Chapter 7

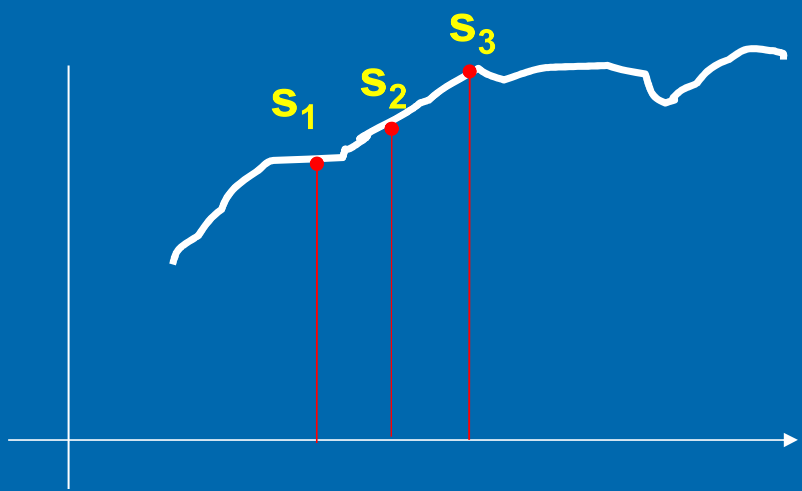
Analog to Digital conversion

Part 4 of 4

7.4 Differential Pulse-Code Modulation (DPCM)

- For speech signal usually there is a relatively smooth change from one speech sample to the next, i.e. that is, there is considerable correlation between adjacent samples.

e.g.

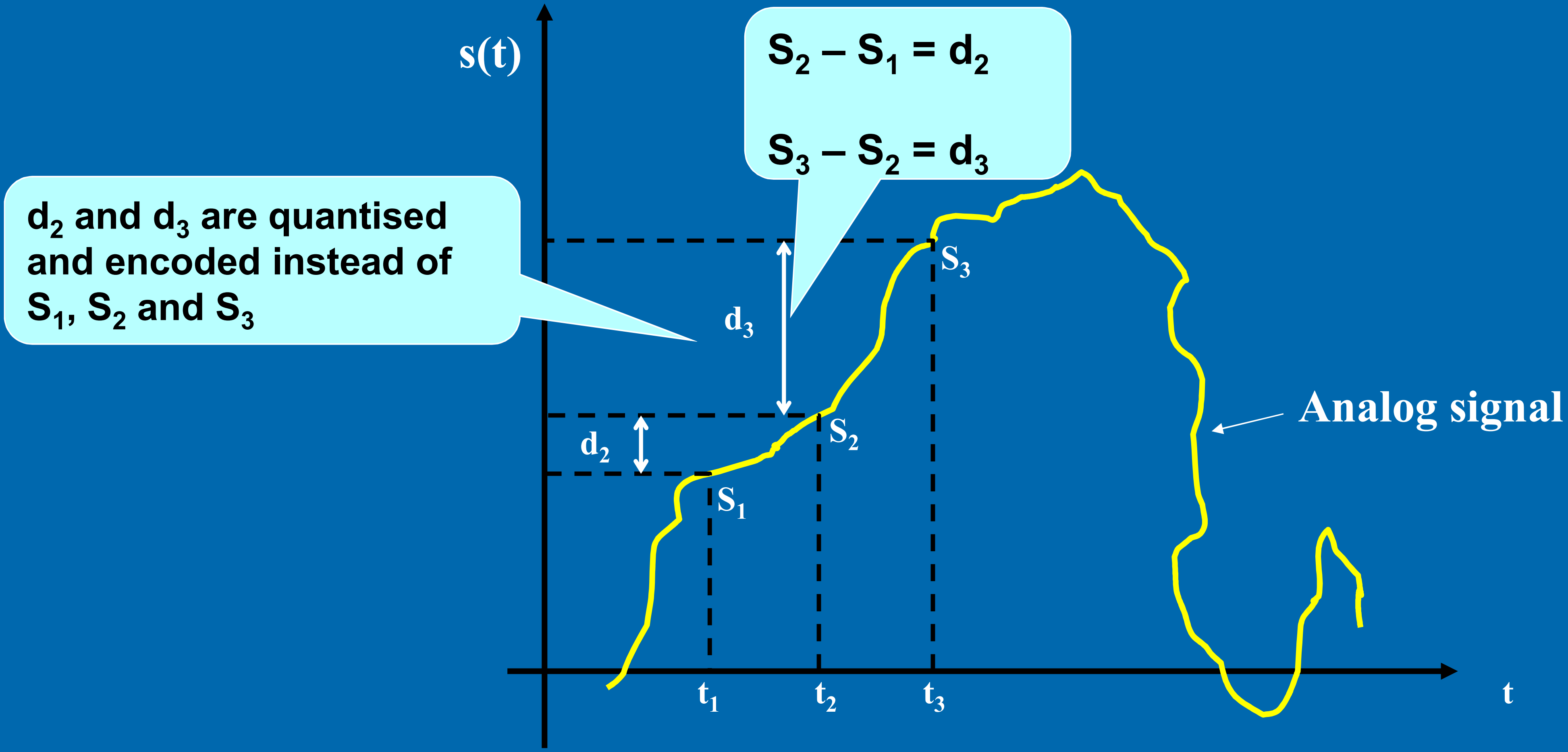


- The difference between adjacent samples will have a smaller variance and range than the speech samples themselves.

- DPCM is designed specifically to take advantage of this.

7.4 Differential Pulse-Code Modulation (DPCM)

- In DPCM, the difference in samples are quantised and encoded instead of quantising and encoding the samples.



7.4 Differential Pulse-Code Modulation (DPCM)

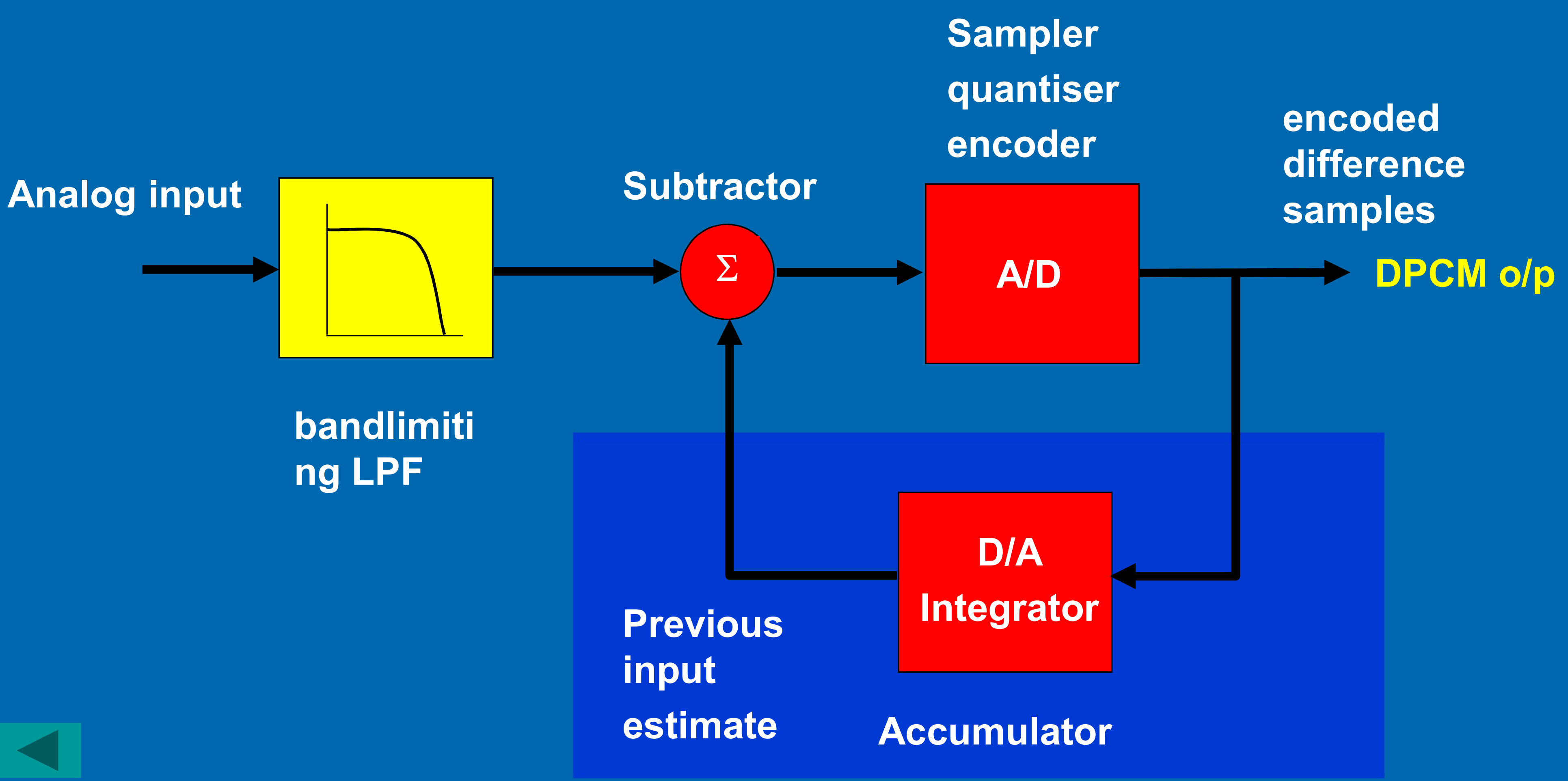
- **Fewer bits are needed to encode difference samples since the range of sample differences is less than the range of individual amplitude samples**

- **DPCM system has lower bit rate than comparable PCM as the sampling rate is often the same as comparable PCM system.**

  Industry standard: DPCM 32 kb/s
  PCM 64 kb/s

- **At the same bit rate, DPCM provides better speech quality than PCM.**

7.4 Differential Pulse-Code Modulation (DPCM)



7.4 Differential Pulse-Code Modulation (DPCM)

- **As in PCM systems, the quantiser used can be uniform or companded and step size can be varied to suit the signal power - Adaptive Differential Pulse Code Modulation (ADPCM).**

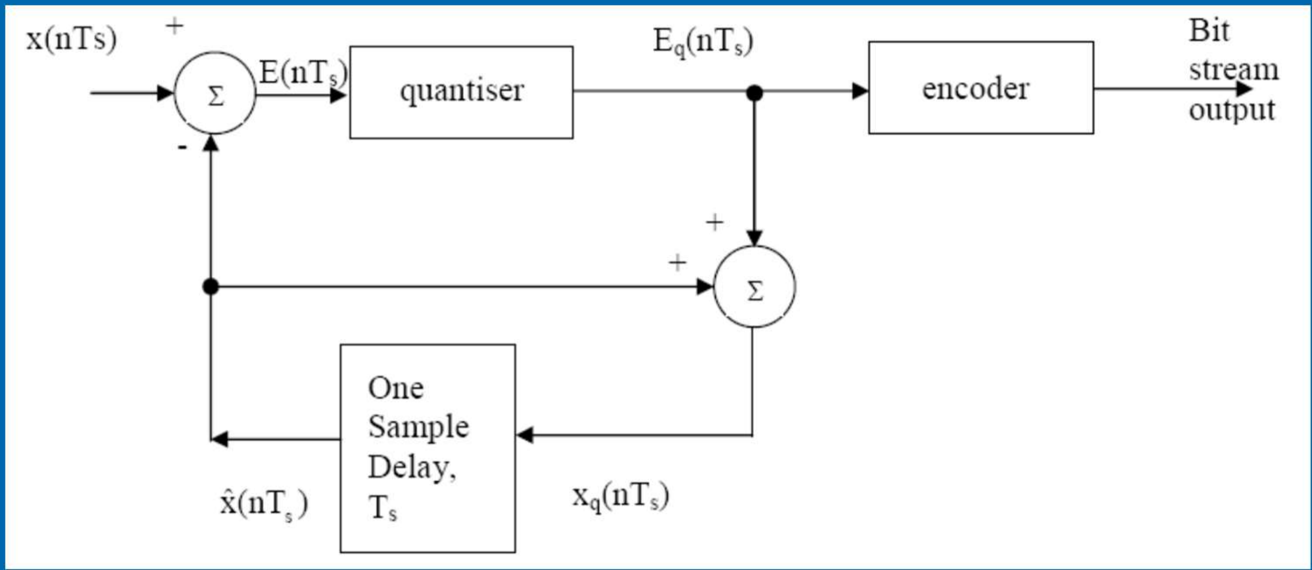
- http://datasheets.maxim-ic.com/en/ds/DS2164Q.pdf

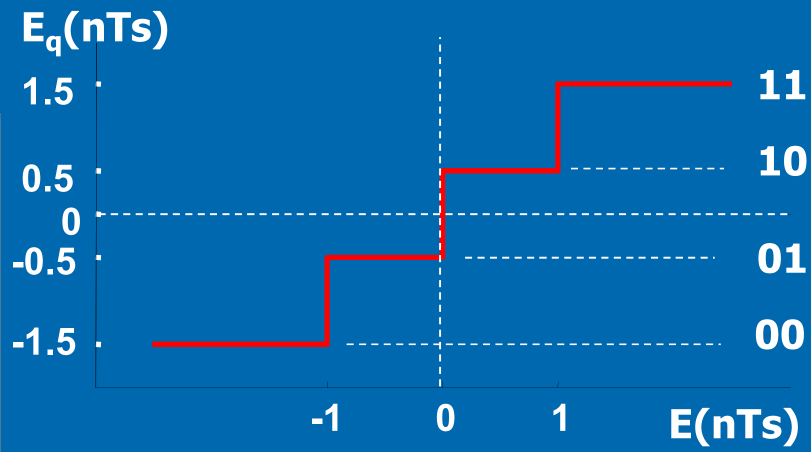
Example 7.9

A DPCM modulator is shown below. Assume that the input $x(nT_s)$ is given in Table 7.1.

a) Complete the remaining boxes in the table

b) What is the output bit stream?





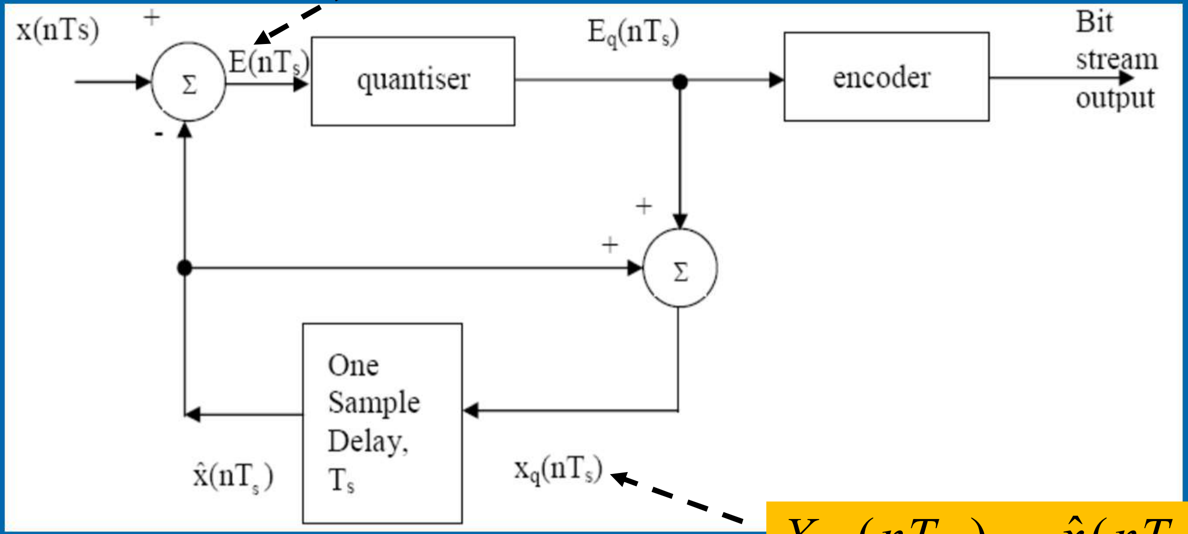
Quantiser Rule:

$$
\begin{aligned}
V_o &= 1.5\,V : & 1\,V &< V_i \le \infty \\
&\ 0.5\,V : & 0\,V &< V_i \le 1\,V \\
&\ -0.5\,V : & -1\,V &< V_i \le 0\,V \\
&\ -1.5\,V : & -\infty &< V_i \le -1\,V
\end{aligned}
$$

Solution:

(a)

$$E(nT_s) = x(nT_s) - \hat{x}(nT_s)$$



$$X_q(nT_s) = \hat{x}(nT_s) + E_q(nT_s)$$

Current sample

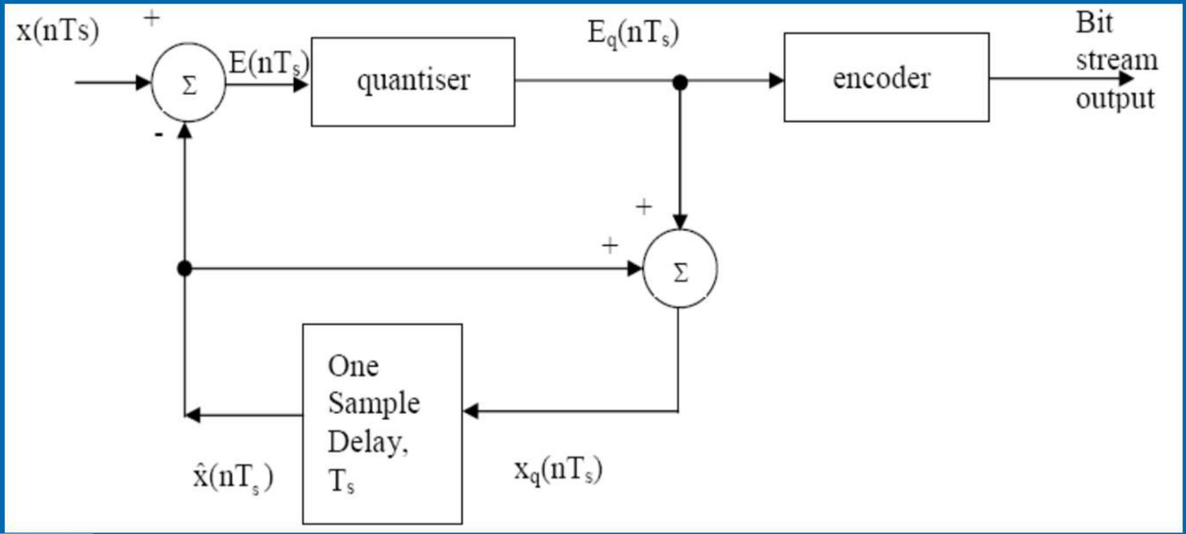
Previous sample

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5				
T_s	2.2					
$2T_s$	1.8					

Table 7.1

Solution:

(a)



Current sample

Previous sample

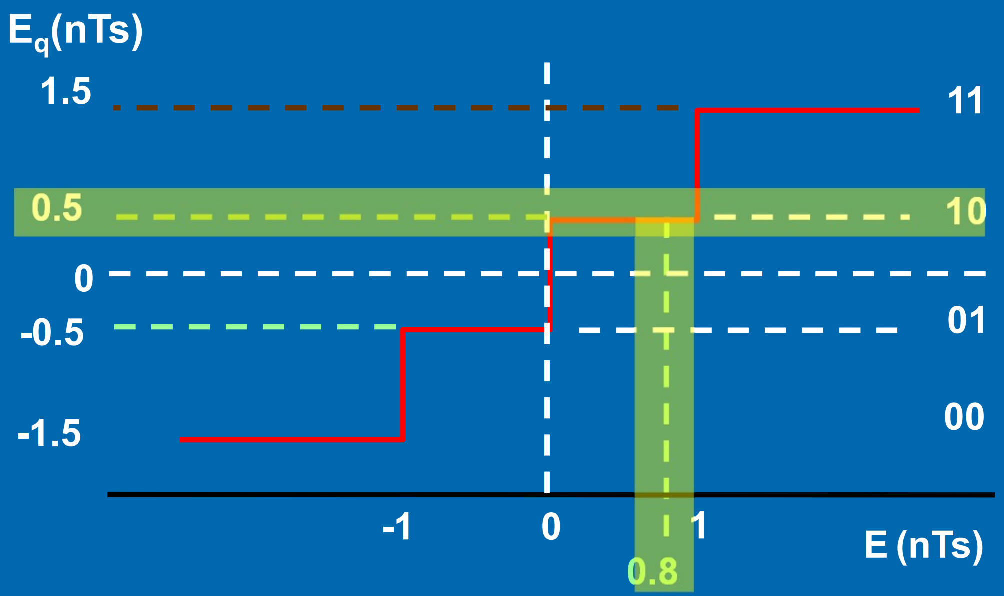
$$E(nT_s) = x(nT_s) - \hat{x}(nT_s)$$

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8			
T_s	2.2					
$2T_s$	1.8					

Table 7.1

Solution:

(a)



$V_o = 1.5\,V : \quad 1\,V < V_i \le \infty$

$0.5\,V : \quad 0\,V < V_i \le 1\,V$

$-0.5\,V : \quad -1\,V < V_i \le 0\,V$

$-1.5\,V : \quad -\infty < V_i \le -1\,V$

Quantiser Rule

Current sample

Previous sample

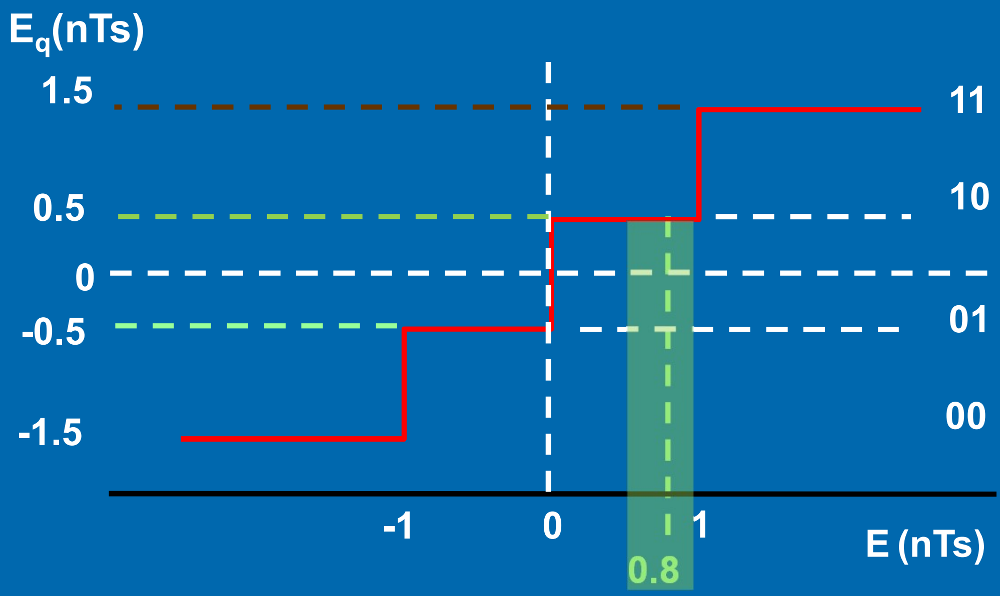
Quantiser output

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5		1 0
T_s	2.2					
$2T_s$	1.8					

Table 7.1

Solution:

(a)



$$V_o = 1.5\,V : \quad 1\,V < V_i \le \infty$$
$$0.5\,V : \quad 0\,V < V_i \le 1\,V$$
$$-0.5\,V : \quad -1\,V < V_i \le 0\,V$$
$$-1.5\,V : \quad -\infty < V_i \le -1\,V$$

Quantiser Rule

$$X_q(nT_s) = \hat{x}(nT_s) + E_q(nT_s)$$

Current sample

Previous sample

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2					
$2T_s$	1.8					

Table 7.1

Solution:

(a)

Current sample

Previous sample

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	*Codeword*
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1				
$2T_s$	1.8					

Table 7.1

Solution:

(a)

Current sample

Previous sample

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1				
$2T_s$	1.8					

Table 7.1

Solution:

(a)

Current sample

Previous sample

$$E(nT_s) = x(nT_s) - \hat{x}(nT_s)$$

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2			
$2T_s$	1.8					

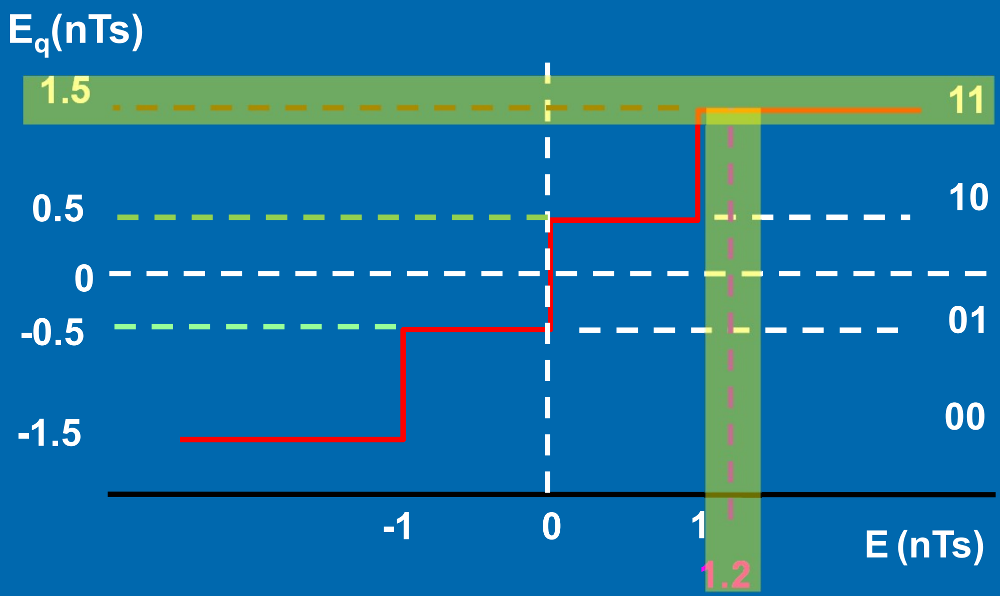
Table 7.1

Solution:

(a)

1.5

1 1



$$V_o = 1.5\ V: \quad 1\ V < V_i \le \infty$$
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$$-1.5\ V: \quad -\infty < V_i \le -1\ V$$

Quantiser Rule

Current sample

Previous sample

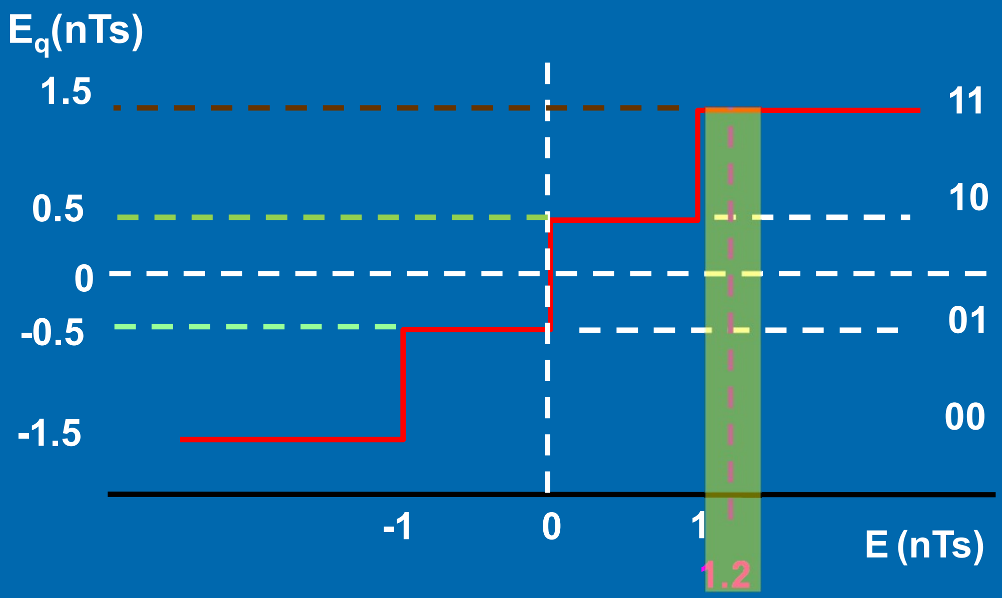
Quantiser output

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5		1 1
$2T_s$	1.8					

Table 7.1

Solution:

(a)



$$\begin{aligned} V_o = 1.5\,V &: \quad 1\,V < V_i \le \infty \\ 0.5\,V &: \quad 0\,V < V_i \le 1\,V \\ -0.5\,V &: \quad -1\,V < V_i \le 0\,V \\ -1.5\,V &: \quad -\infty < V_i \le -1\,V \end{aligned}$$

Quantiser Rule

$$X_q(nT_s) = \hat{x}(nT_s) + E_q(nT_s)$$

Current sample

Previous sample

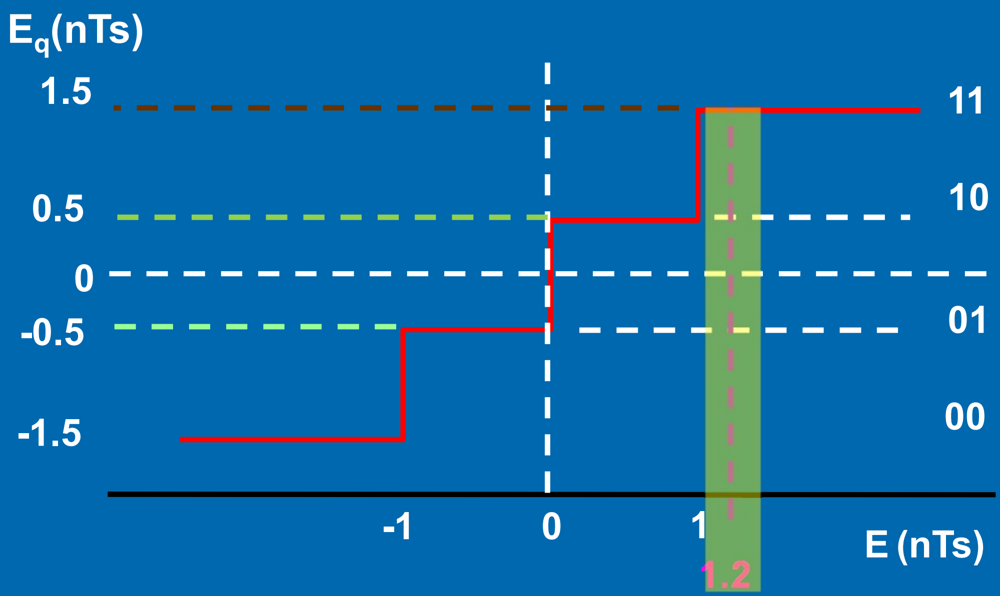
Quantiser output

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5	2.5	1 1
$2T_s$	1.8					

Table 7.1

Solution:

(a)



$$V_o = 1.5\ V : \quad 1\ V < V_i \le \infty$$
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$$-1.5\ V : \quad -\infty < V_i \le -1\ V$$

Quantiser Rule

Current sample

Previous sample

Quantiser output

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5	2.5	1 1
$2T_s$	1.8	2.5				

Table 7.1

Solution:

(a)

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	*Codeword*
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5	2.5	1 1
$2T_s$	1.8	2.5				

Current sample

Previous sample

Table 7.1

Solution:

(a)

Current sample

Previous sample

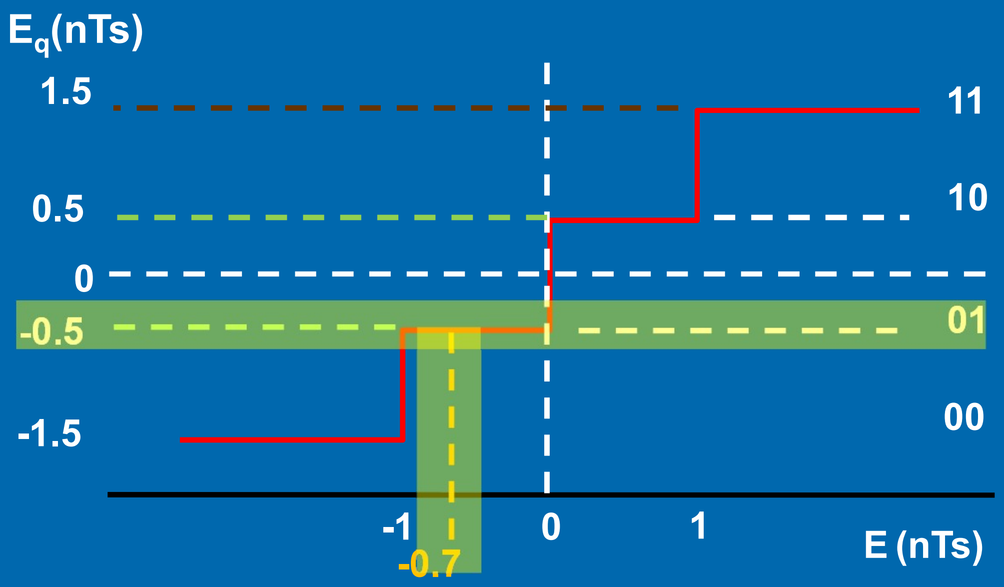
$$E(nT_s) = x(nT_s) - \hat{x}(nT_s)$$

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	*Codeword*
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5	2.5	1 1
$2T_s$	1.8	2.5	- 0.7			

Table 7.1

Solution:

(a)



$$V_o = 1.5\ V : \quad 1\ V < V_i \leq \infty$$
$$0.5\ V : \quad 0\ V < V_i \leq 1\ V$$
$$-0.5\ V : \quad -1\ V < V_i \leq 0\ V$$
$$-1.5\ V : \quad -\infty < V_i \leq -1\ V$$

Quantiser Rule

Current sample

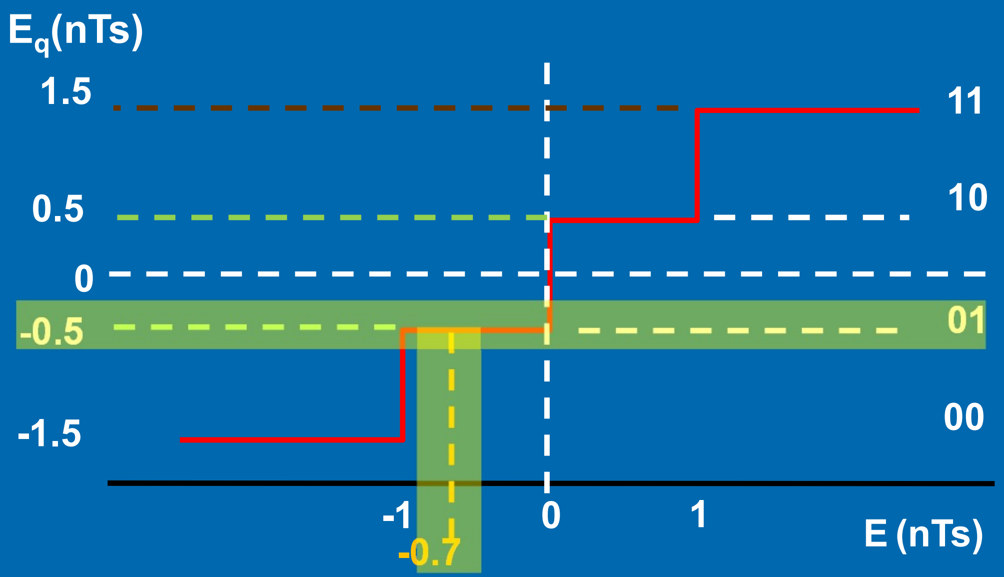
Previous sample

Quantiser output

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5	2.5	1 1
$2T_s$	1.8	2.5	- 0.7	- 0.5		0 1

Table 7.1

Solution:



$$V_o = 1.5\ V : \quad 1\ V < V_i \le \infty$$
$$0.5\ V : \quad 0\ V < V_i \le 1\ V$$
$$-0.5\ V : \quad -1\ V < V_i \le 0\ V$$
$$-1.5\ V : \quad -\infty < V_i \le -1\ V$$

Quantiser Rule

$$X_q(nT_s) = \hat{x}(nT_s) + E_q(nT_s)$$

Current sample | Previous sample | Quantiser output

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	Codeword
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5	2.5	1 1
$2T_s$	1.8	2.5	- 0.7	- 0.5	2	0 1

Table 7.1

Solution:

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(b)

Time	$x(nT_s)$ V	$\hat{x}(nT_s)$ V	$E(nT_s)$ V	$E_q(nT_s)$ V	$x_q(nT_s)$ V	*Codeword*
0	1.3	0.5	0.8	0.5	1	1 0
T_s	2.2	1	1.2	1.5	2.5	1 1
$2T_s$	1.8	2.5	-0.7	- 0.5	2	0 1

Output bit stream:

10 11 01

Table 7.1

7.5 Applications

30-channel PCM-TDM system

- Implemented in telephone networks round the world e.g. SingTel network.
- Complies with ITU-T G.711 standard.
- In the 30 channel PCM, there are actually 32 channels - 30 speech channels + 2 extra channels for signalling and synchronization.

30-channel
PCM
Equipment

7.5 Applications

Basic system parameters of the 30-channel PCM

- 3 important basic parameters are

  (I) Sampling rate

  (ii) Companding and encoding schemes

  (iii) Total output bit rate

7.5 Applications

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Basic system parameters of the 30-channel PCM

(i) Sampling rate

- Voice signal over telephone varies from 0.3 - 3.4 kHz.

  As 3.4 kHz is the highest frequency to be sampled thus the sampling freq ≥ 6800 times/sec

- In practice due to imperfect conditions sampling frequency of 8 kHz is used i.e. 8000 samples/sec.

- The 30-channel PCM system uses the sampling frequency of 8 kHz.

  Sampling takes place every 125 μs (= 1/8000).

7.5 Applications

<u>**Basic system parameters of the 30-channel PCM**</u>

(ii) Companding and Encoding schemes

- **Uses the A-law companding scheme.**
- **Has 256 quantisation levels (128 +ve and 128 -ve).**
- **Each quantisation level is represented by a 8-bit codeword where 7 bits represent the amplitude of the sample and the other 1 bit to represent the sign.**

7.5 Applications

Basic system parameters of the 30-channel PCM

(iii) Total Output bit rate

The output bit rate of 30 channel system.

- **In a 125 μs time frame there are 32 channels.**

  $\therefore$ **each channel occupies** $\dfrac{125\,\mu s}{32}$ **= 3.9 μs.**

- **Each signal sample is represented by 8 bits.**

  $\therefore$ **each bit occupies** $\dfrac{3.9\,\mu s}{8}$ **= 0.488 μs.**

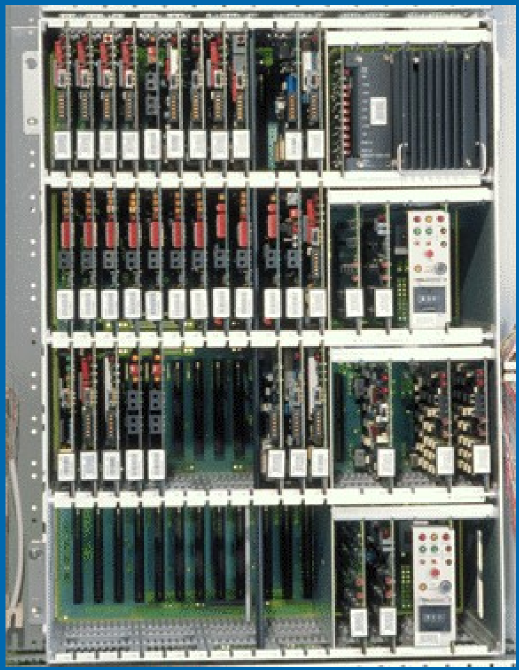
  2 Mbits system

- **Hence, the multiplex link bit rate = 1/(0.488 μs) = 2.048 Mbits/S.**

7.5 Applications

Higher order pulse code modulation (HOPCM)

- **To fully utilize the high bandwidth available on trunk links it is necessary to transmit at a high bit rate. Done by multiplexing multiple 30-channel PCM systems to form a higher speed group.**



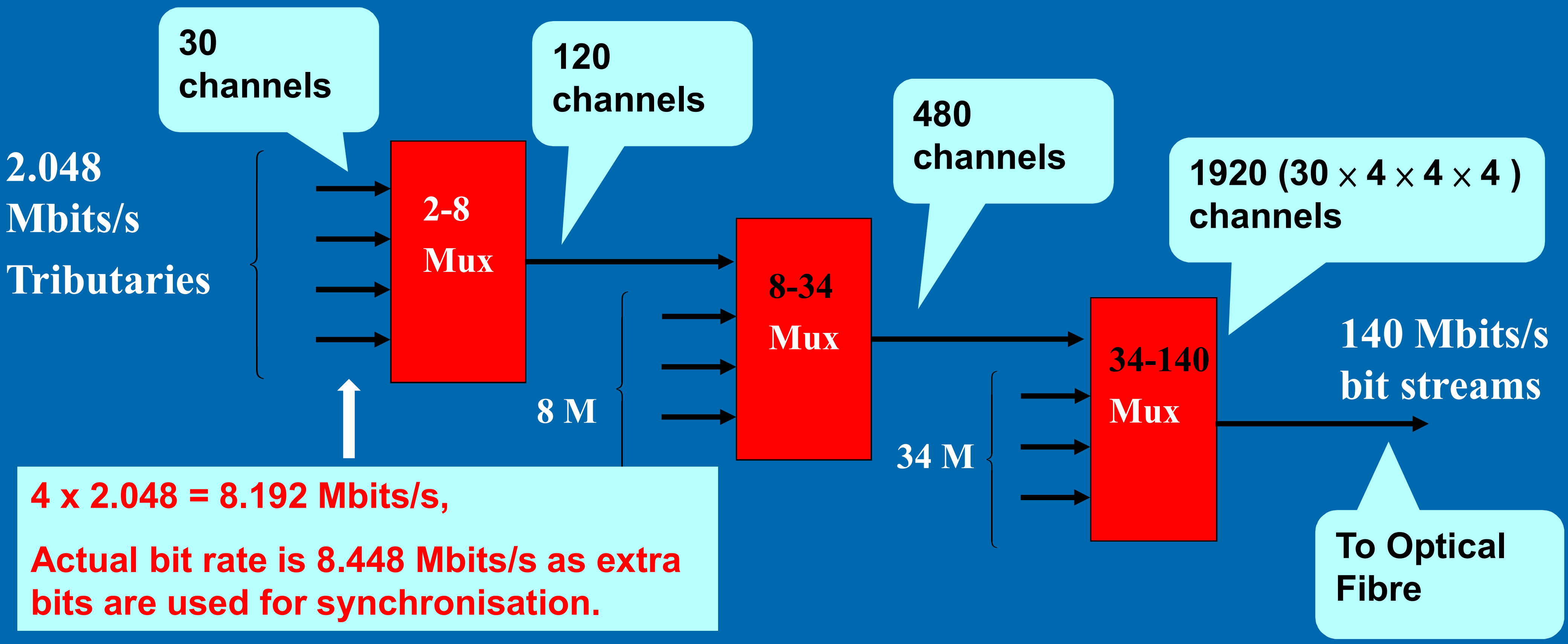
- **In Singapore a 2-8-34-140 Mbit/s hierarchy is used.**

7.5 Applications

Singapore Polytechnic

Higher order pulse code modulation (HOPCM)

- Four 30-channel PCM groups are multiplexed to form a single high speed link of 4 x 2.048 = 8.192 Mbits/s



7.5 Applications

CD Recording System

- Music bandwidth is 15 kHz. Sampling should be at least 30 kHz. Actual rate is **44.1 kHz** due to non-ideal filters.
- Each sample is quantised and converted to 16 bits i.e. no. of levels is 2^{16} = **65,536 levels.**
- Total bit rate for 2 stereo channels is
  44.1 kHz x 16 bits x 2 = **1.41 Mbps**
- For a typical 4-min song the storage is
  1.41 Mbps x 4 x 60 = **338.4 Mbits** or **40.3 Mbytes.**

END

CHAPTER 7

(Part 4 of 4)