Cyclic codes
(Basics & Properties)

Cyclic codes basics & Properties with example

- Cyclic codes are subpart of linear block codes
- It follows following properties.

① Linearity property

- If we have two code words c_i & c_j then

$$c_p = c_i + c_i$$

where, c_p should be a codeword.

② Cyclic shifting

code word $= C(c_1, c_2, c_3, \ldots, c_n)$

- After shifting left or right by any no of bits, ① Linearity property

- If we have two code words c_i & c_j then

$$c_p = c_i + c_j$$

where, c_p shold be a code word.

② Cyclic shifting

$$\text{code word} = (c_1, c_2, c_3, \ldots, c_n)$$

- After shitting left or right by any no of bits, resultant code should be a codeword.

- If codewords follow above two proparty then only that codes will be cyclic codes.

e.g {0000, 0110, 1001, 1111}, is it cyclic codes?

→ Check Property of linearity

0110	0110	1001
1001	1111	1111
✓ 1111	✓ 1001	✓ 0110

– so it follows property of linearity

→ Check Property of shifting

0 1 1 0

0 0 1 1 ← It is not a code word.

→ so above codes are not cyclic codes.

* {0000, 0101, 1010, 1111}, is it a cyclic code?

→ $\boxed{\text{Yes}}$

→ Check property of linearity

$$\checkmark\ \begin{array}{c} 0101 \\ 1010 \\ \hline 1111 \end{array} \qquad \checkmark\ \begin{array}{c} 0101 \\ 1111 \\ \hline 1010 \end{array} \qquad \checkmark\ \begin{array}{c} 1010 \\ 1111 \\ \hline 0101 \end{array}$$

- It follows property of linearity.

→ Check shifting property.

0 1 0 1

1 0 1 0 & It is codeword.

1 0 1 0

0 1 0 1

→ It follows shifting property.

Generator Polynomial (Non-systematic codes)

Cyclic Codes for Non-Systamatic Codeword

* Code word for non-systematic codeword is given by

$$c(x) = m(x) \cdot g(x)$$

where, $c(x)$ = Code word polynomial
$m(x)$ = Message polynomial
$g(x)$ = Generator Polynomial

Cyclic Codes for Non-Systematic Codeword

* Code word for non-systematic codeword is given by

$$C(x) = m(x) \cdot g(x)$$

where, $C(x)$ = Code word polynomial
$m(x)$ = Message polynomial
$g(x)$ = Generator polynomial

$\rightarrow$ $\boxed{C = [\,\underbrace{\text{message}}\,,\ \underbrace{\text{Parity}}\,]}$
×

$\rightarrow$ 1 0 1 1
$x^3 x^2 x^1 x^0$

$$= x^3 \cdot 1 + x^2 \cdot 0 + x^1 \cdot 1 + x^0 \cdot 1$$
$$= x^3 + x + 1$$

* Construct Non-Systematic Cyclic codes (7, 4), using generator Polynomial $g(x) = x^3 + x^2 + 1$, with message (1 0 1 0).

$\rightarrow$ $m = [1\ 0\ 1\ 0]$

$$\begin{array}{cccc} \downarrow & \downarrow & \downarrow & \downarrow \\ x^3 & x^2 & x^1 & x^0 \end{array}$$

$\rightarrow$ $m(x) = x^3 + x$

$g(x) = x^3 + x^2 + 1$

$\rightarrow$ $c(x) = m(x)\, g(x)$

$= (x^3 + x)(x^3 + x^2 + 1)$

$=$

$\rightarrow \; m = [\,1\;0\;1\;0\,]$

$$\begin{array}{cccc} \downarrow & \downarrow & \downarrow & \downarrow \\ x^3 & x^2 & x^1 & x^0 \end{array}$$

$\rightarrow \; m(x) = x^3 + x$

$g(x) = x^3 + x^2 + 1$

$\rightarrow \; c(x) = m(x)\,g(x)$

$$= (x^3 + x)(x^3 + x^2 + 1)$$

$$= x^6 + x^5 + \cancel{x^3} + x^4 + \cancel{x^3} + x$$

$$= x^6 + x^5 + x^4 + x$$

$$\boxed{c = [\,1\;1\;1\;0\;0\;1\;0\,]}$$

While XOR ing ->
Same term becomes 0

Generator Polynomial (Systematic Codes)

Cyclic - Codes for Systamatic Codeword

- Codeword for systamatic Codeword is given by

$$C(x) = x^{n-k}\, m(x) + P(x)$$

where, $P(x) = \text{Rem}\left[\frac{x^{n-k}\, m(x)}{g(x)} \right]$

, $C(x)$ = Codeword polynomial

$m(x)$ = message Polynomial

$g(x)$ = Generator Polynomial

$$\boxed{C = [\, \underbrace{\text{message}}_{} \,,\ \underbrace{\text{Parity}}_{} \,]}$$

* Construct a systematic cyclic code (7,4), using generator polynomial $g(x) = x^3 + x^2 + 1$, with message (1 0 1 0).

→ (7,4) code

$n = 7, \; k = 4$

→ $m = (1\,0\,1\,0)$

$$\begin{array}{cccc} \downarrow & \downarrow & \downarrow & \downarrow \\ x^3 & x^2 & x^1 & x^0 \end{array}$$

$m(x) = x^3 + x$

* Construct a systematic cyclic code (7,4), using generator Polynomial $g(x) = x^3 + x^2 + 1$, with message (1 0 1 0).

→ (7,4) code

$n = 7, \ k = 4$

→ $m = (1\ 0\ 1\ 0)$

$x^3 \ x^2 \ x^1 \ x^0$

$m(x) = x^3 + x$

→ $c(x) = x^{n-k} m(x) + p(x)$

$$p(x) = \text{Rem}\left[\frac{x^{n-k} m(x)}{g(x)}\right]$$

$$= \text{Rem}\left[\frac{x^3 (x^3 + x)}{x^3 + x^2 + 1}\right]$$

$$= \text{Rem}\left[\frac{x^6 + x^4}{x^3 + x^2 + 1}\right.$$

$n = 7, \; k = 4$

$\rightarrow m = (1\,0\,1\,0)$

$x^3 \; x^2 \; x^1 \; x^0$

$m(x) = x^3 + x$

$$r(x) = \text{Rem}\left[\frac{x^{n-k}\, m(x)}{g(x)}\right]$$

$$= \text{Rem}\left[\frac{x^3(x^3+x)}{x^3+x^2+1}\right]$$

$$= \text{Rem}\left[\frac{x^6+x^4}{x^3+x^2+1}\right] = 1$$

$$\begin{array}{r|l}
 & x^3 + x^2 + 1 \\
\hline
x^3+x^2+1 & \cancel{x^6} + x^4 \\
 & \cancel{x^6} + x^5 + x^3 \\
\hline
 & \cancel{x^5} + \cancel{x^4} + x^3 \\
 & \cancel{x^5} + \cancel{x^4} + x^2 \\
\hline
 & \cancel{x^3} + \cancel{x^2} \\
 & \cancel{x^3} + \cancel{x^2} + 1 \\
\hline
 & \rightarrow \boxed{1}
\end{array}$$

→ (7, 4) code

$n = 7, \quad k = 4$

→ $m = (1\ 0\ 1\ 0)$

$\begin{array}{cccc} \downarrow & \downarrow & \downarrow & \downarrow \\ x^3 & x^2 & x^1 & x^0 \end{array}$

$m(x) = x^3 + x$

→ $c(x) = x^{n-k}\, m(x) + p(x)$

$= x^3(x^3 + x) + 1$

$= x^6 + x^4 + 1$

→ $c = [1010001]$

→ $c(x) = x^{n-k}\, m(x) + p(x)$

$p(x) = \text{Rem}\left[\dfrac{x^{n-k}\, m(x)}{g(x)}\right]$

$= \text{Rem}\left[\dfrac{x^3(x^3 + x)}{x^3 + x^2 + 1}\right]$

$= \text{Rem}\left[\dfrac{x^6 + x^4}{x^3 + x^2 + 1}\right] = 1$

$$
\begin{array}{r}
x^3 + x^2 + 1 \\
x^3 + x^2 + 1 \overline{\big)\ \cancel{x^6} + x^4} \\
\underline{\cancel{x^6} + x^5 + x^3} \\
\cancel{x^5} + \cancel{x^4} + x^3 \\
\underline{\cancel{x^5} + \cancel{x^4} + x^2} \\
\cancel{x^3} + x^2 \\
x^3 + x^2 + 1
\end{array}
$$

[g(x)]

, c(x) = Codeword polynomial

m(x) = message Polynomial

g(x) = Generator Polynomial

$$\boxed{C = [\underbrace{\text{message}}, \underbrace{\text{Parity}}]}$$

* Construct a [illegible] code (7, 4), using generator

sys[illegible]

Polynomial [illegible] with message

(1 0 1 [illegible]

[illegible]) + P(x)

→ (7 [illegible] $^{n-k}$ m(x)]

$\rightarrow m = (1\ 0\ 1\ 0)$

$x^3 \quad x^2 \quad x^1 \quad x^0$

$m(x) = x^3 + x$

$\rightarrow c(x) = x^{n-k} m(x) + p(x)$

$= x^3(x^3 + x) + 1$

$= x^6 + x^4 + 1$

$\rightarrow C = [\boxed{1\ 0\ 1\ 0}\ 0\ 0\ 1]$

Message Parity

$\left[\quad g(x) \quad \right]$

$= \text{Rem}\left[\dfrac{x^3(x^3+x)}{x^3+x^2+1}\right]$

$= \text{Rem}\left[\dfrac{x^6+x^4}{x^3+x^2+1}\right] =$

$$
\begin{array}{r l}
 & x^3 + x^2 + 1 \\
x^3+x^2+1 \,\big) & \cancel{x^6} + x^4 \\
 & \cancel{x^6} + x^5 + x^3 \\
\hline
 & \cancel{x^5} + \cancel{x^4} + x^3 \\
 & \cancel{x^5} + \cancel{x^4} + x^2 \\
\hline
 & \cancel{x^3} + \cancel{x^2} \\
 & \cancel{x^3} + \cancel{x^2} + \\
\hline
 & \rightarrow \boxed{1}
\end{array}
$$

Cyclic code for Generator Matrix

Generator matrix of Cyclic Code.

- Generator Matrix

$$[G] = [\, I : P \,]$$

Identity Matrix   Parity Matrix

- If Cyclic code is (n, K), then Generator matrix G is having n coloumns & K rows.
- Identity matrix is known to us.
- So Row of parity matrix based on generator

- Identity matrix is known to us.
- So Row of parity matrix based on generator polynomial $G(x)$ is given by.

1^{st} row : $\text{Rem}\left[\dfrac{x^{n-1}}{g(x)}\right]$

2^{nd} row : $\text{Rem}\left[\dfrac{x^{n-2}}{g(x)}\right]$

$\vdots$

K^{th} row : $\text{Rem}\left[\dfrac{x^{n-K}}{g(x)}\right]$

* If generator polynomial of cyclic code $(7,4)$ is given by

$$g(x) = x^3 + x + 1.$$

then construct generator matrix.

→ $(7,4)$ code

$\boxed{7 = n}$, $\boxed{K = 4}$

→ $$G = \left[\begin{array}{cccc:ccc} 1 & 0 & 0 & 0 & - & - & - \\ 0 & 1 & 0 & 0 & - & - & - \\ 0 & 0 & 1 & 0 & - & - & - \\ 0 & 0 & 0 & 1 & - & - & - \end{array}\right]$$

- 1st Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-1}}{g(x)}\right] = \text{Rem}\left[\frac{x^6}{x^3+x+1}\right]$$

- 2nd Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-2}}{g(x)}\right] = \text{Rem}\left[\frac{x^5}{x^3+x+1}\right]$$

- 3rd Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-3}}{g(x)}\right] = \text{Rem}\left[\frac{x^4}{x^3+x+1}\right]$$

- 4th Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-4}}{g(x)}\right] = \text{Rem}\left[\frac{x^3}{x^3+x+1}\right]$$

- 3rd Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-3}}{g(x)}\right] = \text{Rem}\left[\frac{x^4}{x^3+x+1}\right] =$$

- 4th Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-4}}{g(x)}\right] = \text{Rem}\left[\frac{x^3}{x^3+x+1}\right] =$$

$$\begin{array}{r|l} & x^3+x+1 \\ \hline x^3+x+1 & \cancel{x^6} \\ & \cancel{x^6}+x^4+x^3 \\ \hline & \cancel{x^4}+x^3 \\ & \cancel{x^4}+x^2+x \\ \hline & \cancel{x^3}+x^2+\cancel{x} \\ & \cancel{x^3}+\cancel{x}+1 \\ \hline & x^2+1 \end{array}$$

$$G = \left[\begin{array}{cccc:ccc} 1 & 0 & 0 & 0 & - & - & - \\ 0 & 1 & 0 & 0 & - & - & - \\ 0 & 0 & 1 & 0 & - & - & - \\ 0 & 0 & 0 & 1 & - & - & - \end{array}\right]$$

- 1^{st} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-1}}{g(x)}\right] = \text{Rem}\left[\frac{x^6}{x^3+x+1}\right] = x^2+1$$

- 2^{nd} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-2}}{g(x)}\right] = \text{Rem}\left[\frac{x^5}{x^3+x+1}\right] =$$

- 3^{rd} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-3}}{\quad}\right] = \text{Rem}\left[\frac{x^4}{x^3+x+1}\right] =$$

$$= \text{Rem}\left[\frac{x^{7-3}}{g(x)}\right] = \text{Rem}\left[\frac{x^4}{x^3+x+1}\right] =$$

- 4^{th} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-4}}{g(x)}\right] = \text{Rem}\left[\frac{x^3}{x^3+x+1}\right] =$$

$$
\begin{array}{r|l}
 & x^3+x+1 \\
\hline
x^3+x+1 & \cancel{x^6} \\
 & \cancel{x^6}+x^4+x^3 \\
\hline
 & \cancel{x^4}+x^3 \\
 & x^4+x^2+x \\
\hline
 & \cancel{x^3}+x^2+x \\
 & \cancel{x^3}+x+1 \\
\hline
 & x^2+1
\end{array}
\qquad
\begin{array}{r|l}
 & x^2+1 \\
\hline
x^3+x+1 & \cancel{x^5} \\
 & \cancel{x^5}+x^3+x^2 \\
\hline
 & \cancel{x^3}+x^2 \\
 & x^3+x+1 \\
\hline
 & x^2+x+1
\end{array}
$$

- 2^{nd} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-2}}{g(x)}\right] = \text{Rem}\left[\frac{x^5}{x^3+x+1}\right] = x^2+x+1$$

- 3^{rd} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-3}}{g(x)}\right] = \text{Rem}\left[\frac{x^4}{x^3+x+1}\right] = x^2+1$$

- 4^{th} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-4}}{g(x)}\right] = \text{Rem}\left[\frac{x^3}{x^3+x+1}\right] = x+1$$

$$\begin{array}{r|l} & x^3+x+1 \\ \hline +x+1 & \cancel{x^6} \\ & \cancel{x^6}+x^4+x^3 \\ \hline & \cancel{x^4}+x^3 \end{array}$$

$$\begin{array}{r|l} & x^2+1 \\ \hline x^3+x+1 & \cancel{x^5} \\ & \cancel{x^5}+x^3+x^2 \\ \hline & \cancel{x^3}+x^2 \end{array}$$

$$\begin{array}{r|l} & x \\ \hline x^3+x+1 & \cancel{x^4} \\ & \cancel{x^4}+x^2+x \\ \hline & x^2+1 \end{array}$$

$$= \text{Rem}\left[\frac{x^{7-1}}{g(x)}\right] = \text{Rem}\left[\frac{x^{6}}{x^3+x+1}\right] = x^2+1 = [1\ 0\ 1]$$

- 2^{nd} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-2}}{g(x)}\right] = \text{Rem}\left[\frac{x^5}{x^3+x+1}\right] = x^2+x+1 = [1\ 1\ 1]$$

- 3^{rd} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-3}}{g(x)}\right] = \text{Rem}\left[\frac{x^4}{x^3+x+1}\right] = x^2+1 = [1\ 0\ 1]$$

- 4^{th} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-4}}{g(x)}\right] = \text{Rem}\left[\frac{x^3}{x^3+x+1}\right] = x+1 = [0\ 1\ 1]$$

x^3+x+1) x^6 quotient x^3+x+1; $x^6+x^4+x^3$

x^3+x+1) x^5 quotient x^2+1; $x^5+x^3+x^2$

x^3+x+1) x^4 quotient x; x^4+x^2+x

→ (7, 4) code

$\boxed{7 = n}$, $\boxed{K = 4}$

→ $G = \left[\begin{array}{cccc:ccc} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{array}\right]$

- 1^{st} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-1}}{g(x)}\right] = \text{Rem}\left[\frac{x^6}{x^3+x+1}\right] = x^2+1 = [1\ 0\ 1]$$

- 2^{nd} Row of Parity Matrix

$$= \text{Rem}\left[\frac{x^{7-2}}{g(x)}\right] = \text{Rem}\left[\frac{x^5}{x^3+x+1}\right] = x^2+x+1 = [1\ 1\ 1]$$

Encoder designing for cyclic codes

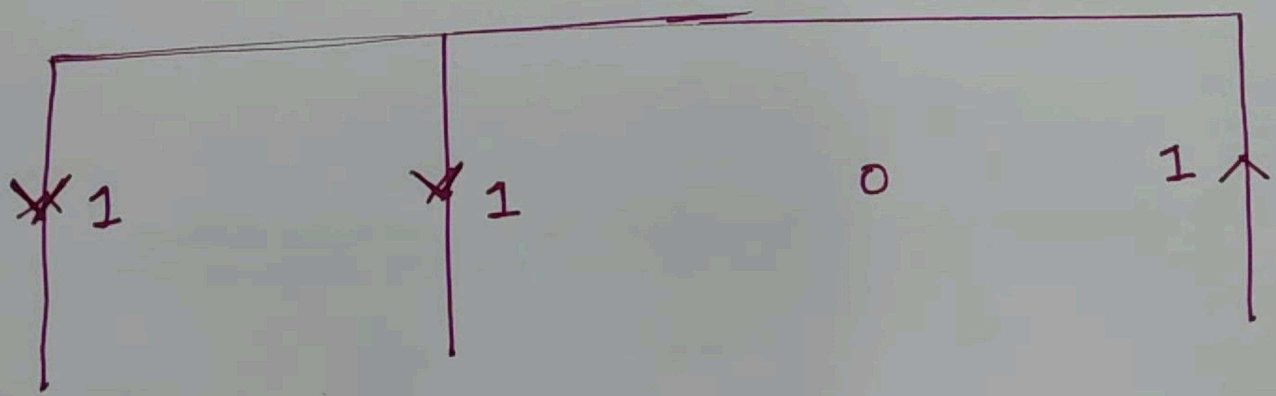
Cyclic Encoder designing

- If generator Polynomial is $g(x) = 1 + x + x^3$
  Calculate ① Cyclic encoder
  ② codeword If message is (1110)

(2) codeword if message is (1110)

$- g(x) = 1 + x + x^3$

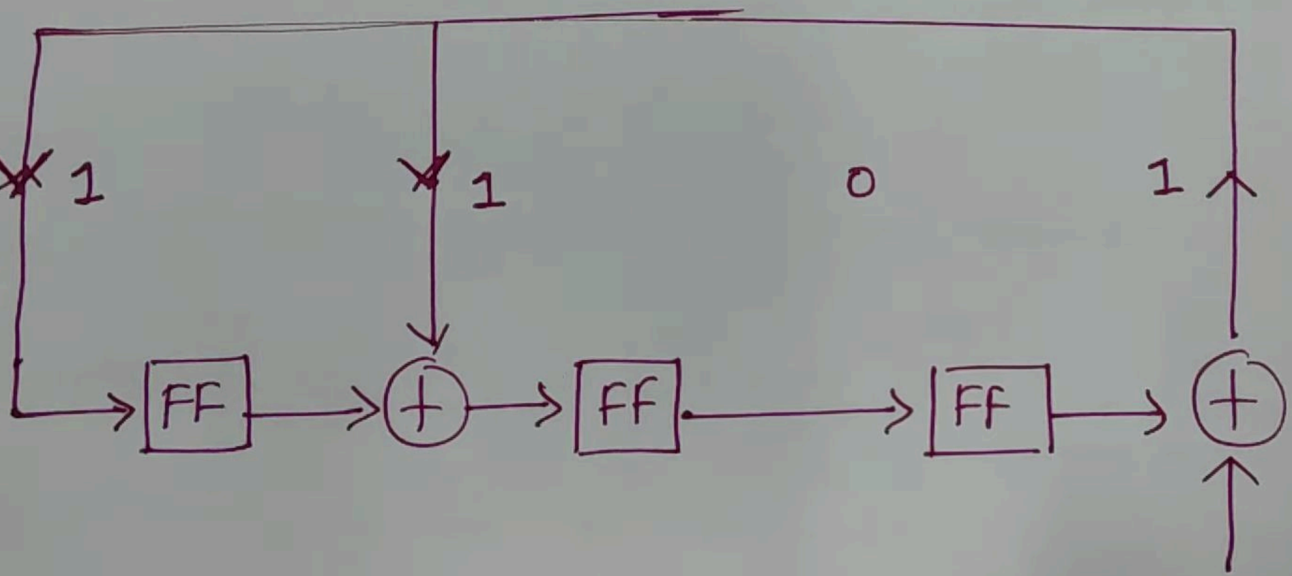
$= \underline{1} + \underline{x} + \underline{0} \times x^2 + \underline{x}^3$



② codeword If message is (1110)

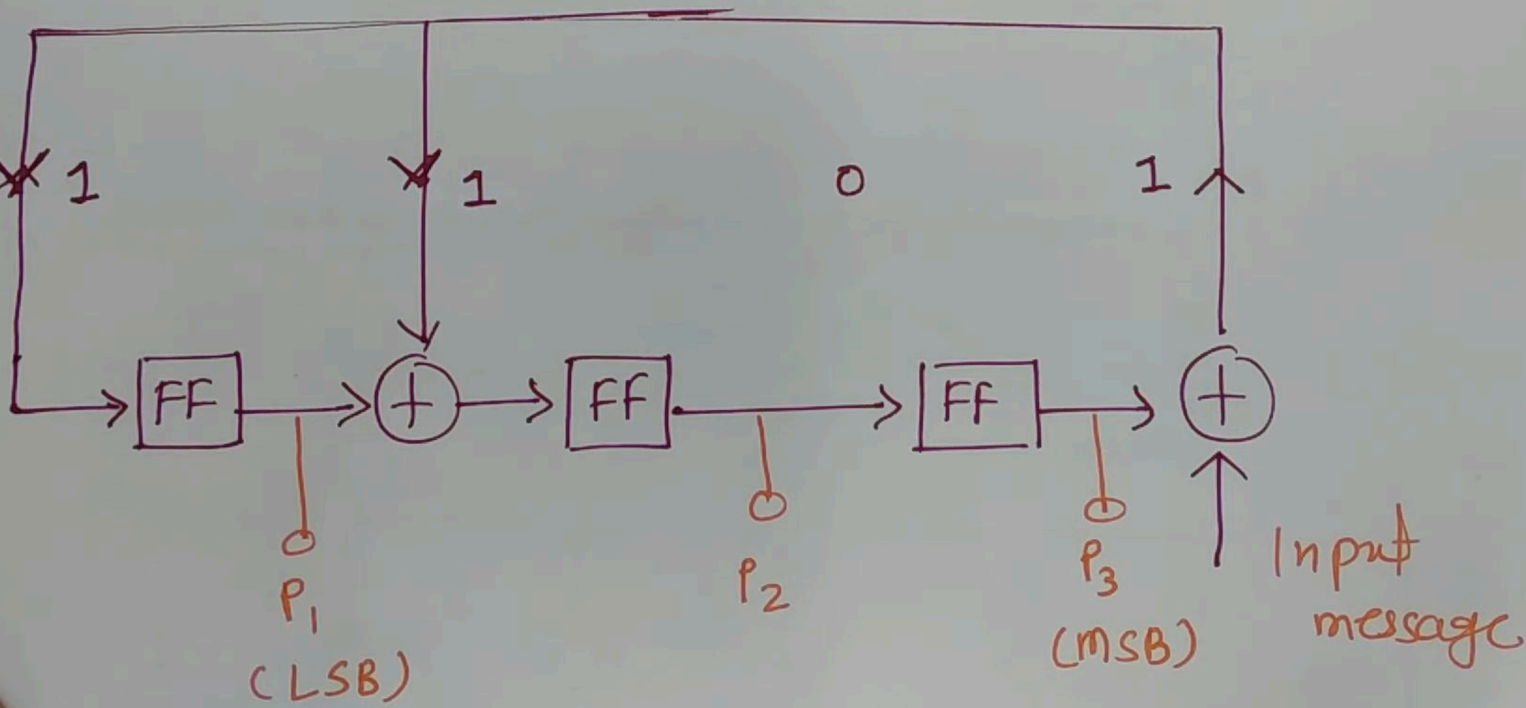
$- g(x) = 1 + x + x^3$

$= \underline{1} + \underline{x} + \underline{0} \times x^2 + \underline{x}^3$



$$- g(x) = 1 + x + x^3$$

$$= \underline{1} + \underline{x} + \underline{0} \times x^2 + \underline{x}^3$$



P_1
(LSB)

P_2

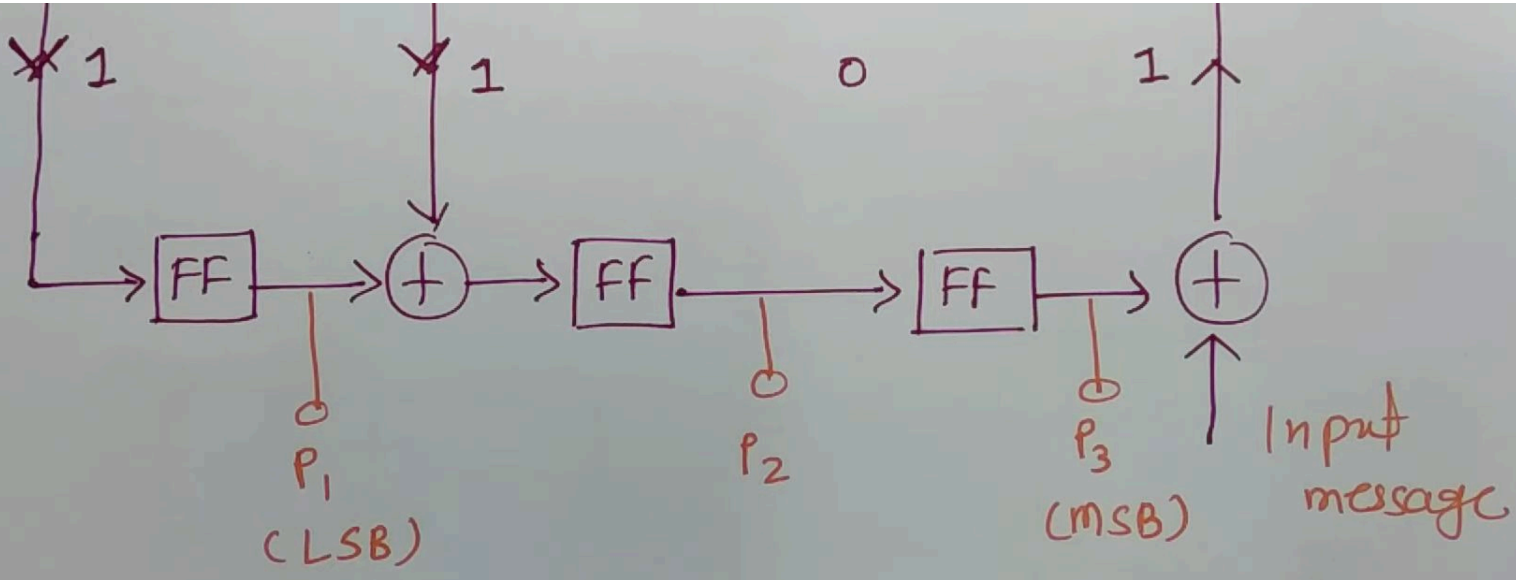
P_3
(MSB)

Input message

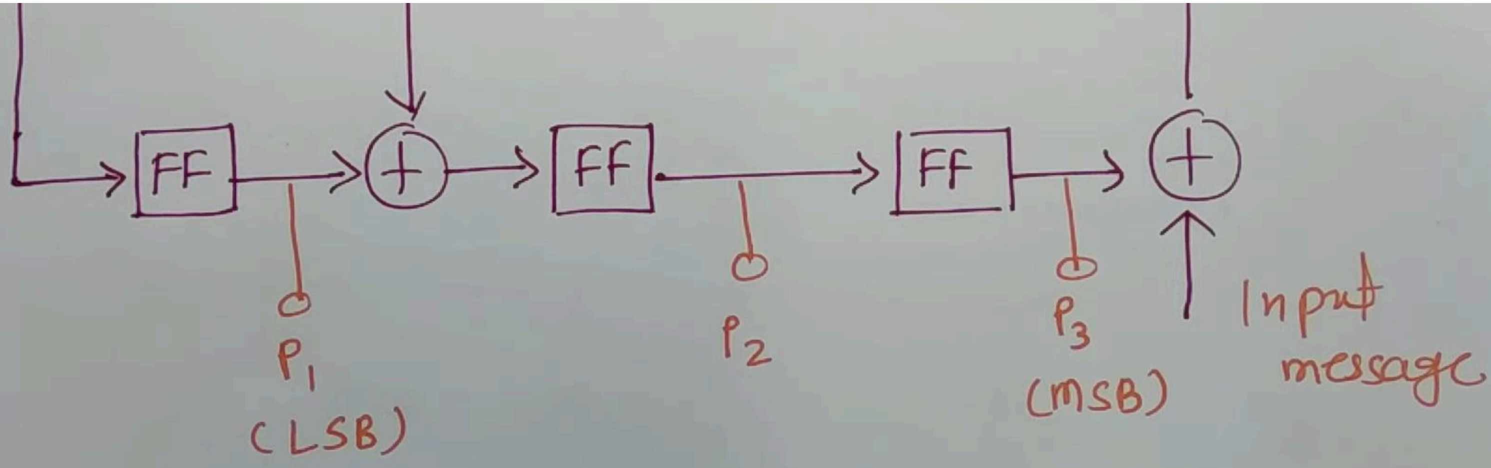
m	P_1	P_2	P_3
	0	0	0

P_1 (LSB) P_2 P_3 (MSB) Input message

m	P_1	P_2	P_3
	0	0	0
1			
1			
1			
0			



m	P_1	P_2	P_3
	0	0	0
1	1	1	0
1			



m	P_1	P_2	P_3
	0	0	0
1	1	1	0
1	1	0	1
1			

P_1 (LSB) P_2 P_3 (MSB) Input message

m	P_1	P_2	P_3
	0	0	0
1	1	1	0
1	1	0	1
1	0	1	0
0			

P_1 (LSB) $\quad P_2 \quad P_3$ (MSB) Input message

m	P_1	P_2	P_3
	0	0	0
1	1	1	0
1	1	0	1
1	0	1	0
0	0	0	1

m	P_1	P_2	P_3
	0	0	0
1	1	1	0
1	1	0	1
1	0	1	0
0	0	0	1

LSB.

MSB

m	P_1	P_2	P_3
	0	0	0
1	1	1	0
1	1	0	1
1	0	1	0
0	0	0	1

LSB.   MSB

Codeword = [Message , Parity]

= [1110 , 100]

Syndrome Calculation Circuit

SYNDROME CALCULATOR FOR CYCLIC CODE

Ques :- Design a Syndrome calculator for a (7,4) Cyclic Hamming code generated by the polynomial $G(P) = P^3 + P + 1$. Calculate Syndrome for $Y = (1001101)$

View key concept

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generated by the polynomial ...
Syndrome for $Y = (1001101)$

$$g(p) = p^{n-k} + \sum_{i=1}^{n-k-1} g_i p^i + 1$$

$(n,k) = (7,4)$ Number of FF $= n-k$
$= 3$

$n=7$ $k=4$

$$g(p) = p^{7-4} + \sum_{i=1}^{7-4-1} g_i p^i + 1$$

$$= p^3 + \sum_{i=1}^{2} g_i p^i + 1$$

$$g(p) = p^3 + g_1 p^1 + g_2 p^2 + 1$$

$$g(p) = p^3 + g_2 p^2 + g_1 p + 1$$

Given $G(p) = p^3 + p + 1$

$g_2 = 0$ $g_1 = 1$

generated by the polynomial ...

Syndrome for $Y = (1001101)$

$$g(p) = p^{n-k} + \sum_{i=1}^{n-k-1} g_i p^i + 1$$

$(n,k) = (7,4)$ Number of FF $= n-k$ $= 3$

$\underline{\underline{n=7}}$ $\underline{\underline{k=4}}$

$$g(p) = p^{7-4} + \sum_{i=1}^{7-4-1} g_i p^i + 1$$

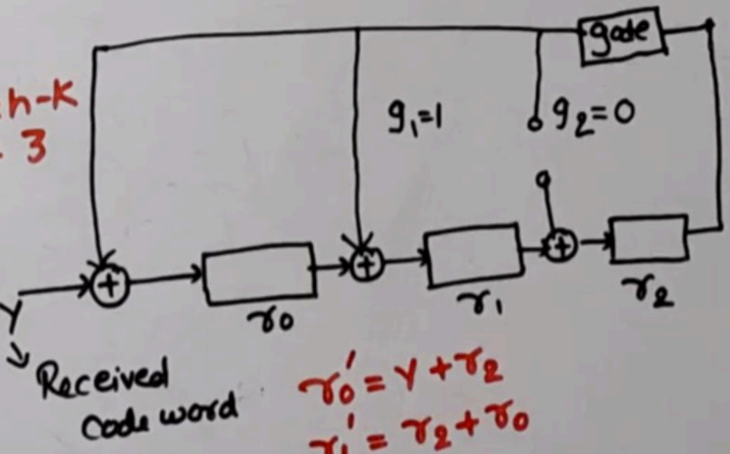
$$= p^3 + \sum_{i=1}^{2} g_i p^i + 1$$

$$g(p) = p^3 + g_1 p^1 + g_2 p^2 + 1$$

$$g(p) = p^3 + g_2 p^2 + g_1 p + 1$$

Given $G(p) = p^3 + p + 1$

$g_2 = 0 \quad g_1 = 1$



$r_0' = Y + r_2$

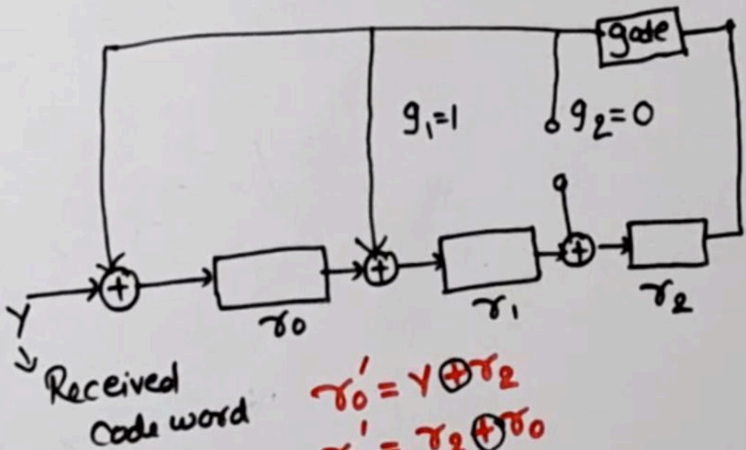
$r_1' = r_2 + r_0$

$r_2' = r_1$

generated by the polynomial

Syndrome for $Y = (1001101)$

No. of Shift	Y	r_0' $(Y \oplus r_2)$	r_1' $(r_2 \oplus r_0)$	r_2' r_1
		0	0	0
1	1			
2	0			
3	0			
4	1			
5	1			
6	0			
7	1			

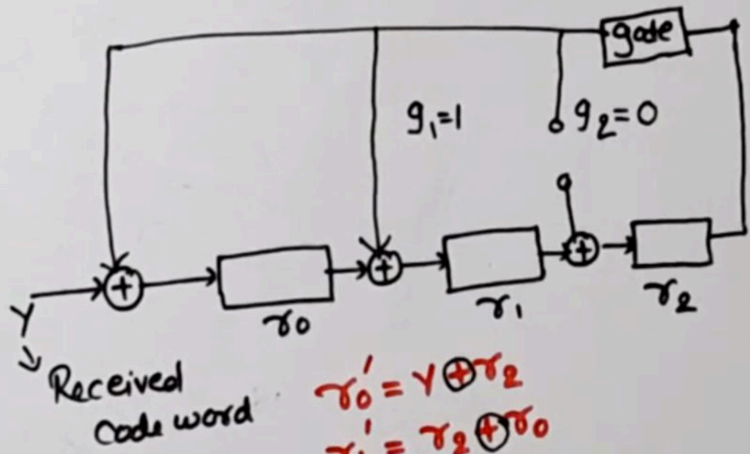


$$r_0' = Y \oplus r_2$$
$$r_1' = r_2 \oplus r_0$$
$$r_2' = r_1$$
$$S = [r_2' \; r_1' \; r_0']$$

generated by the polynomial ...

Syndrome for $Y = (1001101)$

No. of Shift	Y	r_0' $(Y \oplus r_2)$	r_1' $(r_2 \oplus r_0)$	r_2' r_1
		0	0	0
1	1	1	0	0
2	0	0	1	0
3	0	0	0	1
4	1	0	1	0
5	1	1	0	1
6	0	1	0	0
7	1	1	1	0



$r_0' = Y \oplus r_2$

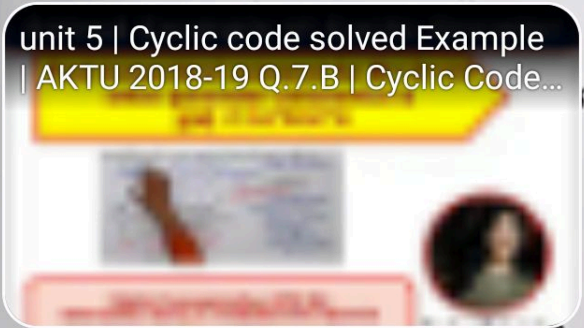
$r_1' = r_2 \oplus r_0$

$r_2' = r_1$

$S = [r_2' \; r_1' \; r_0']$

generated by the polynom...

Syndrome for $Y = (1001101)$



r_2'

r_1

0

0

0

1

3 0 → 0 0

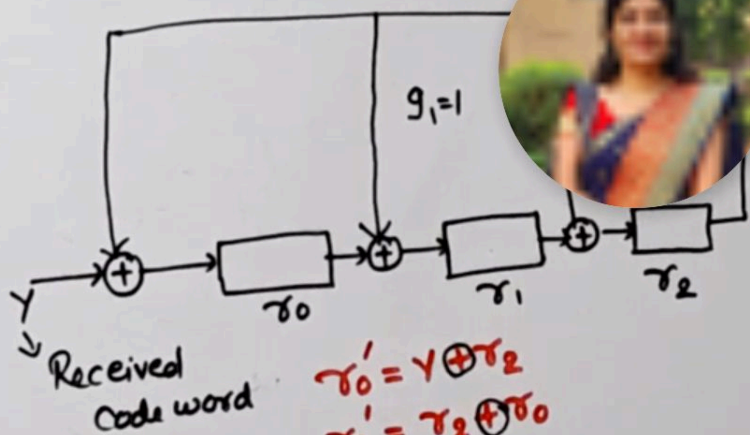
0

1

0

0

r_2



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$S = [0 \; 1 \; 1]$

=

Cyclic Redundancy Test

❖ Basics of Cyclic Redundancy Check

- ❑ CRC uses a Divisor with L bits. {Divisor may be given in Galois fields.}
- ❑ Here we append L – 1 bits with data bits.
- ❑ Here we perform binary division for CRC generation.
- ❑ Receiver and Transmitter should be agreed upon by the same Divisor.

❖ Example of Cyclic Redundancy Check

- ❑ Data = 01010001, Divisor = 1001. Find transmitted codeword using CRC.

```
01010001 | 000
 1001
 001100
   1001
   01011
    1001
    0010 00
      1001
      00 010  ← CRC
```

Tx Codeword = $\underbrace{01010001}_{\text{data}}\ \underbrace{010}_{\text{crc}}$

❖ Example of Cyclic Redundancy Check

❖ Example of Cyclic Redundancy Check

❑ Data = 1110010101, Divisor = $X^3 + X^2 + 1$. Find transmitted codeword using CRC.

= 1101

```
1110010101 | 000
1101
001101
  1101
  00000101 | 0
       110 | 1
       011 | 10
        11 | 01
        00 | 110  ← CRC
```

Tx Codeword = $\underbrace{1110010101}_{\text{data}}\ \underbrace{110}_{\text{CRC}}$

Examples on CRC – Cyclic Redundancy Check

Example 1 – The message 11001001 is to be transmitted using the CRC polynomial $X^3 + 1$ to protect it from errors. The message that should be transmitted is .... If the received codeword at the receiver is 11011001011 then how the receiver will take decision?

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→ Divisor = x^3+1 = 1001 ← L = 4 bits

```
11001001 | 000
1001
01011
 1001
 001000
   1001
   000011 | 00
        10 | 01
        01 | 010
         1 | 001
         0 | 011  → CRC
```

$\boxed{011} \rightarrow$ CRC

Tx = $\underbrace{11001001}_{\text{data}}\ \underbrace{011}_{\text{CRC}}$

→ 11011001 | 011 , D = 1001

```
11011001|011
1001
----
01001
 1001
 ----------
 0000001|011
        1001
        ----
        0|010
```

$0\,|\,\boxed{010} \leftarrow R_x \neq 0$

<u>Error</u>