding
21- b = (r < 0); %threshold at zero
22- if sum(b) > 1
23-     msg_cap1 = 1;
24- else
25-     msg_cap1 = 0;
26- end
    
```

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Simulation of (7,4) Hamming Code in MATLAB

So I have done my encoding, Ok. So 1, 2, 3; 2, 3, 4 and 1, 2, 4, so let us check that once again,

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### Example: (7,4) Hamming Code

$r = [r_1 \ r_2 \ \dots \ r_n]$ 

**Hard Decision**  
 If  $r_i > 0$ ,  $b_i = 0$   
 If  $r_i < 0$ ,  $b_i = 1$ .

 $b = [b_1 \ b_2 \ \dots \ b_n]$ 

Find  $c$  that minimizes  $d_H(c, b)$

 $\hat{c}$

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  1000101

•  $b = [0110110]$ ,  $\hat{c} = ?$


$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$

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Simulation of (7,4) Hamming Code in MATLAB

exactly what it is, Ok.

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```

11 msg = randi([0 1],1,k); %generate random k-bit message
12 %Encoding
13 cword = [msg mod(msg(1)+msg(2)+msg(3),2) ...
14          mod(msg(2)+msg(3)+msg(4),2) ...
15          mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
16
17 s = 1 - 2 * cword; %BPSK bit to symbol conversion
18 r = s + sigma * randn(1,n); %AWGN channel
19
20 %Hard-decision decoding
21 b = (r < 0); %threshold at zero
22 if sum(b) > 1
23     msg_cap1 = 1;
24 else
25     msg_cap1 = 0;
26 end
          
```

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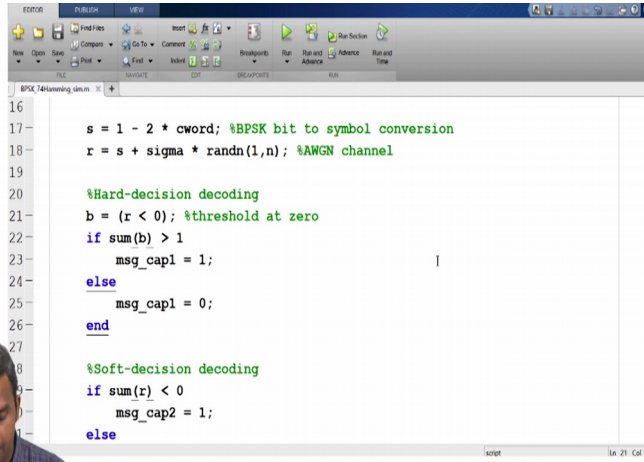


Simulation of (7,4) Hamming Code in MATLAB

So that is done. Ok, you have done the encoding. You can write this a bit differently. You can store the generator matrix and do it if you like. There are various ways of doing it, Ok.

So after this the bit to symbol conversion is straightforward. It is the same thing. Nothing needs to be changed. This gives you the symbol vector. And then this gives you the received vector, right? I am adding, creating noise of Gaussian distribution multiplying with sigma and then adding it to this.

Now hard decision decoding, the threshold at zero is the same but this condition is not going to be the same,

(Refer Slide Time 06:40)



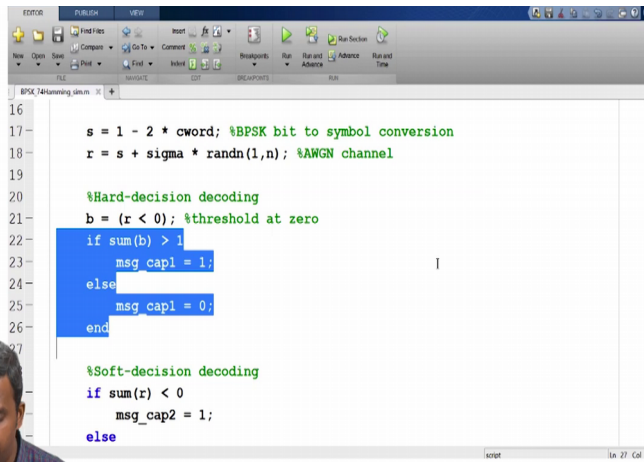


```
16
17 s = 1 - 2 * cword; %BPSK bit to symbol conversion
18 r = s + sigma * randn(1,n); %AWGN channel
19
20 %Hard-decision decoding
21 b = (r < 0); %threshold at zero
22 if sum(b) > 1
23     msg_cap1 = 1;
24 else
25     msg_cap1 = 0;
26 end
27
28 %Soft-decision decoding
29 if sum(r) < 0
30     msg_cap2 = 1;
31 else
```

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but this condition is not going to be the same, right? So need to have something different here; it cannot be the same as this. We will have to do something different

(Refer Slide Time 06:47)



```
16
17 s = 1 - 2 * cword; %BPSK bit to symbol conversion
18 r = s + sigma * randn(1,n); %AWGN channel
19
20 %Hard-decision decoding
21 b = (r < 0); %threshold at zero
22 if sum(b) > 1
23     msg_cap1 = 1;
24 else
25     msg_cap1 = 0;
26 end
27
28 %Soft-decision decoding
29 if sum(r) < 0
30     msg_cap2 = 1;
31 else
```

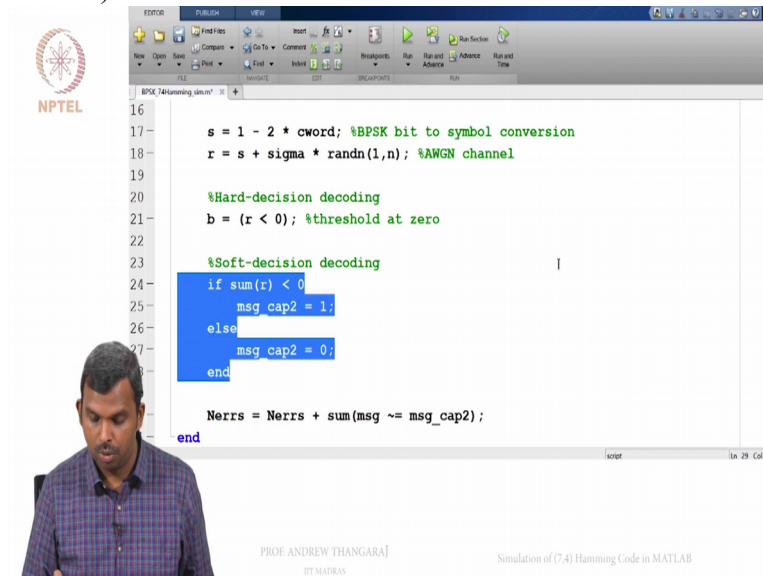
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here so let us delete this.

Same thing with soft decision decoding,

(Refer Slide Time 06:53)



this cannot be the same. This will have to be real out, Ok. Remember what we do in hard decision decoding, you have to find the distance of the hard decision vector  $b$  from every codeword and find that codeword which is closest to it, Ok. So that is the task in hard decision decoding.

And soft decision decoding, you have to find the distance between the received word, right, real received word and all possible symbol vectors, right and then find that symbol vector which is closest to, closest to the received vector in Euclidean distance, Ok.

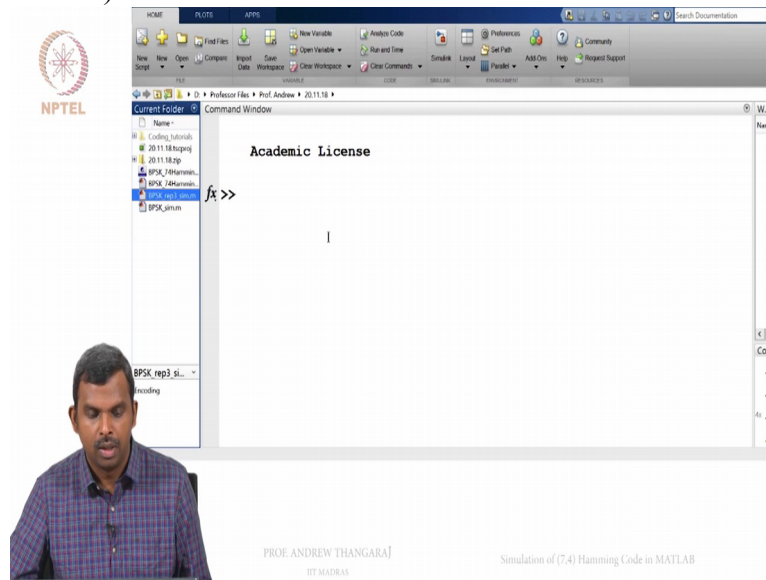
But we also saw B P S K K S instead of finding the Euclidean distance and finding the minimum symbol vector; you can take a dot product and find the maximum dot product. So which symbol vector has maximum correlation with your received vector?

So that is also something that you can find, Ok. So once we will do it in that fashion. We will do soft decision decoding in that fashion. I will take dot product with all symbol vectors and pick that symbol vector which gives me the best one.

So for both these things I need the list of codewords, Ok. So I need the list of all codewords of the Hamming code. And I want to store them in some, in a vector and then use it, Ok. And also all symbol vectors right. So right, so both of these, both of these I need. I am going to generate it.

For small codewords, codes like this one can quickly generate. It is not very difficult to write a piece of few lines of code to generate these codewords. But in general if you have larger code, it might be difficult and it won't work, Ok. But nevertheless let us get started with the, with generating these codewords

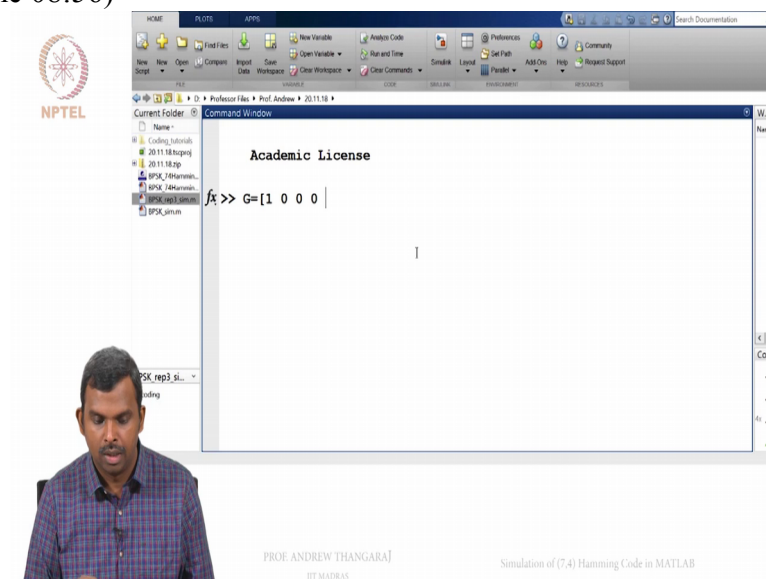
(Refer Slide Time 08:41)



Ok.

So I will do, I will describe how I usually generate codewords. This is not the only way to do it. There are so many other ways in which one can do this so one can write down the, first generator matrix, Ok.

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So let me take some help from what I have before,



(Refer Slide Time 08:59)

**Example: (7,4) Hamming Code**

$r = [r_1 \ r_2 \ \dots \ r_n]$  → **Hard Decision** →  $b = [b_1 \ b_2 \ \dots \ b_n]$  → Find  $c$  that minimizes  $d(c, b)$  →  $\hat{c}$

If  $r_i > 0$ ,  $b_i = 0$   
 If  $r_i < 0$ ,  $b_i = 1$ .

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  | 000101  
 •  $b = [0110110]$ ,  $\hat{c} = ?$

$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$

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Simulation of (7,4) Hamming Code in MATLAB

1 0 1, 1 1 1 (()) Ok.

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```


>> G = [1 0 0 0 1 0 1; 0 1 0 0 1 1 1; 0 0 1 0 1 1 0]
  
```

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Simulation of (7,4) Hamming Code in MATLAB

Let us check.

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### Example: (7,4) Hamming Code

$r = [r_1 \ r_2 \ \dots \ r_n]$ 

**Hard Decision**  
 If  $r_i > 0$ ,  $b_i = 0$   
 If  $r_i < 0$ ,  $b_i = 1$ .

 $b = [b_1 \ b_2 \ \dots \ b_n]$ 

Find  $c$  that minimizes  $d_H(c, b)$

 $\hat{c}$

Message	Codeword
0000	0000000
0001	0001011
0010	0010110
0101	0101100
1011	1011000
0110	0110001
1100	1100010
1000	1000101

Message	Codeword
0100	0100111
1001	1001110
0011	0011101
0111	0111010
1110	1110100
1101	1101001
1010	1010011
1111	1111111

•  $b = [1010101]$ ,  $\hat{c} = ?$  1000101

•  $b = [0110110]$ ,  $\hat{c} = ?$


$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$

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Simulation of (7,4) Hamming Code in MATLAB

1 0 0 1 1 (0)), Ok

(Refer Slide Time 09:30)



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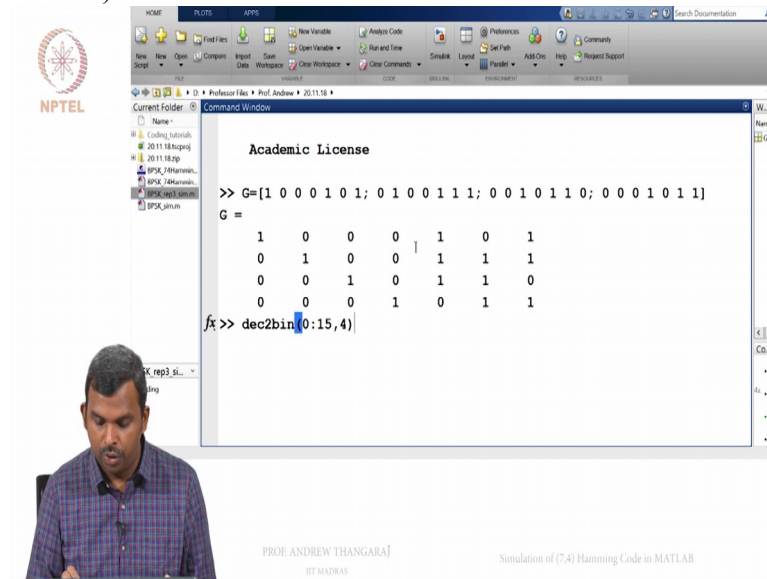
```
>> G=[1 0 0 0 1 0 1; 0 1 0 0 1 1 1; 0 0 1 0 1 1 0; 0 0 0 1 0 1 1]
G =
     1     0     0     0     1     0     1
     0     1     0     0     1     1     1
     0     0     1     0     1     1     0
     0     0     0     1     0     1     1
```

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Simulation of (7,4) Hamming Code in MATLAB

so you can check. This is the generator matrix that I had before, alright. So now I have to multiply with the message bits. How many message bits do I have? I have 4 message bits so there are 16 possible binary vectors. So how do you get a list of 16 possible binary vectors? So it turns out that there is this little command here which I use. There are, I am sure other possibilities here.

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NPTEL

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```
>> G=[1 0 0 0 1 0 1; 0 1 0 0 1 1 1; 0 0 1 1 0 1 1; 0 0 0 1 1 0 1]
G =
     1     0     0     0     1     0     1
     0     1     0     0     1     1     1
     0     0     1     1     0     1     1
     0     0     0     1     1     0     1

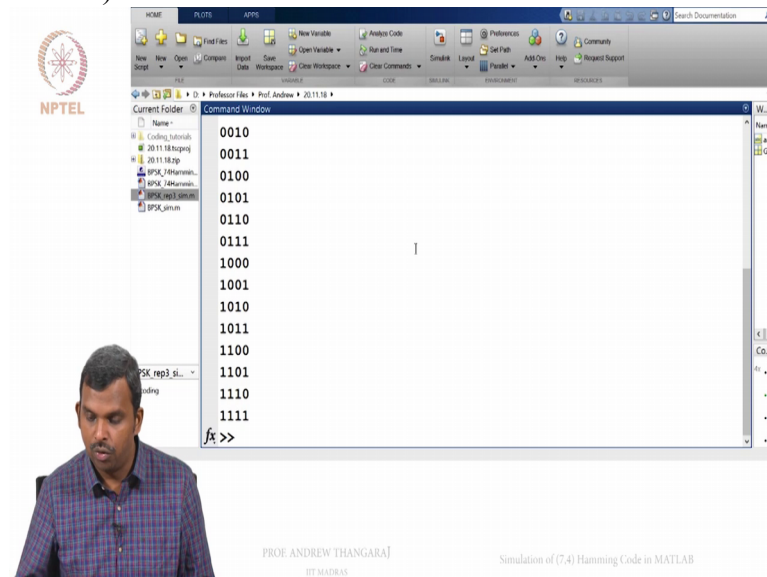
fx >> dec2bin(0:15,4)
```

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Simulation of (7,4) Hamming Code in MATLAB

So if we do this,

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NPTEL

```
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111


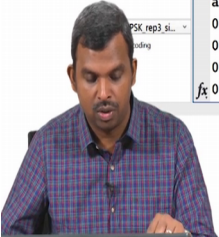
fx >>
```

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Simulation of (7,4) Hamming Code in MATLAB

it will give you the list of all binary vectors in Matlab. Ok, so

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```
>> G=[1 0 0 0 1 0 1; 0 1 0 0 1 1 1; 0 0 1 0 1 1 0; 0 0 0 1 0 1 1]
G =
    1     0     0     0     1     0     1
    0     1     0     0     1     1     1
    0     0     1     0     1     1     0
    0     0     0     1     0     1     1

>> dec2bin(0:15,4)
ans =
0000
0001
0010
0011
```



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Simulation of (7,4) Hamming Code in MATLAB

0 0 0 0, 0 0 0 1, 0 0 1 0. So the problem is this is a string and it turns out, I want to convert it into vectors, right?

I do not want a string, I want a matrix. For that I use this little trick. I usually subtract it,

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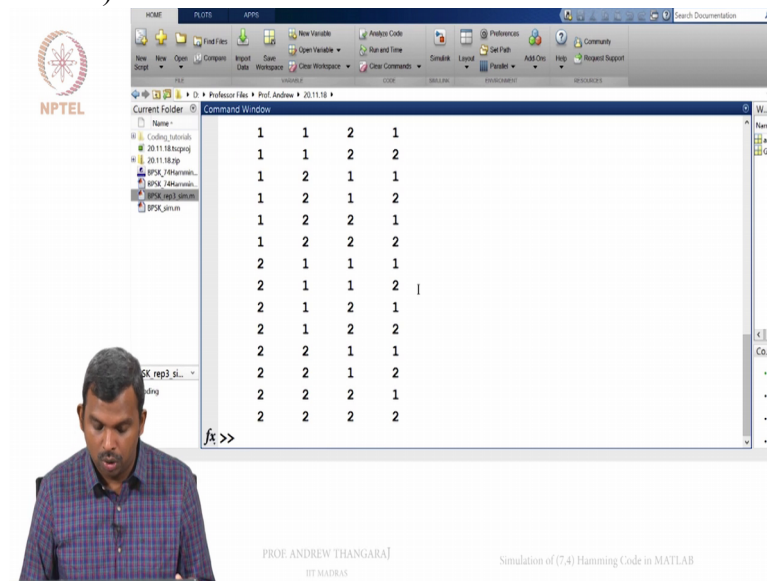
```
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111
fx>> dec2bin(0:15,4) - 47
```

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Simulation of (7,4) Hamming Code in MATLAB

I think 47

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NPTEL

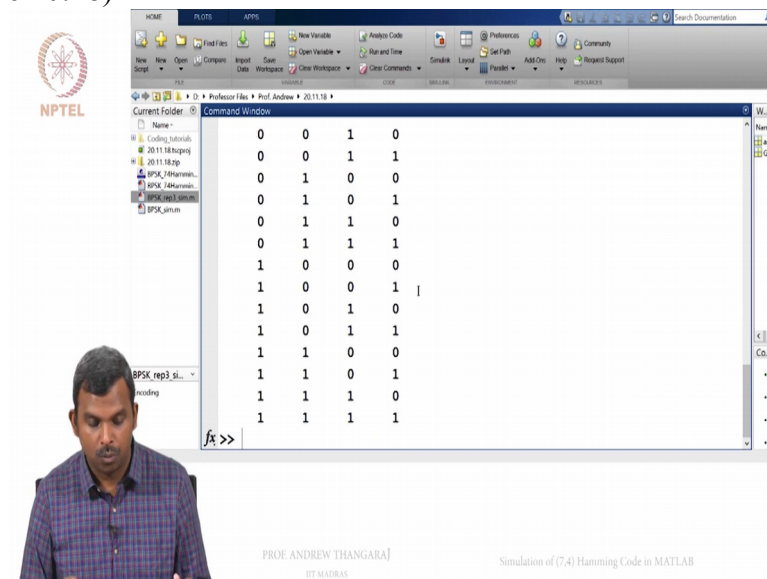
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Simulation of (7,4) Hamming Code in MATLAB

1	1	2	1
1	1	2	2
1	2	1	1
1	2	1	2
1	2	2	1
1	2	2	2
2	1	1	1
2	1	1	2
2	1	2	1
2	1	2	2
2	2	1	1
2	2	1	2
2	2	2	1
2	2	2	2

will do it, no it will not. 48 would do it.

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NPTEL



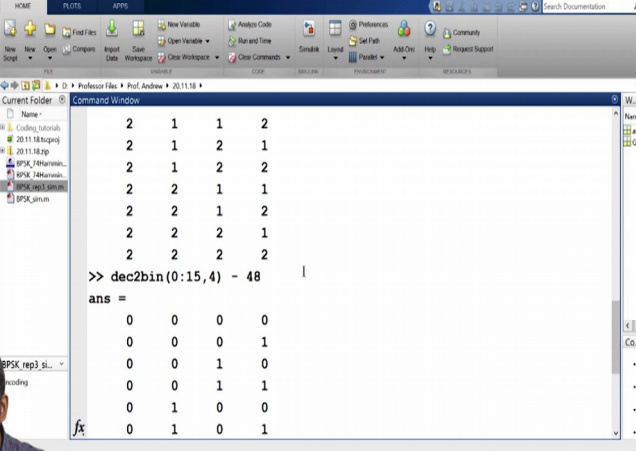
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Simulation of (7,4) Hamming Code in MATLAB

0	0	1	0
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0
0	1	1	1
1	0	0	0
1	0	0	1
1	0	1	0
1	0	1	1
1	1	0	0
1	1	0	1
1	1	1	0
1	1	1	1

Ok. So if you do d e c to b I n

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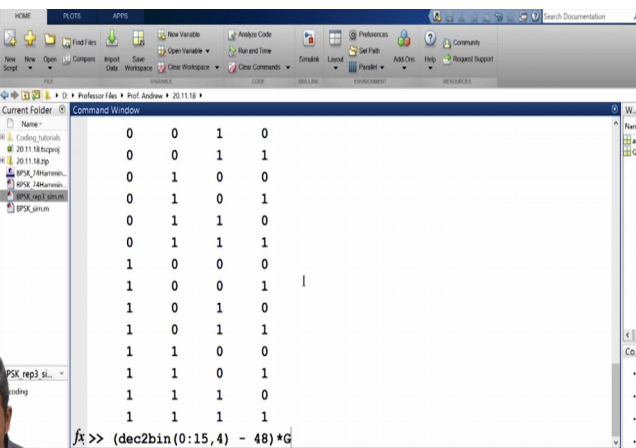
Simulation of (7,4) Hamming Code in MATLAB

and then you subtract 48 from it, Matlab does this conversion from strings to bits at least.

So you have 0 1, this is a good enough trick to use so I will do this. So this gives me the vector of all possible binary sequences of length 4. Ok, you might have other ways of generating this. So I am just generating it like this, Ok, 0 0 0 0, 0 0 0 1 so on till 1 1 1 1.

Ok this is 16 vectors here. So let us store this, you don't have to necessarily store this, you can just keep this and multiply with G on the right. Ok

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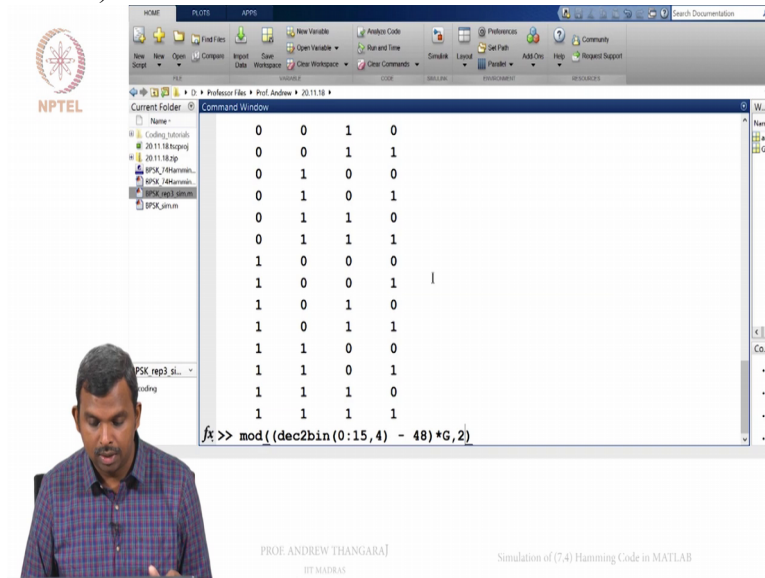
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Simulation of (7,4) Hamming Code in MATLAB

but we have to do modulo 2. If you do not do modulo 2, you won't get right answers. Ok, mod of this comma 2.



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NPTEL

Command Window

0	0	1	0
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0
0	1	1	1
1	0	0	0
1	0	0	1
1	0	1	0
1	0	1	1
1	1	0	0
1	1	0	1
1	1	1	0
1	1	1	1

fx >> mod((dec2bin(0:15,4) - 48)\*G,2)

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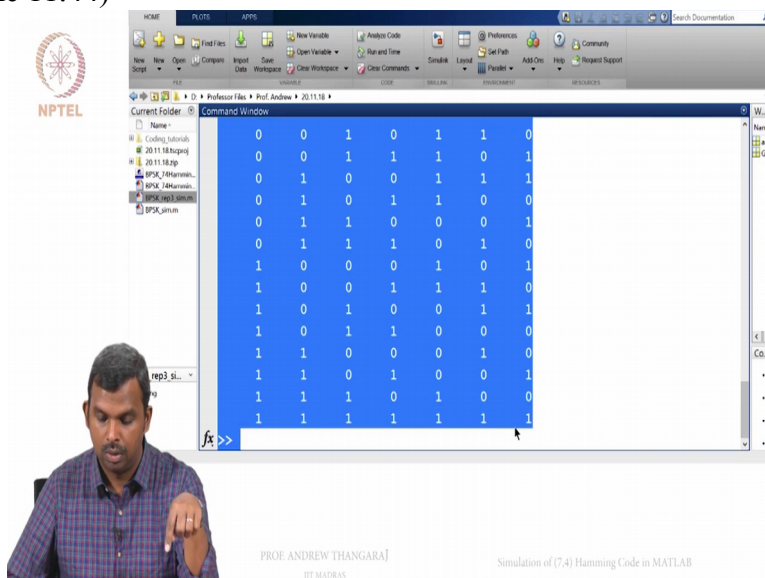
Simulation of (7,4) Hamming Code in MATLAB

So turns out this is the list of all codewords that I want, Ok.

So this is the list of all codewords in the Hamming code. You see I found all the binary sequences of length 4, multiplied with G. I did a modulo 2. I got the, I got all codewords, Ok. So you can check if you like that we got the codewords, Ok.

So now I can do a simple cut and paste from here to my editor window,

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NPTEL

Command Window

0	0	1	0	1	1	0
0	0	1	1	1	0	1
0	1	0	0	1	1	1
0	1	0	1	1	0	0
0	1	1	0	0	0	1
0	1	1	1	0	1	0
1	0	0	0	1	0	1
1	0	0	1	1	1	0
1	0	1	0	0	1	1
1	0	1	1	0	0	0
1	1	0	0	0	1	0
1	1	0	1	0	0	1
1	1	1	0	1	0	0
1	1	1	1	1	1	1

fx >>



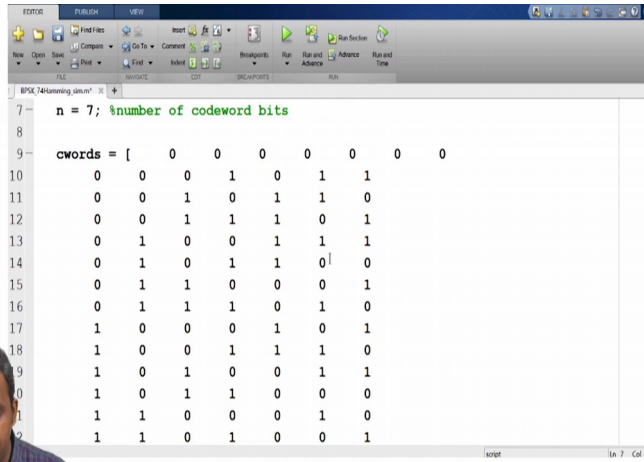
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Simulation of (7,4) Hamming Code in MATLAB

Ok. So one can, I mean one need not do it inside the simulation block. You can do it outside. I can call it Ok, codewords Ok or you can use any other notation that you like. So here I can paste it.

So it is good to put

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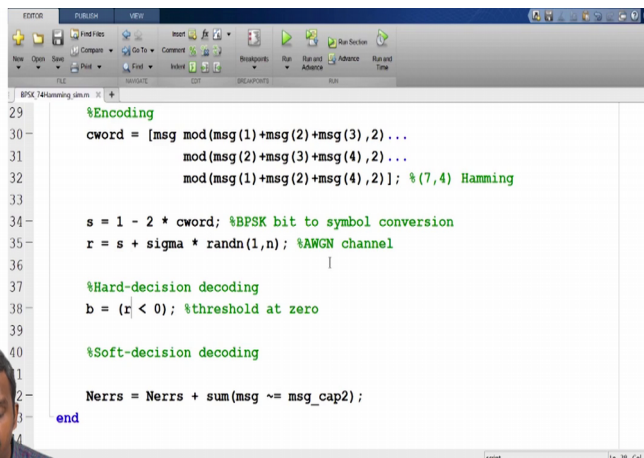
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Simulation of (7,4) Hamming Code in MATLAB

semicolons to indicate that the... So I want to immediately point out, this is something that you cannot do for long codes, Ok. So if you have, if you have say  $k$  equals 100 or 1000, this will be  $2$  power 100, you cannot list out all the codewords like this but for us it is Ok.

So this is a small enough operation. You can do it very easily, Ok. So once I have the list of codewords

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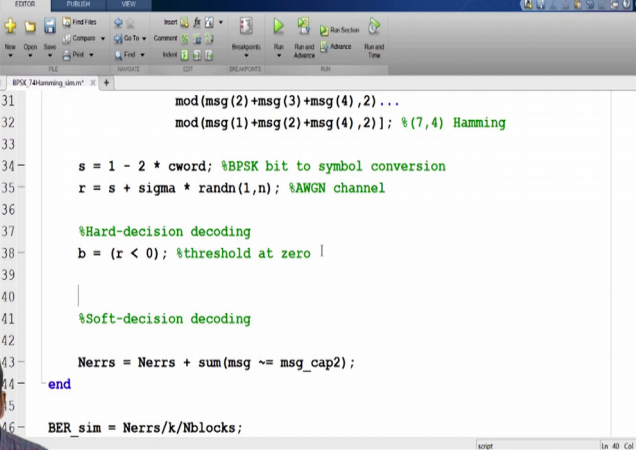






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Simulation of (7,4) Hamming Code in MATLAB

and I have my hard decision vector  $b$ , it is relatively easy to write down the hard decision decoding, Ok.

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```
31 mod(msg(2)+msg(3)+msg(4),2)...
32 mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39
40 %Soft-decision decoding
41
42
43 Nerrs = Nerrs + sum(msg ~= msg_cap2);
44 end
45
46 BER_sim = Nerrs/k/Nblocks;
```

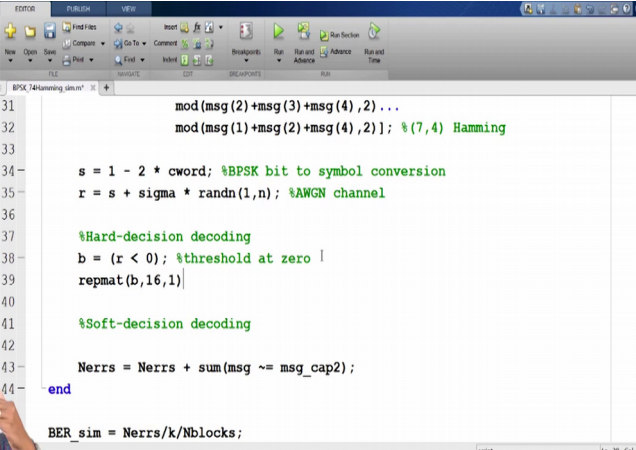
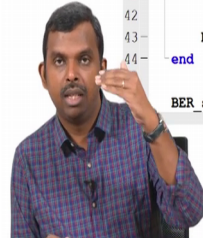

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Simulation of (7,4) Hamming Code in MATLAB

So I have to find the distance between this vector b and every codeword in my array c words, Ok. So I had the list of all codewords. I have to find the distance between this and that, Ok. So even for this I am going to use a little bit of a device here. It is just to get it done very quickly.

So I can do this repeating the matrix, Ok. So I will do it 16 times 1, Ok. So this will create a vector of b

(Refer Slide Time 13:35)




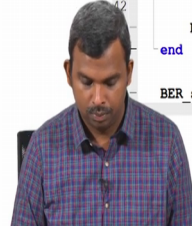
```
31 mod(msg(2)+msg(3)+msg(4),2)...
32 mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 repmat(b,16,1)
40
41 %Soft-decision decoding
42
43 Nerrs = Nerrs + sum(msg ~= msg_cap2);
44 end
45
46 BER_sim = Nerrs/k/Nblocks;
```

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Simulation of (7,4) Hamming Code in MATLAB

repeated 16 times. So you can try this out if you have installation, Ok. And then I will add it to c words and do a modulo 2,

(Refer Slide Time 13:47)



```

31      mod(msg(2)+msg(3)+msg(4),2)...
32      mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34      s = 1 - 2 * cword; %BPSK bit to symbol conversion
35      r = s + sigma * randn(1,n); %AWGN channel
36
37      %Hard-decision decoding
38      b = (r < 0); %threshold at zero
39      repmat(b,16,1)*cwords
40
41      %Soft-decision decoding
42
43      Nerrs = Nerrs + sum(msg ~= msg_cap2);
44  end
45
46  BER_sim = Nerrs/k/Nblocks;
  
```

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Simulation of (7,4) Hamming Code in MATLAB

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```

31      mod(msg(2)+msg(3)+msg(4),2)...
32      mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34      s = 1 - 2 * cword; %BPSK bit to symbol conversion
35      r = s + sigma * randn(1,n); %AWGN channel
36
37      %Hard-decision decoding
38      b = (r < 0); %threshold at zero
39      mod(repmat(b,16,1)+cwords,2)
40
41      %Soft-decision decoding
42
43      Nerrs = Nerrs + sum(msg ~= msg_cap2);
44  end
45
46  BER_sim = Nerrs/k/Nblocks;
  
```



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Simulation of (7,4) Hamming Code in MATLAB

Ok this will give me the XORs; I am XORing b with every possible codeword, Ok.

And then what do I do, Ok so this gives me just the XORs of all the codewords and now I can look at the weights, right? So, so this I will call as the distance array, Ok.

(Refer Slide Time 14:14)

```



31      mod(msg(2)+msg(3)+msg(4),2)...
32      mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34      s = 1 - 2 * cword; %BPSK bit to symbol conversion
35      r = s + sigma * randn(1,n); %AWGN channel
36
37      %Hard-decision decoding
38      b = (r < 0); %threshold at zero
39      dist = mod(repmat(b,16,1)+cwords,2)
40
41      %Soft-decision decoding
42
43      Nerrs = Nerrs + sum(msg ~= msg_cap2);
44  end
45
46  BER_sim = Nerrs/k/Nblocks;
  
```

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Simulation of (7,4) Hamming Code in MATLAB

So this is just the XORs, so how do I find the weight? So it turns out you can multiply a vector on the right, Ok and this will give me the distances,

(Refer Slide Time 14:32)

```

31      mod(msg(2)+msg(3)+msg(4),2)...
32      mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34      s = 1 - 2 * cword; %BPSK bit to symbol conversion
35      r = s + sigma * randn(1,n); %AWGN channel
36
37      %Hard-decision decoding
38      b = (r < 0); %threshold at zero
39      dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40
41      %Soft-decision decoding
42
43      Nerrs = Nerrs + sum(msg ~= msg_cap2);
44  end
45
46  BER_sim = Nerrs/k/Nblocks;
  
```

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Simulation of (7,4) Hamming Code in MATLAB



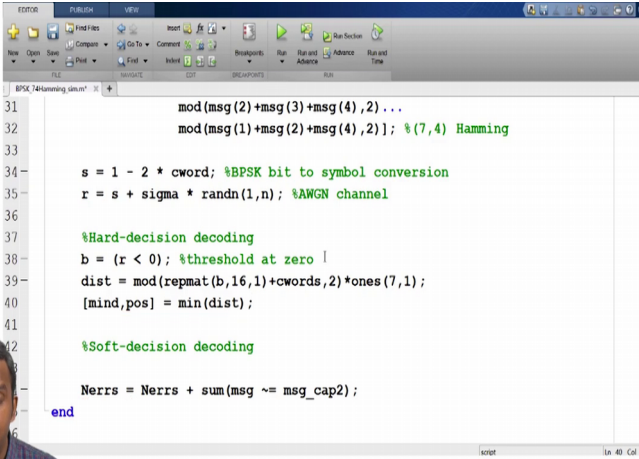
Ok.

So I will illustrate it may be later on we will see how this works out. So I am repeating the received vector b 16 times, I am doing XOR with each codeword. I get a list of XORs, they are 16 in number each is a vector of length 7. How do I find the weight of that now?

I multiply on the right with 1s of 7 comma 1. So it simply multiplies and adds up and gives me the weight, Ok. So I am not done now. I have to find, out of all these guys the one which has the least distance, Ok.

So that one can find using this min, so min d comma position equals min of distance. So of all these distances which one

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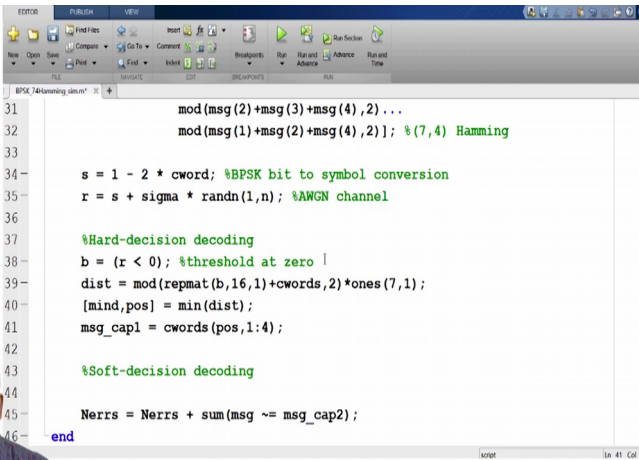
Simulation of (7,4) Hamming Code in MATLAB

```

31      mod(msg(2)+msg(3)+msg(4),2)...
32      mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34      s = 1 - 2 * cword; %BPSK bit to symbol conversion
35      r = s + sigma * randn(1,n); %AWGN channel
36
37      %Hard-decision decoding
38      b = (r < 0); %threshold at zero
39      dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40      [mind,pos] = min(dist);
41
42      %Soft-decision decoding
43
44      Nerrs = Nerrs + sum(msg ~= msg_cap2);
45  end
  
```

is the minimum, Ok? So that this solves and then once I know p o s, the minimum itself does not really matter. I can find message cap 1 as c words of pos comma 1 colon 4,

(Refer Slide Time 15:47)

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Simulation of (7,4) Hamming Code in MATLAB

```

31      mod(msg(2)+msg(3)+msg(4),2)...
32      mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34      s = 1 - 2 * cword; %BPSK bit to symbol conversion
35      r = s + sigma * randn(1,n); %AWGN channel
36
37      %Hard-decision decoding
38      b = (r < 0); %threshold at zero
39      dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40      [mind,pos] = min(dist);
41      msg_cap1 = cwords(pos,1:4);
42
43      %Soft-decision decoding
44
45      Nerrs = Nerrs + sum(msg ~= msg_cap2);
46  end
  
```



Ok.



So hopefully it was clear to people. I wrote it down a bit quickly. Think about what I am doing. I am finding the distance between  $b$  and every possible codeword and finding that codeword which is closest minimum distance between this and that, Ok. So let us do, so we will run this. I mean I have to check if I have made any mistakes or not. Maybe I made a mistake.

When we ran it we will know if it causes any errors, we will go and look at it and check it out, we will do that at that time. So soft decision decoding, it is similar except that the distance is going to be, it is not distance, I will call it correlation, correlation is going to be with the received word  $r$  but I am going to have the list of symbol vectors. So it is  $1 - 2$  into  $c$  words multiplied by the transpose of  $r$ .

(Refer Slide Time 16:47)

```

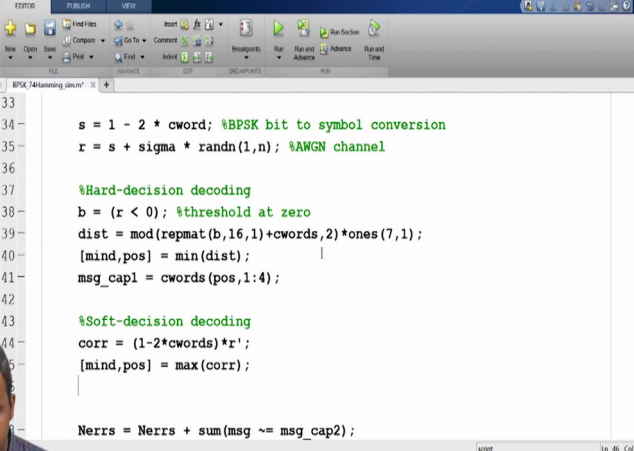


33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45
46 Nerrs = Nerrs + sum(msg ~= msg_cap2);
47 end
  
```

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Simulation of (7,4) Hamming Code in MATLAB

Ok, so this will give me the list of all correlations and once again find min and pos but in this case, I have to do max, max of correlation

(Refer Slide Time 16:59)



```
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind,pos] = max(corr);
46
47 Nerrs = Nerrs + sum(msg ~= msg_cap2);
```

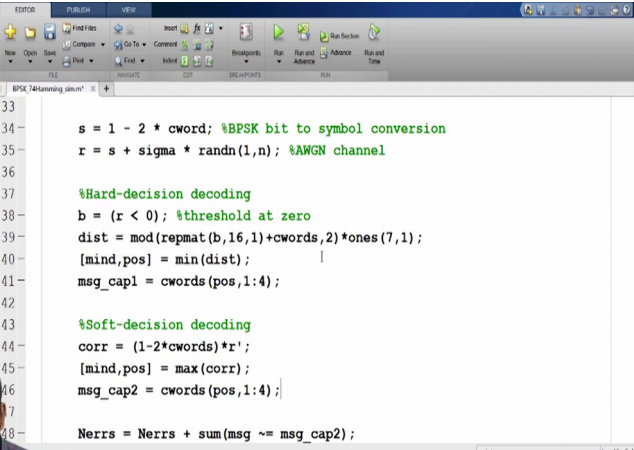


script Lin 46 Col 5

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Simulation of (7,4) Hamming Code in MATLAB

and then what I have here is the same,

(Refer Slide Time 17:08)



```
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = Nerrs + sum(msg ~= msg_cap2);
```

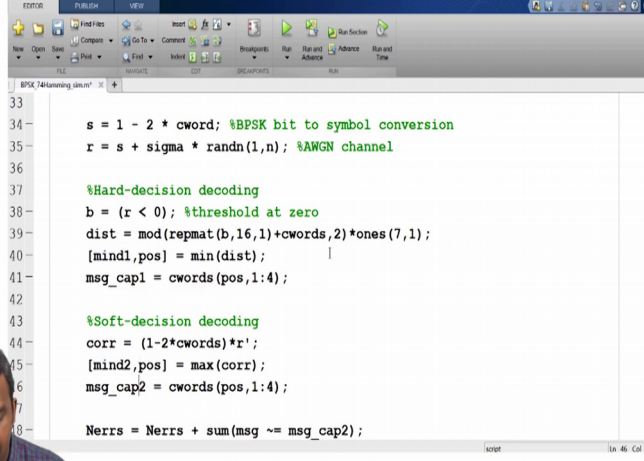


script Lin 46 Col 32

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Simulation of (7,4) Hamming Code in MATLAB

Ok. So, so Matlab is pointing out that, Ok so maybe I will call m ind1, m ind2 just to keep

(Refer Slide Time 17:19)



```
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind1,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = Nerrs + sum(msg ~= msg_cap2);
49
50 end
```

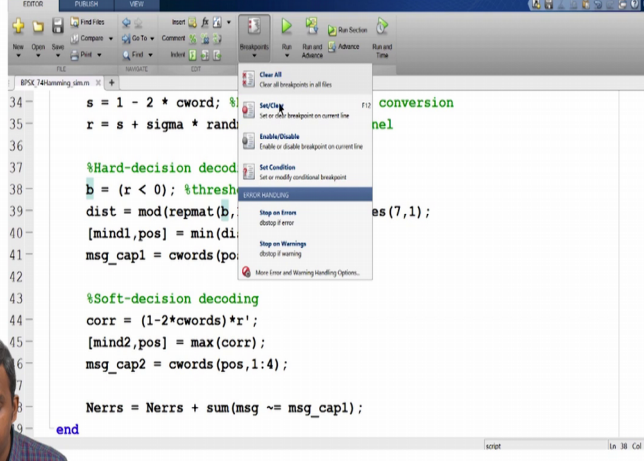


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Simulation of (7,4) Hamming Code in MATLAB

Matlab happy and then this is just a, just a way of counting errors. May be I will use hard decision decoder first, Ok.

So let us see how this works. So one useful thing I do usually when I run this is I put a breakpoint here

(Refer Slide Time 17:40)





```
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind1,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = Nerrs + sum(msg ~= msg_cap2);
49
50 end
```

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Simulation of (7,4) Hamming Code in MATLAB

and then

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```



34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind1,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = Nerrs + sum(msg ~= msg_cap1);
49 end
  
```

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Simulation of (7,4) Hamming Code in MATLAB

I run it to see what is going on. So maybe, maybe we will put lower

(Refer Slide Time 17:46)

```



1 EbNodB = 1;
2 R = 4/7; % (7,4) Hamming (4/7 bits/symbol)
3 EbNo = 10^(EbNodB/10);
4 sigma = sqrt(1/(2*R*EbNo));
5
6 k = 4; %number of message bits
7 n = 7; %number of codeword bits
8
9 cwords = [0 0 0 0 0 0 0;
10 0 0 0 1 0 1 1;
11 0 0 1 0 1 1 0;
12 0 0 1 1 1 0 1;
13 0 1 0 0 1 1 1;
14 0 1 0 1 1 0 0;
15 0 1 1 0 0 0 1;
16 0 1 1 1 0 1 0];
  
```

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Simulation of (7,4) Hamming Code in MATLAB

$E_b/N_0$  and then let us just

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```

31 cword = [msg(mod(msg(1)+msg(2)+msg(3)+msg(4),2)...
32         mod(msg(2)+msg(3)+msg(4),2)...
33         mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
34
35 s = 1 - 2 * cword; %BPSK bit to symbol conversion
36 r = s + sigma * randn(1,n); %AWGN channel
37
38 %Hard-decision decoding
39 b = (r < 0); %threshold at zero
40 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
41 [mind1,pos] = min(dist);
42 msg_cap1 = cwords(pos,1:4);
43
44 %Soft-decision decoding
45 corr = (1-2*cwords)*r';
46 [mind2,pos] = max(corr);
  
```



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Simulation of (7,4) Hamming Code in MATLAB

run it, Ok.

So it has come up to this point and stopped and to see what it is doing, you can go

(Refer Slide Time 17:54)

```

>> BPSK_74Hamming_sim
fx K>>
  
```

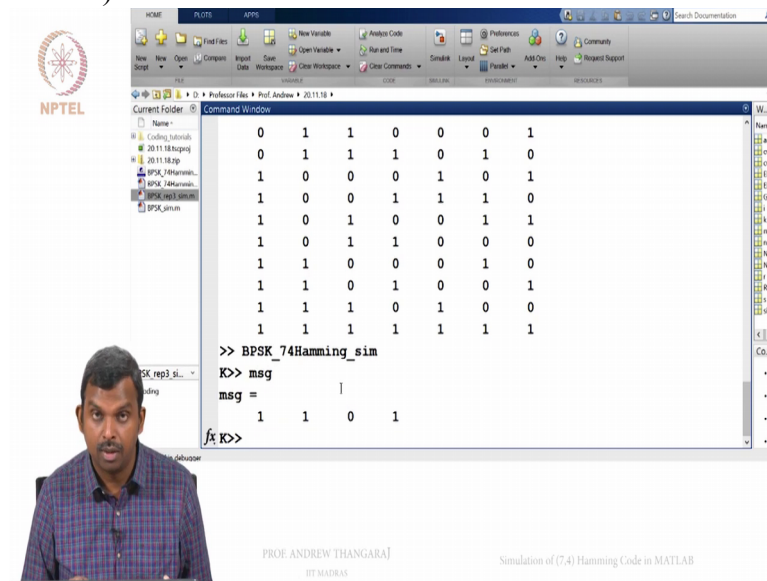
0	0	1	1	1	0	1
0	1	0	0	1	1	1
0	1	0	1	1	0	0
0	1	1	0	0	0	1
0	1	1	1	0	1	0
1	0	0	0	1	0	1
1	0	0	1	1	1	0
1	0	1	0	0	1	1
1	0	1	1	0	0	0
1	1	0	0	0	1	0
1	1	0	1	0	0	1
1	1	1	0	1	0	0
1	1	1	1	1	1	1

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Simulation of (7,4) Hamming Code in MATLAB

here and look at the message that was generated,

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NPTEL

Command Window

```

0 1 1 0 0 0 1
0 1 1 1 0 1 0
1 0 0 0 1 0 1
1 0 0 1 1 1 0
1 0 1 0 0 1 1
1 0 1 1 0 0 0
1 1 0 0 0 1 0
1 1 0 1 0 0 1
1 1 1 0 1 0 0
1 1 1 1 1 1 1

>> BPSK_74Hamming_sim
K>> msg
msg =
    1

K>> cword
cword =
    1    1    0    1

K>>

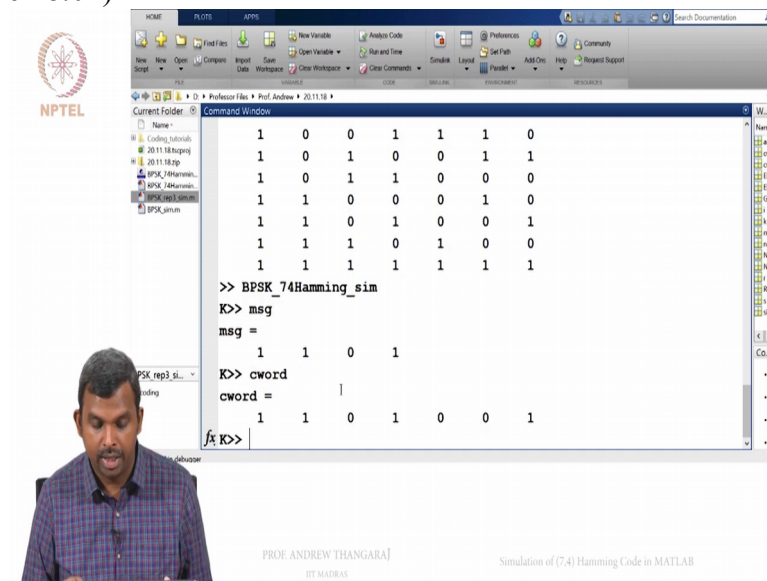
```

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Simulation of (7,4) Hamming Code in MATLAB

1 1 0 1, the c word

(Refer Slide Time 18:01)



NPTEL

Command Window

```

1 0 0 1 1 1 0
1 0 1 0 0 1 1
1 0 1 1 0 0 0
1 1 0 0 0 1 0
1 1 0 1 0 0 1
1 1 1 0 1 0 0
1 1 1 1 1 1 1

>> BPSK_74Hamming_sim
K>> msg
msg =
    1    1    0    1

K>> cword
cword =
    1    1    0    1    0    0    1

K>>

```

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Simulation of (7,4) Hamming Code in MATLAB

that was generated 1 1 0 1 0 0 1 and then s



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Simulation of (7,4) Hamming Code in MATLAB

```

>> BPSK_74Hamming_sim
K>> msg
msg =
    1    1    0    0
K>> cword
cword =
    1    1    0    1    0    0    1
K>> s
s =
   -1   -1    1   -1    1    1   -1
K>>
  
```

which is minus 1 minus 1 1 etc and then r,

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Simulation of (7,4) Hamming Code in MATLAB

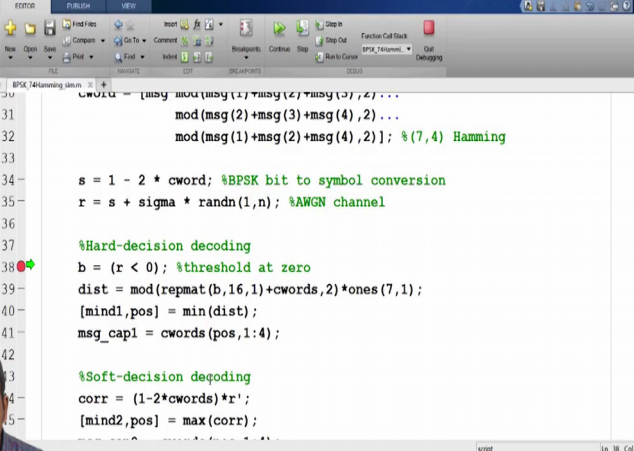


```

msg =
    1    1    0    1
K>> cword
cword =
    1    1    0    1    0    0    1
K>> s
s =
   -1   -1    1   -1    1    1   -1
K>> r
r =
Columns 1 through 6
   -0.7342   -2.0902    0.6385   -0.7144    3.9833    3.3088
Column 7
   -2.1254
K>>
  
```

Ok.

So you can see noise got added. Lot of things have happened. It does not appear there has been an error but nevertheless let us see what happens, Ok. So this is r,

(Refer Slide Time 18:26)



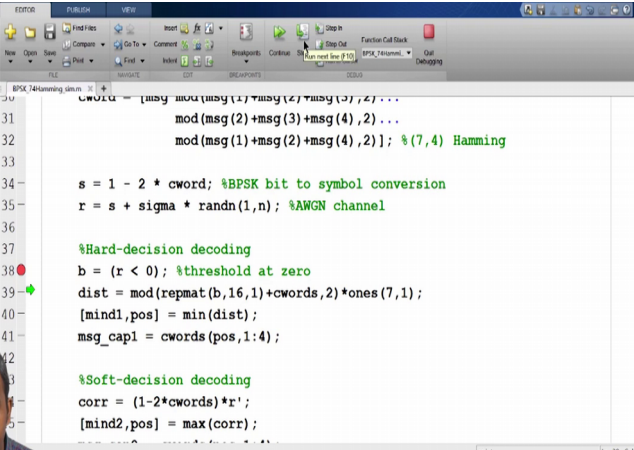


```
31 cword = [msg mod(msg(1)+msg(2)+msg(3)+msg(4),2) ...
32         mod(msg(2)+msg(3)+msg(4),2) ...
33         mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
34
35 s = 1 - 2 * cword; %BPSK bit to symbol conversion
36 r = s + sigma * randn(1,n); %AWGN channel
37
38 %Hard-decision decoding
39 b = (r < 0); %threshold at zero
40 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
41 [mind1,pos] = min(dist);
42 msg_cap1 = cwords(pos,1:4);
43
44 %Soft-decision decoding
45 corr = (1-2*cwords)*r';
46 [mind2,pos] = max(corr);
```

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Simulation of (7,4) Hamming Code in MATLAB

Ok. So I am going to run one step, so I will get

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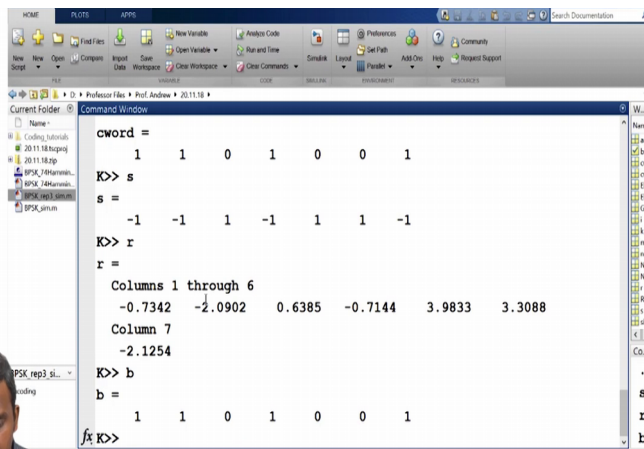
```
31 cword = [msg mod(msg(1)+msg(2)+msg(3)+msg(4),2) ...
32         mod(msg(2)+msg(3)+msg(4),2) ...
33         mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
34
35 s = 1 - 2 * cword; %BPSK bit to symbol conversion
36 r = s + sigma * randn(1,n); %AWGN channel
37
38 %Hard-decision decoding
39 b = (r < 0); %threshold at zero
40 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
41 [mind1,pos] = min(dist);
42 msg_cap1 = cwords(pos,1:4);
43
44 %Soft-decision decoding
45 corr = (1-2*cwords)*r';
46 [mind2,pos] = max(corr);
```

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Simulation of (7,4) Hamming Code in MATLAB

b, Ok. So let us check what b is,

(Refer Slide Time 18:35)



The MATLAB Command Window shows the following commands and outputs:

```

cword =
    1     1     0     1     0     0     1
K> s
s =
   -1   -1     1   -1     1     1   -1
K> r
r =
Columns 1 through 6
   -0.7342   -2.0902    0.6385   -0.7144    3.9833    3.3088
Column 7
   -2.1254
K> b
b =
    1     1     0     1     0     0     1
K>
  
```

NPTEL

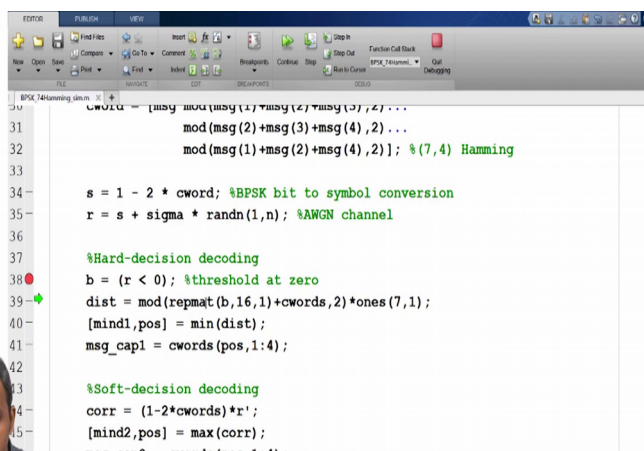
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Simulation of (7,4) Hamming Code in MATLAB

Ok.

So it sort of agrees with the codeword here but nevertheless let us to go through

(Refer Slide Time 18:40)



The MATLAB Editor shows the following code for decoding:

```

31 cword = [msg(1)+msg(2)+msg(3)+msg(4), 2*...
32         mod(msg(2)+msg(3)+msg(4),2)...
33         mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
34
35 s = 1 - 2 * cword; %BPSK bit to symbol conversion
36 r = s + sigma * randn(1,n); %AWGN channel
37
38 %Hard-decision decoding
39 b = (r < 0); %threshold at zero
40 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
41 [mind1,pos] = min(dist);
42 msg_cap1 = cwords(pos,1:4);
43
44 %Soft-decision decoding
45 corr = (1-2*cwords)*r';
46 [mind2,pos] = max(corr);
  
```



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Simulation of (7,4) Hamming Code in MATLAB

what the decoder is going to do. It is going to find distance,

(Refer Slide Time 18:43)

```



31 cword = [msg mod(msg(1)+msg(2)+msg(3)+msg(4),2)...
32         mod(msg(2)+msg(3)+msg(4),2)...
33         mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
34
35 s = 1 - 2 * cword; %BPSK bit to symbol conversion
36 r = s + sigma * randn(1,n); %AWGN channel
37
38 %Hard-decision decoding
39 b = (r < 0); %threshold at zero
40 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
41 [mind1,pos] = min(dist);
42 msg_cap1 = cwords(pos,1:4);
43
44 %Soft-decision decoding
45 corr = (1-2*cwords)*r';
46 [mind2,pos] = max(corr);
  
```

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Simulation of (7,4) Hamming Code in MATLAB

Ok. So let me show you how this worked. It gave you a array of distance.

(Refer Slide Time 18:49)

```

7
4
4
3
3
4
3
4
4
3
3
0
4
3
  
```

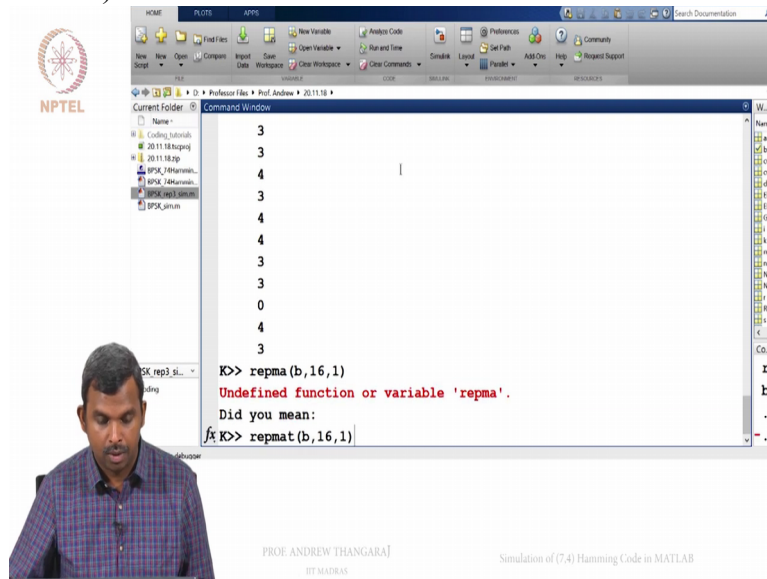
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Simulation of (7,4) Hamming Code in MATLAB

It tells you what the distances are from every possible codeword, Ok.

So how did it work? We did this repmat of b comma 16 comma 1,

(Refer Slide Time 19:05)



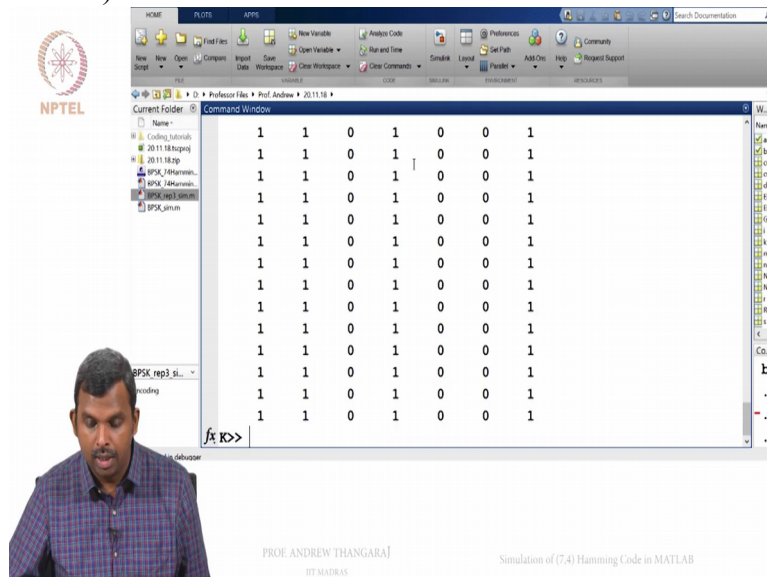
The screenshot shows the MATLAB Command Window with the following text:

```
K>> repma(b,16,1)
Undefined function or variable 'repma'.
Did you mean:
fx K>> repmat(b,16,1)
```

The video frame shows Prof. Andrew Thangaraj, a man with short dark hair wearing a blue and white checkered shirt, looking at the screen. The NPTEL logo is in the top left corner. The bottom of the slide contains the text "PROF. ANDREW THANGARAJ" and "Simulation of (7,4) Hamming Code in MATLAB".

sorry Ok

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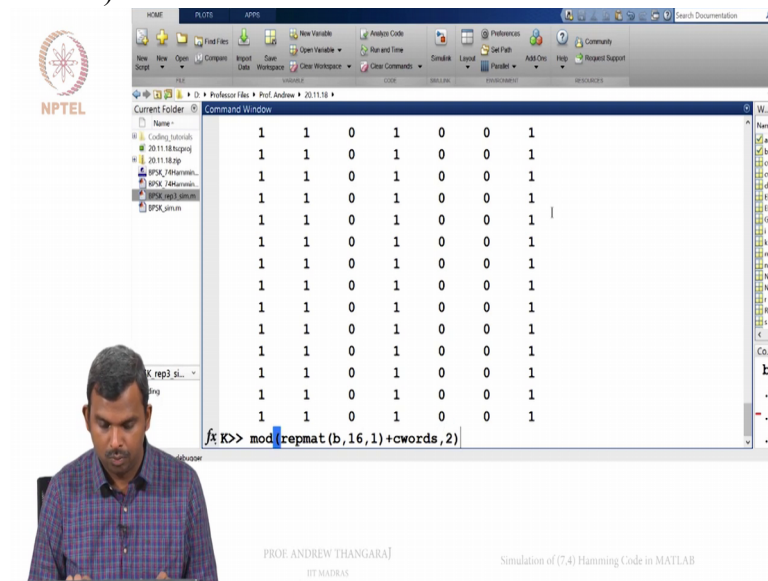
The screenshot shows the MATLAB Command Window displaying a 16x7 matrix of ones:

```
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
1 1 0 1 0 0 1
```

The video frame shows Prof. Andrew Thangaraj, a man with short dark hair wearing a blue and white checkered shirt, looking at the screen. The NPTEL logo is in the top left corner. The bottom of the slide contains the text "PROF. ANDREW THANGARAJ" and "Simulation of (7,4) Hamming Code in MATLAB".

so it repeated the same received vector 16 times. And then I did a XOR of this with my c words,

(Refer Slide Time 19:26)



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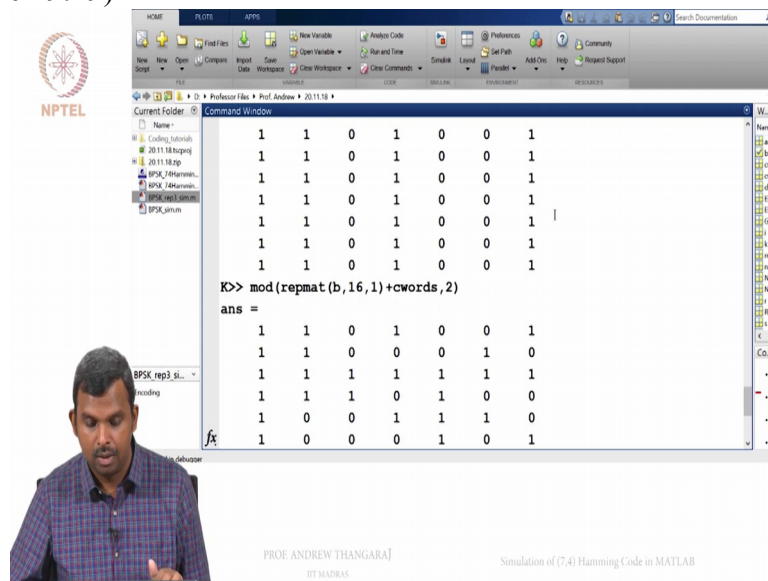
Simulation of (7,4) Hamming Code in MATLAB

1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1

K>> mod(repmat(b,16,1)+cwords,2)

Ok so this gave me all the distances,

(Refer Slide Time 19:29)



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Simulation of (7,4) Hamming Code in MATLAB

1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1
1	1	0	1	0	0	1

K>> mod(repmat(b,16,1)+cwords,2)

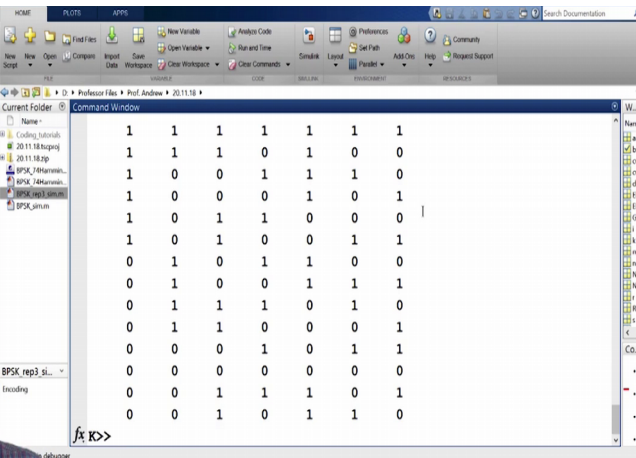
ans =

1	1	0	1	0	0	1
1	1	0	0	0	1	0
1	1	1	1	1	1	1
1	1	1	0	1	0	0
1	0	0	1	1	1	0
1	0	0	0	1	0	1

Ok. How do I find the weight of each



(Refer Slide Time 19:31)



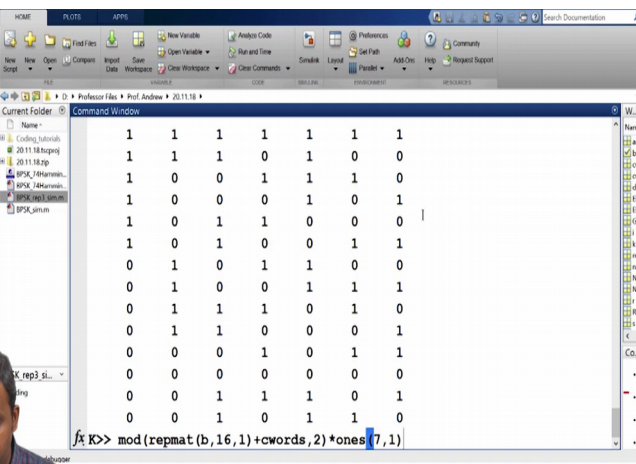
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of these guys? I simply multiply the right with 1s of 7 comma 1.

(Refer Slide Time 19:37)



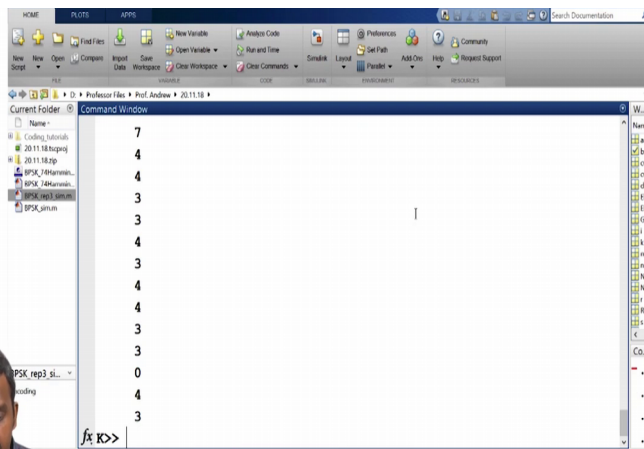
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So this gives me this vector,

(Refer Slide Time 19:38)



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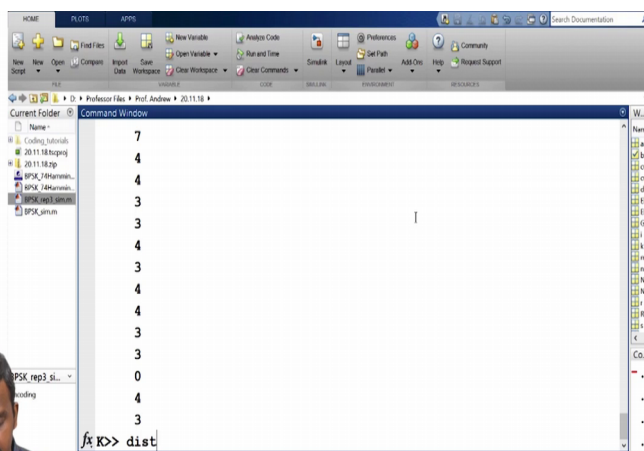
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Ok.

So this is the same as my dist vector,

(Refer Slide Time 19:42)



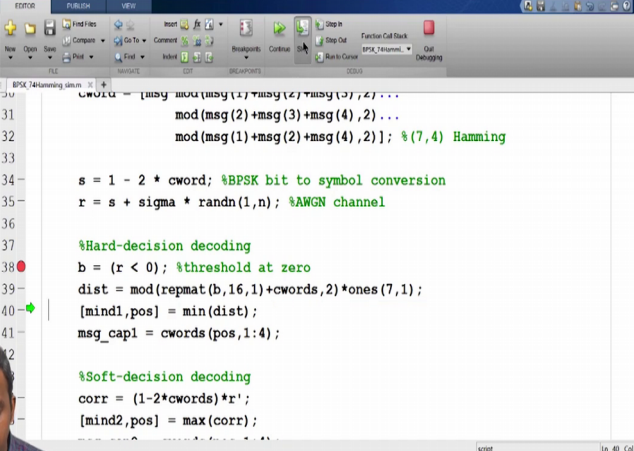


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Ok. So the next step finds the minimum

(Refer Slide Time 19:47)



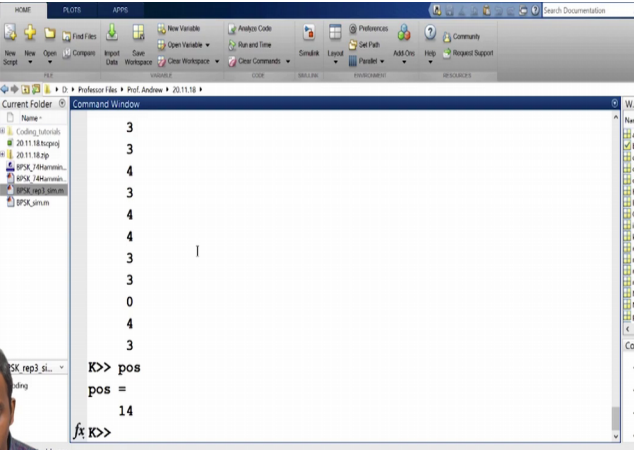


```
31 cwords = [msg mod(msg(1)+msg(2)+msg(3)+msg(4),2)...
32           mod(msg(2)+msg(3)+msg(4),2)...
33           mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
34
35 s = 1 - 2 * cword; %BPSK bit to symbol conversion
36 r = s + sigma * randn(1,n); %AWGN channel
37
38 %Hard-decision decoding
39 b = (r < 0); %threshold at zero
40 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
41 [mind1,pos] = min(dist);
42 msg_cap1 = cwords(pos,1:4);
43
44 %Soft-decision decoding
45 corr = (1-2*cwords)*r';
46 [mind2,pos] = max(corr);
```

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and then sets the message cap. So let us check what it did. The position

(Refer Slide Time 19:55)



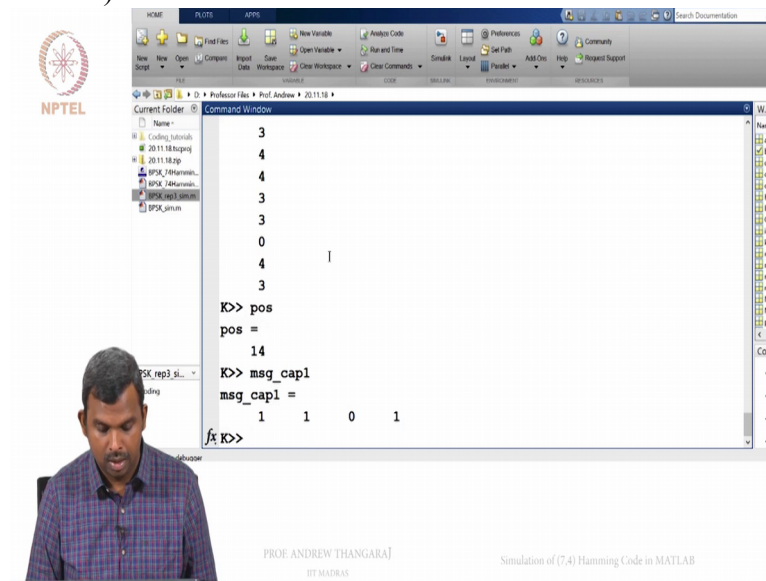
```
3
3
4
3
4
4
3
3
0
4
3
K>> pos
pos =
14
K>>
```

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Simulation of (7,4) Hamming Code in MATLAB

is 14 and message cap 1

(Refer Slide Time 19:59)



The image shows a MATLAB Command Window with the following code and output:

```
K>> pos
pos =
    14
K>> msg_cap1
msg_cap1 =
     1     1     0     1
fx K>>
```

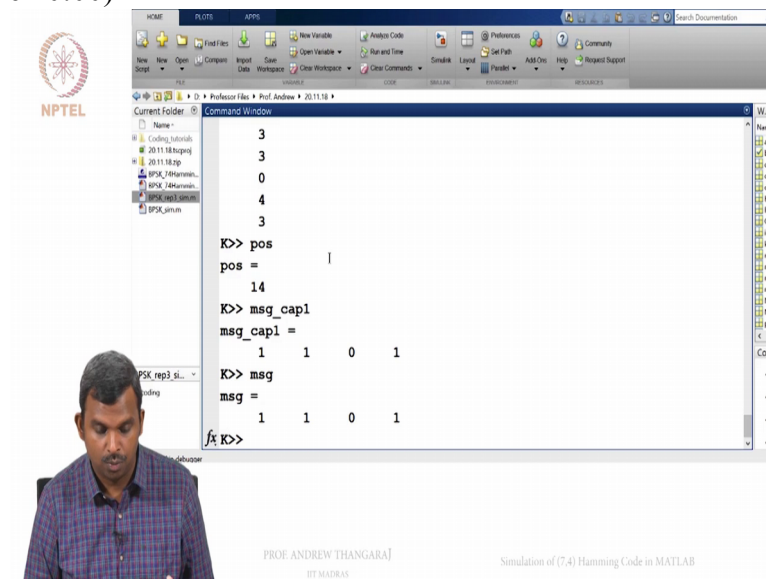
The output shows the position of the error (pos = 14) and the corrected message (msg\_cap1 = [1 1 0 1]).

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Simulation of (7,4) Hamming Code in MATLAB

agrees with the message,

(Refer Slide Time 20:00)



The image shows a MATLAB Command Window with the following code and output:

```
K>> pos
pos =
    14
K>> msg_cap1
msg_cap1 =
     1     1     0     1
K>> msg
msg =
     1     1     0     1
fx K>>
```

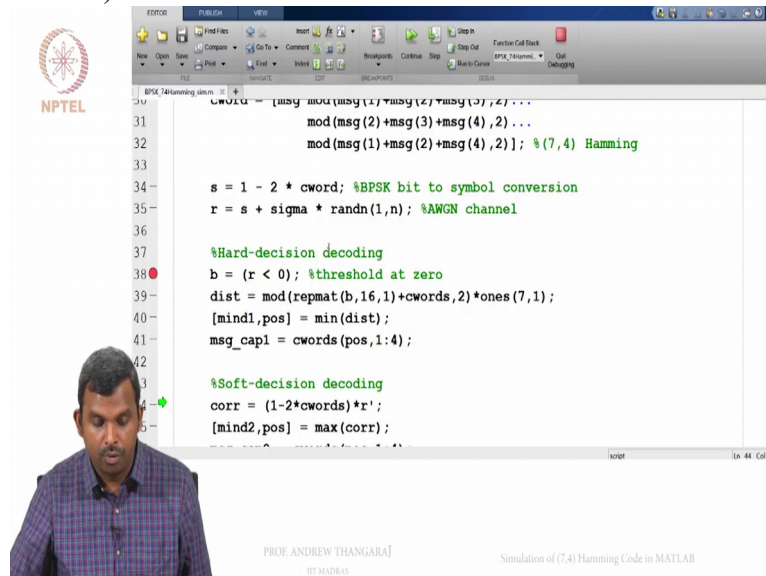
The output shows the position of the error (pos = 14) and the corrected message (msg\_cap1 = [1 1 0 1]).

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Simulation of (7,4) Hamming Code in MATLAB

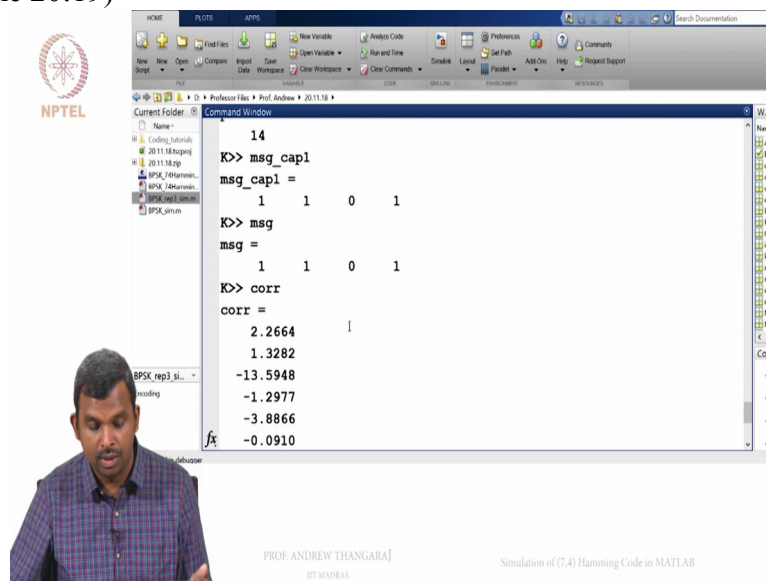
Ok. So this was how the decoder worked.

(Refer Slide Time 20:03)



So let us see if my soft decision decoding is implemented correctly or not. The first step is the correlation, Ok. So remember it works with the soft decision decoding. So correlation will be number, Ok

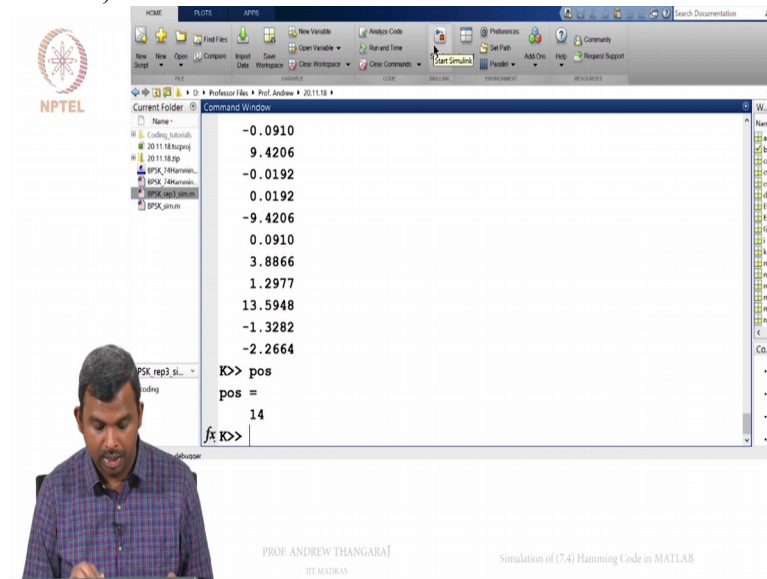
(Refer Slide Time 20:19)



see you get a whole bunch of numbers. The next step is the max of the correlation and assigning message cap.

So pos, again

(Refer Slide Time 20:30)



The image shows a MATLAB Command Window with the following output:

```
-0.0910  
9.4206  
-0.0192  
0.0192  
-9.4206  
0.0910  
3.8866  
1.2977  
13.5948  
-1.3282  
-2.2664  
K> pos  
pos =  
14  
fx K>
```

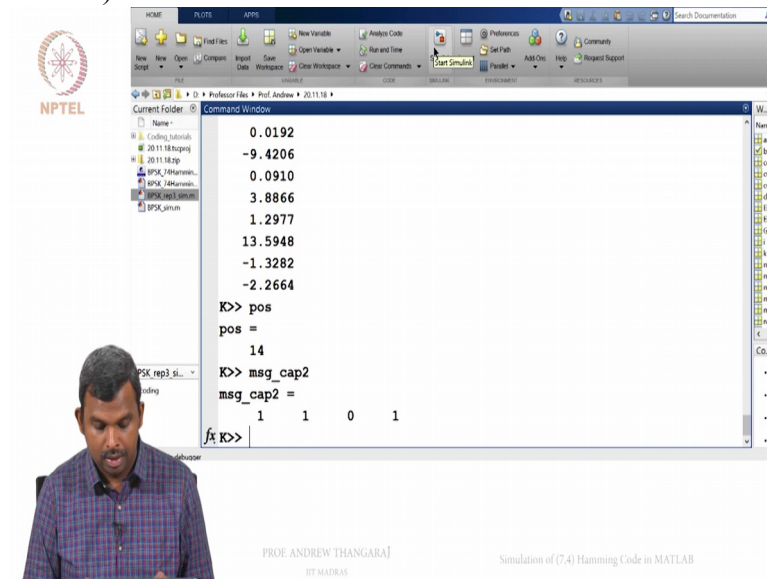
The output displays a list of 11 numerical values, followed by the command `K> pos` and the result `pos = 14`. The MATLAB interface includes a file browser on the left and a command window on the right. The NPTEL logo is visible in the top left corner.

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Simulation of (7,4) Hamming Code in MATLAB

it is 14 and message cap 2

(Refer Slide Time 20:33)



The image shows a MATLAB Command Window with the following output:

```
0.0192  
-9.4206  
0.0910  
3.8866  
1.2977  
13.5948  
-1.3282  
-2.2664  
K> pos  
pos =  
14  
K> msg_cap2  
msg_cap2 =  
1 1 0 1  
fx K>
```

The output displays a list of 8 numerical values, followed by the command `K> pos` and the result `pos = 14`, and then the command `K> msg_cap2` and the result `msg_cap2 = 1 1 0 1`. The MATLAB interface includes a file browser on the left and a command window on the right. The NPTEL logo is visible in the top left corner.

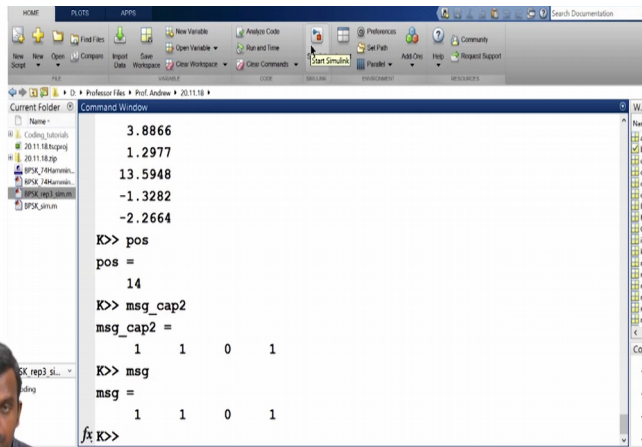
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Simulation of (7,4) Hamming Code in MATLAB

and message also agrees.



(Refer Slide Time 20:35)



The MATLAB Command Window displays the following output:

```

3.8866
1.2977
13.5948
-1.3282
-2.2664

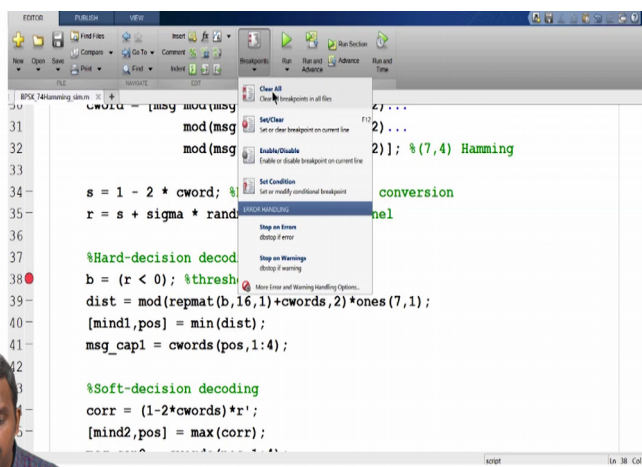
K> pos
pos =
    14
K> msg_cap2
msg_cap2 =
     1     1     0     1
K> msg
msg =
     1     1     0     1
K>

```

Below the Command Window, a video inset shows Prof. Andrew Thangaraj speaking. The slide footer includes the NPTEL logo, the text "PROF. ANDREW THANGARAJ IIT MADRAS", and the title "Simulation of (7,4) Hamming Code in MATLAB".

So it is just a easy enough calculation. So this is something that I typically do, just continue and you can quit debugging, Ok.

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The MATLAB Editor displays the following code:

```



31 cword = randi(2, 1, 16);
32 mod(msg, 2) = mod(cword, 2);
33 mod(msg, 2) = mod(cword, 2);
34
35 s = 1 - 2 * cword; %
36 r = s + sigma * randn(1, 16); %
37
38 %Hard-decision decoding
39 b = (r < 0); %threshold
40 dist = mod( repmat(b, 16, 1) + cword, 2) * ones(7, 1);
41 [mind1, pos] = min(dist);
42 msg_cap1 = cword(pos, 1:4);
43
44 %Soft-decision decoding
45 corr = (1 - 2 * cword) * r';
46 [mind2, pos] = max(corr);

```

Below the Editor, a video inset shows Prof. Andrew Thangaraj speaking. The slide footer includes the NPTEL logo, the text "PROF. ANDREW THANGARAJ IIT MADRAS", and the title "Simulation of (7,4) Hamming Code in MATLAB".

So you can clear this thing, so it looks like

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```


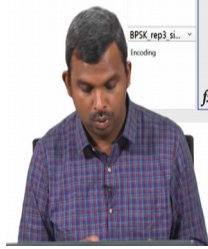
1- EbNodB = 1;
2- R = 4/7; % (7,4) Hamming (4/7 bits/symbol)
3- EbNo = 10^(EbNodB/10);
4- sigma = sqrt(1/(2*R*EbNo));
5-
6- k = 4; % number of message bits
7- n = 7; % number of codeword bits
8-
9- cwords = [0 0 0 0 0 0 0;
10-           0 0 0 1 0 1 1;
11-           0 0 1 0 1 1 0;
12-           0 0 1 1 1 0 1;
13-           0 1 0 0 1 1 1;
14-           0 1 0 1 1 0 0;
15-           0 1 1 0 0 0 1;
16-           0 1 1 1 0 1 0];
  
```

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Simulation of (7,4) Hamming Code in MATLAB

things are working fine. So let us may be pick  $E_b$  over  $N$  naught 4 and then run this then see, use for the hard decision decoder see what happens. So let me just save this. I have  $E_b$  over  $N$  naught 4, I am going to run it now b p s k 7 4 hamming sim

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```

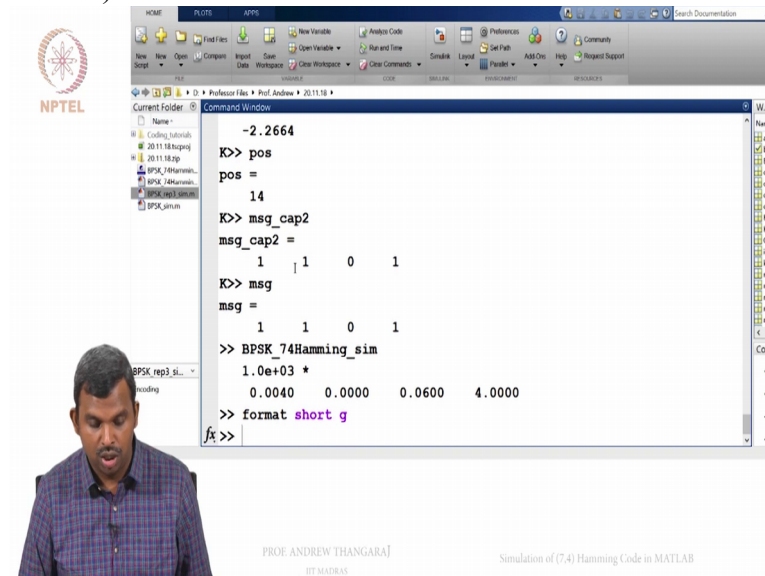
-1.3282
-2.2664
K> pos
pos =
    14
K> msg_cap2
msg_cap2 =
     1     1     0     1
K> msg
msg =
     1     1     0     1
>> BPSK_74Hamming_sim
1.0e+03 *
    0.0040    0.0000    0.0600    4.0000
fx>>
  
```

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Simulation of (7,4) Hamming Code in MATLAB

so let us do its format short g,

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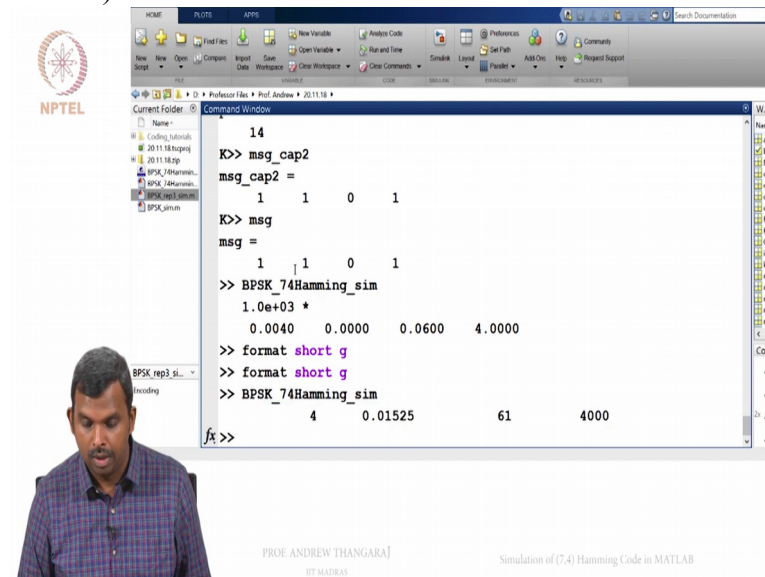
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Simulation of (7,4) Hamming Code in MATLAB

Ok.

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So we get point 0 1, there were 4000 bits that were transmitted. Remember we had 1000 blocks of 4 bits each, codeword is 7000 bits but then, 4000 bits were the message bits. There were 61 bit errors and you got this.

Now it turns out one more error to track

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```



38- b = (r < 0); %threshold at zero
39- dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40- [mind1,pos] = min(dist);
41- msg_cap1 = cwords(pos,1:4);
42-
43- %Soft-decision decoding
44- corr = (1-2*cwords)*r';
45- [mind2,pos] = max(corr);
46- msg_cap2 = cwords(pos,1:4);
47-
48- Nerrs = Nerrs + sum(msg ~= msg_cap1);
49- end
50-
51- BER_sim = Nerrs/k/Nblocks;
52-
53- disp([EbNodB BER_sim Nerrs k*Nblocks])
  
```

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Simulation of (7,4) Hamming Code in MATLAB

which is very important is the block error bit, Ok. So far we did not have to do it; we were just looking at the message errors.

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```

22- 1 1 0 1 0 0 1;
23- 1 1 1 0 1 0 0;
24- 1 1 1 1 1 1 1;
25-
26- Nerrs = 0; Nblocks = 1000;
27- for i = 1:Nblocks
28-     msg = randi([0 1],1,k); %generate random k-bit message
29-     %Encoding
30-     cword = [msg mod(msg(1)+msg(2)+msg(3),2)...
31-              mod(msg(2)+msg(3)+msg(4),2)...
32-              mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33-
34-     s = 1 - 2 * cword; %BPSK bit to symbol conversion
35-     r = s + sigma * randn(1,n); %AWGN channel
36-
37-     %Hard-decision decoding
  
```



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Simulation of (7,4) Hamming Code in MATLAB

So this I will make a little bit of a modification here. So this I will make as n-bit errors and Matlab does this thing of `(( ))` convert everything, this is good.

And I will have n-block errors which is also zero, which will be,

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```


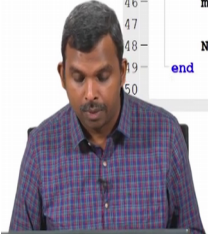
22 1 1 0 1 0 0 1;
23 1 1 1 0 1 0 0;
24 1 1 1 1 1 1 1;
25
26 Nbiterrs = 0; Nblkerrs = 0; Nblocks = 1000;
27 for i = 1: Nblocks
28     msg = randi([0 1],1,k); %generate random k-bit message
29     %Encoding
30     cword = [msg mod(msg(1)+msg(2)+msg(3),2)...
31             mod(msg(2)+msg(3)+msg(4),2)...
32             mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
    
```

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Simulation of (7,4) Hamming Code in MATLAB

I mean how many codeword errors you have? So what will happen here is,

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```



35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind1,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nbiterrs = Nbiterrs + sum(msg ~= msg_cap1);
49 end
50
    
```

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Simulation of (7,4) Hamming Code in MATLAB

so I will count this N errors as sum of this guy, Ok. So this is the

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```

35- r = s + sigma * randn(1,n); %AWGN channel
36-
37- %Hard-decision decoding
38- b = (r < 0); %threshold at zero
39- dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40- [mind1,pos] = min(dist);
41- msg_cap1 = cwords(pos,1:4);
42-
43- %Soft-decision decoding
44- corr = (1-2*cwords)*r';
45- [mind2,pos] = max(corr);
46- msg_cap2 = cwords(pos,1:4);
47-
48- Nerrs = sum(msg ~= msg_cap1);
49-
50- Nbiterrs = Nbiterrs + ;

```


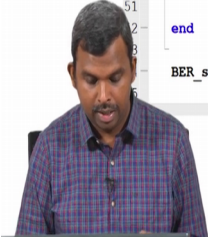
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Simulation of (7,4) Hamming Code in MATLAB

error in one block, Ok.

And if N errors is greater than zero, if there is an error I will add N bit errors plus this,

(Refer Slide Time 22:47)

```

40- [mind1,pos] = min(dist);
41- msg_cap1 = cwords(pos,1:4);
42-
43- %Soft-decision decoding
44- corr = (1-2*cwords)*r';
45- [mind2,pos] = max(corr);
46- msg_cap2 = cwords(pos,1:4);
47-
48- Nerrs = sum(msg ~= msg_cap1);
49- if Nerrs > 0
50-     Nbiterrs = Nbiterrs + Nerrs;
51- end
52-
53- BER_sim = Nbiterrs/k/Nblocks;

```



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Simulation of (7,4) Hamming Code in MATLAB

and N block errors equals N block errors plus 1,



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```



40- [mind1,pos] = min(dist);
41- msg_cap1 = cwords(pos,1:4);
42-
43- %Soft-decision decoding
44- corr = (1-2*cwords)*r';
45- [mind2,pos] = max(corr);
46- msg_cap2 = cwords(pos,1:4);
47-
48- Nerrs = sum(msg ~= msg_cap1);
49- if Nerrs > 0
50-     Nbiterrs = Nbiterrs + Nerrs;
51-     Nblkerrs = Nblkerrs + 1;
52- end
53-
54- BER_sim = Nbiterrs/k/Nblocks;
  
```

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Simulation of (7,4) Hamming Code in MATLAB

Ok.

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```

40- [mind1,pos] = min(dist);
41- msg_cap1 = cwords(pos,1:4);
42-
43- %Soft-decision decoding
44- corr = (1-2*cwords)*r';
45- [mind2,pos] = max(corr);
46- msg_cap2 = cwords(pos,1:4);
47-
48- Nerrs = sum(msg ~= msg_cap1);
49- if Nerrs > 0
50-     Nbiterrs = Nbiterrs + Nerrs;
51-     Nblkerrs = Nblkerrs + 1;
52- end
53-
54- BER_sim = Nbiterrs/k/Nblocks;
  
```



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Simulation of (7,4) Hamming Code in MATLAB

So once again what I am doing here, I am looking at if there was an error in this block. If there was an error in this block I am incrementing N block errors by 1 and then N bit errors by number of errors, Ok.

So this is a simple way. B E R is this, and F E R sim is actually N block errors by N blocks, Ok.

(Refer Slide Time 23:20)

```

42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = sum(msg ~= msg_cap1);
49 if Nerrs > 0
50     Nbiterrs = Nbiterrs + Nerrs;
51     Nblkerrs = Nblkerrs + 1;
52 end
53 end
54
55 BER_sim = Nbiterrs/k/Nblocks;
56 FER_sim = Nblkerrs/Nblocks;
57

```



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Simulation of (7,4) Hamming Code in MATLAB

So this is the frame error rate just like I report bit error rates I have to report the, so B E R came out this way, so I will just make a few adjustments here.

N block errors will be output. I will put out F E R sim, B E R sim, bit errors, may be the bit errors can come later, block errors

(Refer Slide Time 23:53)

```

43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = sum(msg ~= msg_cap1);
49 if Nerrs > 0
50     Nbiterrs = Nbiterrs + Nerrs;
51     Nblkerrs = Nblkerrs + 1;
52 end
53 end
54
55 BER_sim = Nbiterrs/k/Nblocks;
56 FER_sim = Nblkerrs/Nblocks;
57
58 disp([EbNodB FER_sim BER_sim Nblkerrs Nbiterrs Nblocks])
59

```

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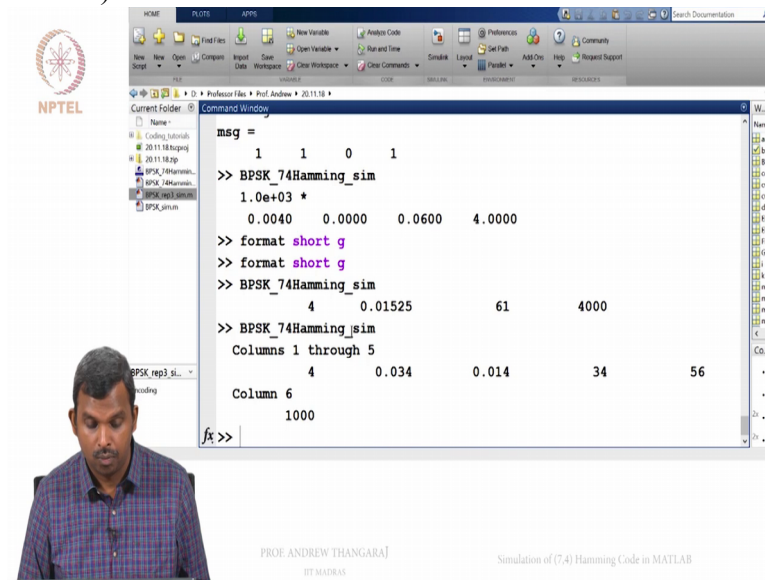
Simulation of (7,4) Hamming Code in MATLAB

then N blocks. I have made a few changes here. I am tracking block errors as well.

You can see how I track block errors here. I am counting the number of errors in the block. If there were any errors in the block I am incrementing the number of block errors by 1 and number of bit errors by N error.

So this is also something important. B E R, F E R we run so, so let me think if I have made any changes here which are problematic? So let us run it once again.

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Block Error Rate (BER)	Bit Error Rate (BER)
0.034	0.014



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So you get more answers. So there were, so you can see we ran 1000 blocks, Ok. There were 34 block errors, 56 bit errors.

Remember every block error may correspond to one or more bit errors. So number of bit errors will be greater than the number of block errors and the block error rate is point 0 3 4, bit error rate is point 0 1 4 Ok. So as figure of merit you should have at least like 20, 30 blocks in error. Ok, so that is a good number to have to get a good reliable statistic Ok.

So you can do the soft decision decoder

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```



43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = sum(msg ~= msg_cap1);
49 if Nerrs > 0
50     Nbiterrs = Nbiterrs + Nerrs;
51     Nblkerrs = Nblkerrs + 1;
52 end
53 end
54
55 BER_sim = Nbiterrs/k/Nblocks;
56 FER_sim = Nblkerrs/Nblocks;
57
58 disp([EbNodB FER_sim BER_sim Nblkerrs Nbiterrs Nblocks])
  
```

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as well. So how do you I check for the soft decision decoder? I can simply change this to 2, Ok. So if I change this to 2, I should get the soft decision decoder, so let us run the same

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```

>> format short g
>> format short g
>> BPSK_74Hamming_sim
      4      0.01525      61      4000
>> BPSK_74Hamming_sim
Columns 1 through 5
      4      0.034      0.014      34      56
Column 6
      1000
>> BPSK_74Hamming_sim
Columns 1 through 5
      4      0.005      0.002      5      8
Column 6
      1000
fx >>
  
```

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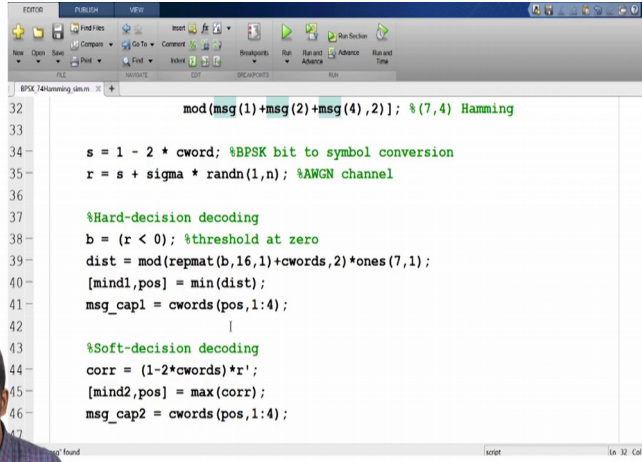
Simulation of (7,4) Hamming Code in MATLAB

thing and you can see it is significantly better. Ok the soft decision decoder is almost an order of magnitude better than the hard decision decoder.

There were just 5 block errors out of 1000 and bit errors were just very small in number, Ok. So that is, that is the magic of doing soft decision decoding and you can see clearly soft decision decoding is significantly better in the Hamming code, Ok.

So, so, so you can see how this encoding and decoding has worked for small codes. This is something you can do, for instance the 6 comma 3 example that we saw in the lectures, you can make

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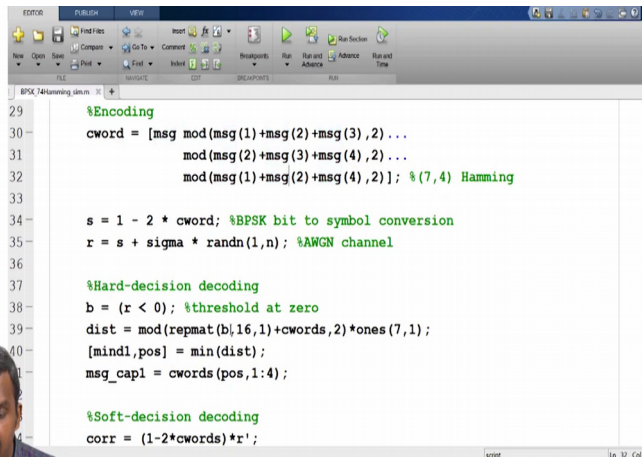
```

32 mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind1,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47

```

quick modification here to change the encoding and change

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```

29 %Encoding
30 cword = [msg mod(msg(1)+msg(2)+msg(3),2) ...
31          mod(msg(2)+msg(3)+msg(4),2) ...
32          mod(msg(1)+msg(2)+msg(4),2)]; % (7,4) Hamming
33
34 s = 1 - 2 * cword; %BPSK bit to symbol conversion
35 r = s + sigma * randn(1,n); %AWGN channel
36
37 %Hard-decision decoding
38 b = (r < 0); %threshold at zero
39 dist = mod(repmat(b,16,1)+cwords,2)*ones(7,1);
40 [mind1,pos] = min(dist);
41 msg_cap1 = cwords(pos,1:4);
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45

```

the decoding, the list of codewords will have to be changed and you will get your decoder to bug, Ok?

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```
42
43 %Soft-decision decoding
44 corr = (1-2*cwords)*r';
45 [mind2,pos] = max(corr);
46 msg_cap2 = cwords(pos,1:4);
47
48 Nerrs = sum(msg ~= msg_cap2);
49 if Nerrs > 0
50     Nbiterrs = Nbiterrs + Nerrs;
51     Nblkerrs = Nblkerrs + 1;
52 end
53 end
54
55 BER_sim = Nbiterrs/k/Nblocks;
56 FER_sim = Nblkerrs/Nblocks;
```

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So that is the end of the simulation for 7 4 Hamming code. Hopefully you can take this template and modify it for some other small codes as well. But however if the code size becomes really, really large this is the difficult thing to implement, Ok.

So, so we will stop here for this lecture and the next lecture will be a very nice and important bridge between the modern codes and the starting point of classical codes. We will take 2 codes and look at their decoders in, in very closely and think about them and how they can be used in multiple ways, Ok.

So the two codes we will use are very simple codes, the repetition code and what is called a single parity check code. These two are very crucial. They play a very important role in the bigger decoders, very popular decoders for modern codes. So we will do that in the next lecture. Thank you very much.