Chapter 10

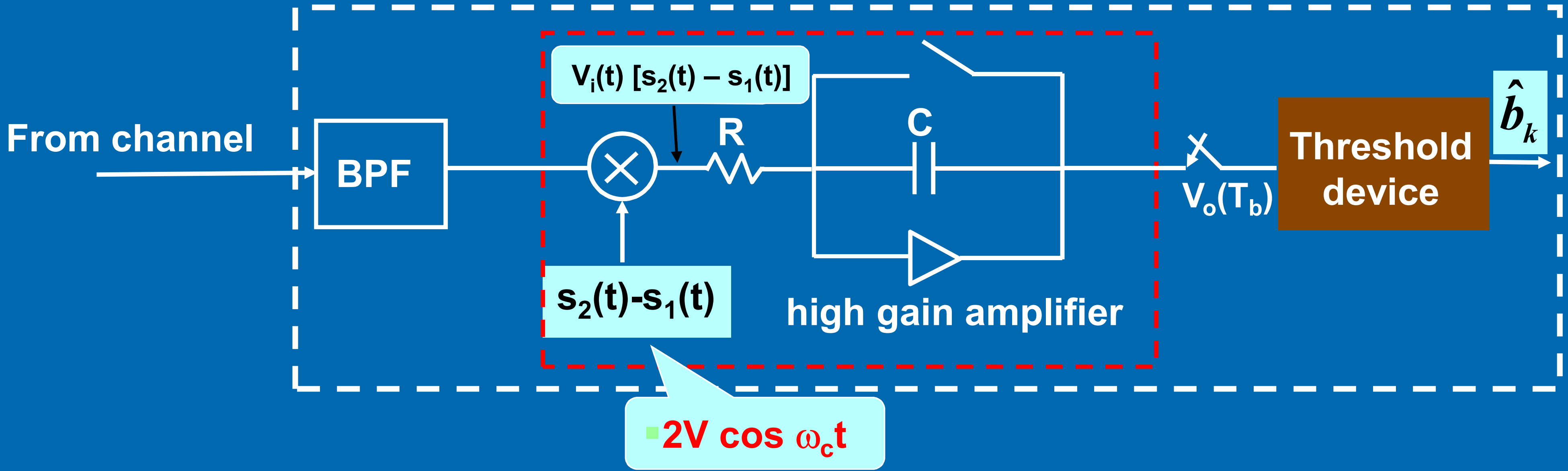
Digital Modulation

(Part 2 of 2)

10.5 Differential Phase-Shift Keying (DPSK)

- Coherent BPSK system requires complex hardware to generate the receiver local carrier for coherent detection.
- DPSK uses non-coherent detection.

Coherent BPSK system



10.5 Differential Phase-Shift Keying (DPSK)

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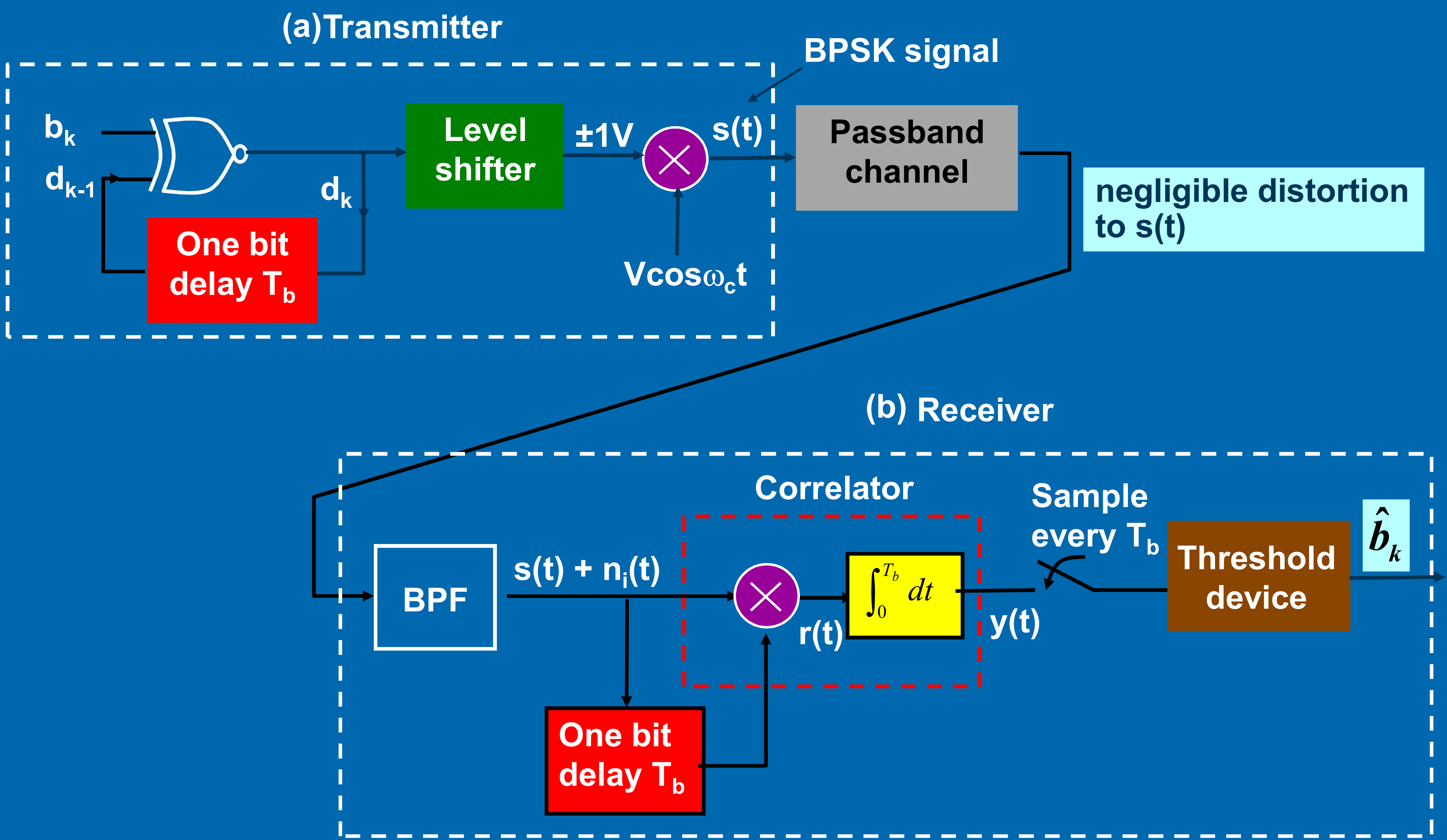
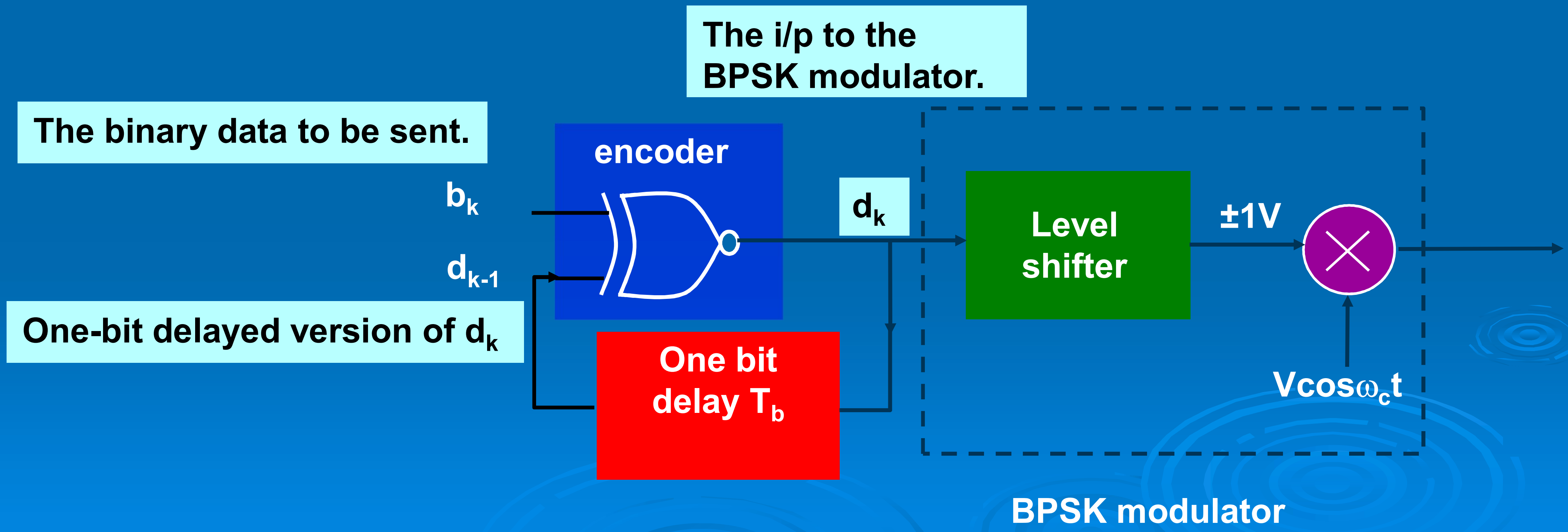


10.5 Differential Phase-Shift Keying (DPSK)

Transmitter

- The binary data is contained in the difference between the phase angles of two successive signaling elements.



Transmitter

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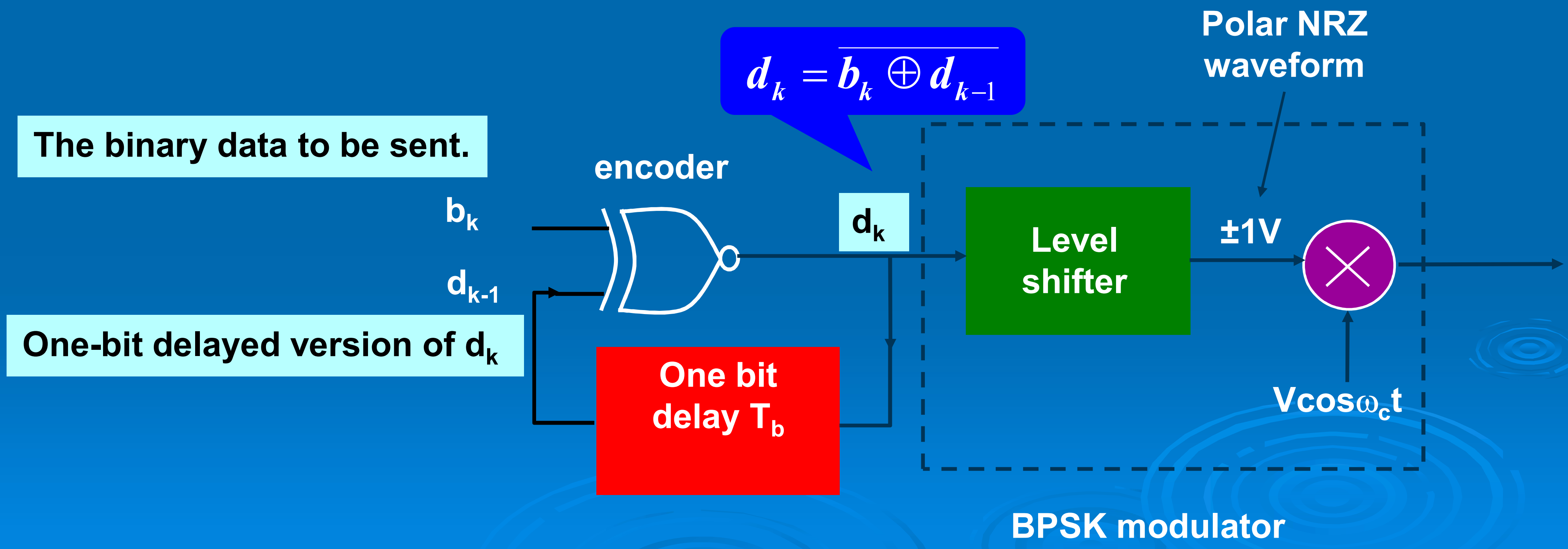

Transmitter

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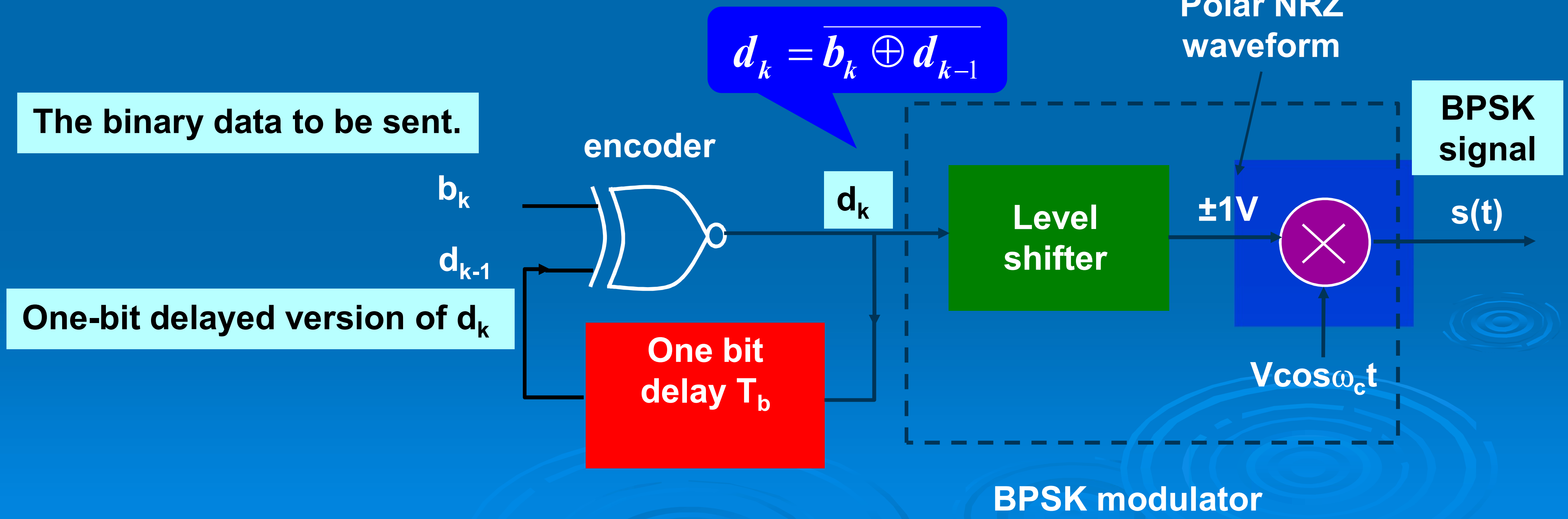


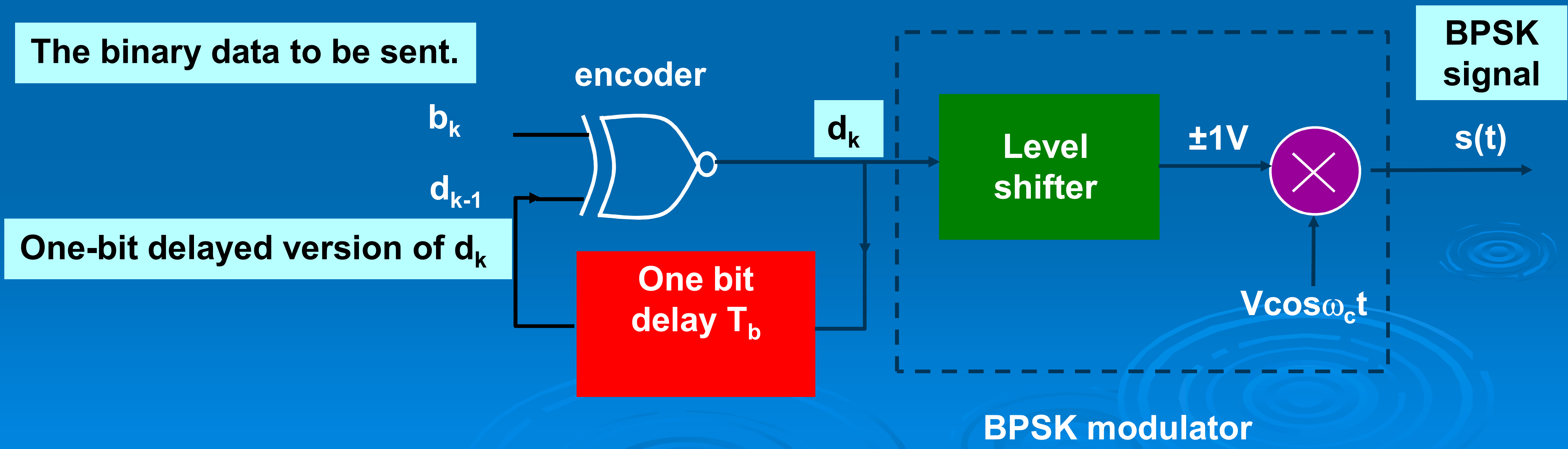
10.5 Differential Phase-Shift Keying (DPSK)

Transmitter

$$s(t) = \begin{cases} s_2(t) = V\cos\omega_c t & 0 < t < T_b; \quad d_k = 1; \\ s_1(t) = -V\cos\omega_c t & 0 < t < T_b; \quad d_k = 0; \end{cases}$$

$d_k = 1$

$V\cos\omega_c t$



10.5 Differential Phase-Shift Keying (DPSK)

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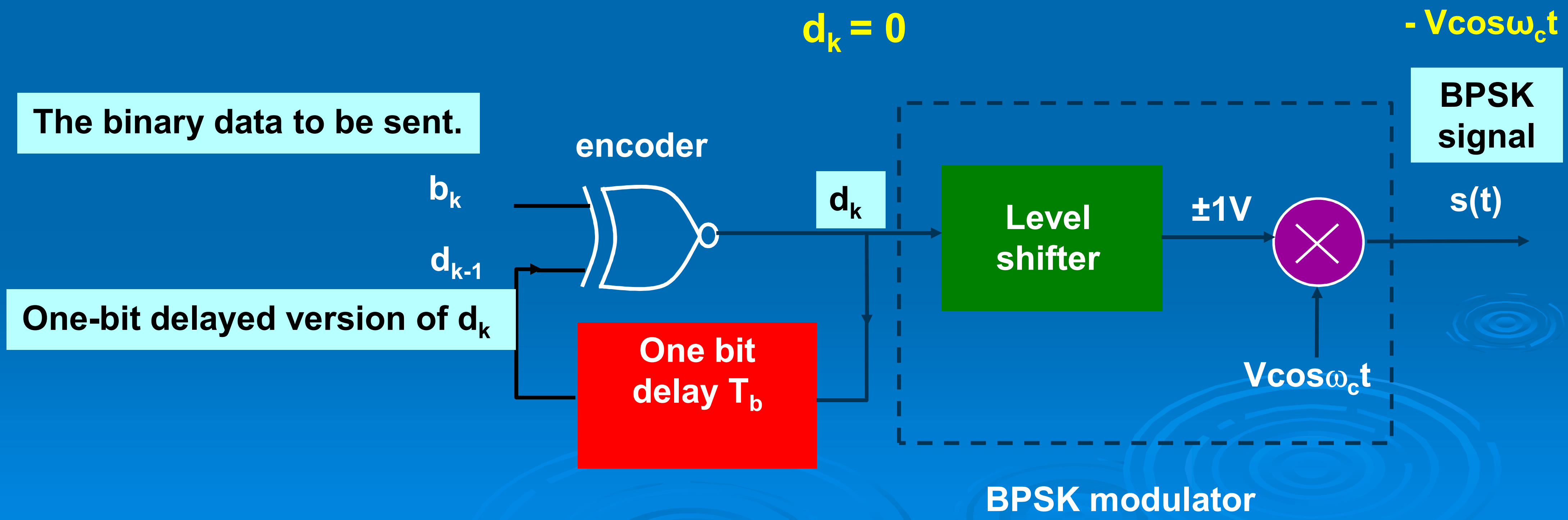

10.5 Differential Phase-Shift Keying (DPSK)

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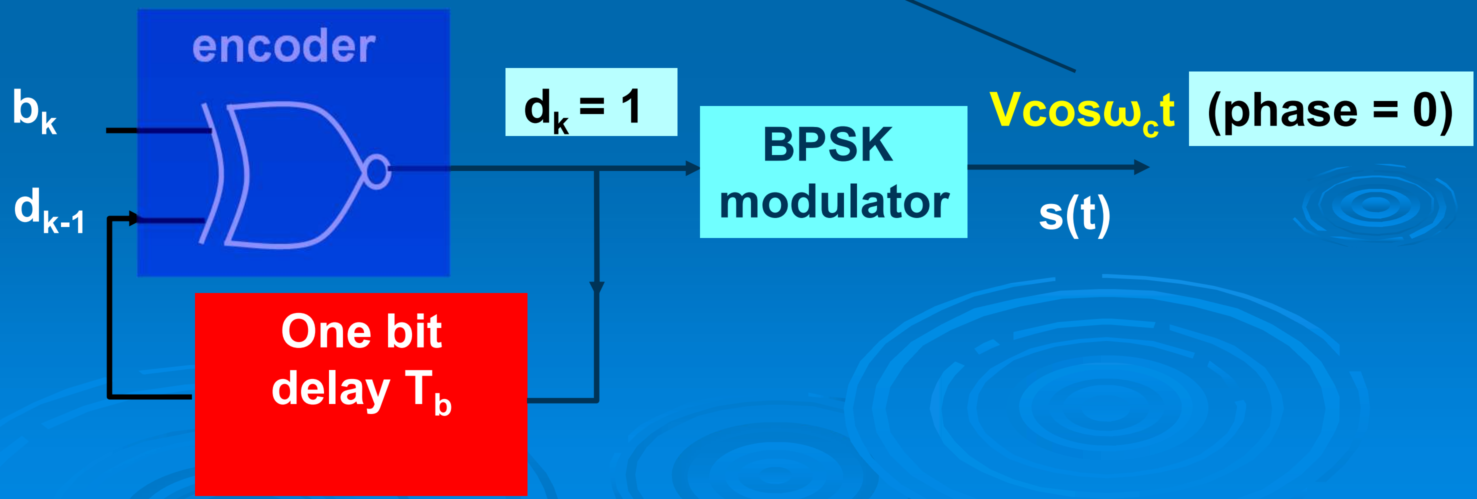
Differential encoding

Bit Time	0	1	2	3	4	5	6	7
Input sequence, b_k		1	1	0	1	0	0	0
Encoded sequence, d_k	1*	1						
Phase of transmitted s(t)	0	0						

*Arbitrary starting reference bit

Truth table for ex-NOR

Inputs		output
1	1	1
0	0	1
1	0	0
0	1	0



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Truth table for ex-NOR

Inputs		output
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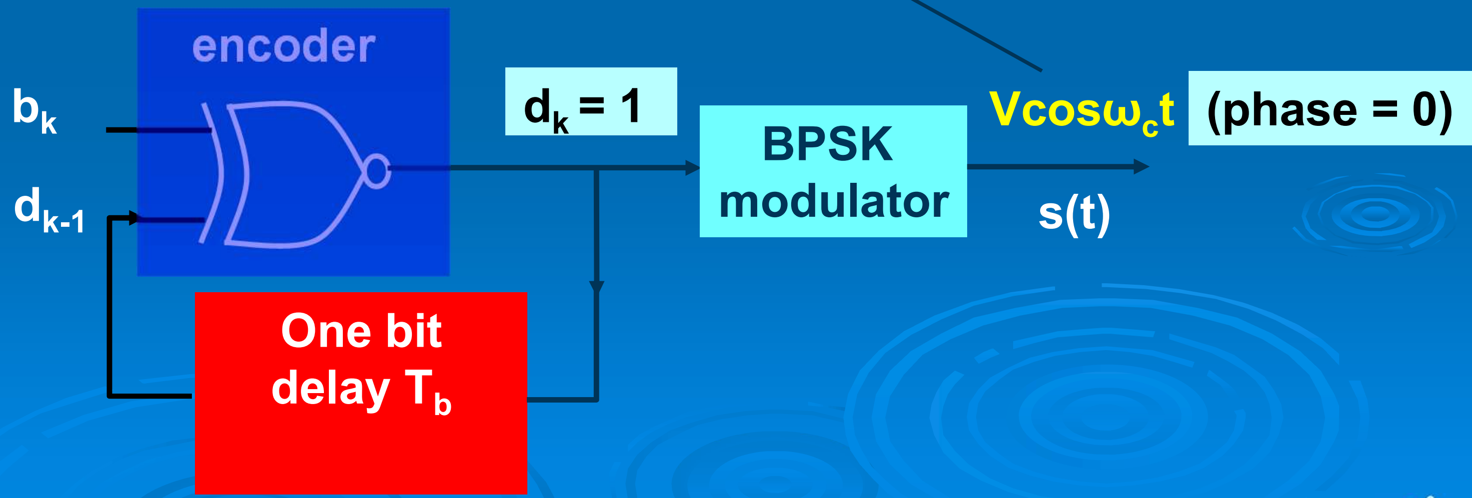
0	0	1
1	0	0
0	1	0



10.5 Differential Phase-Shift Keying (DPSK)

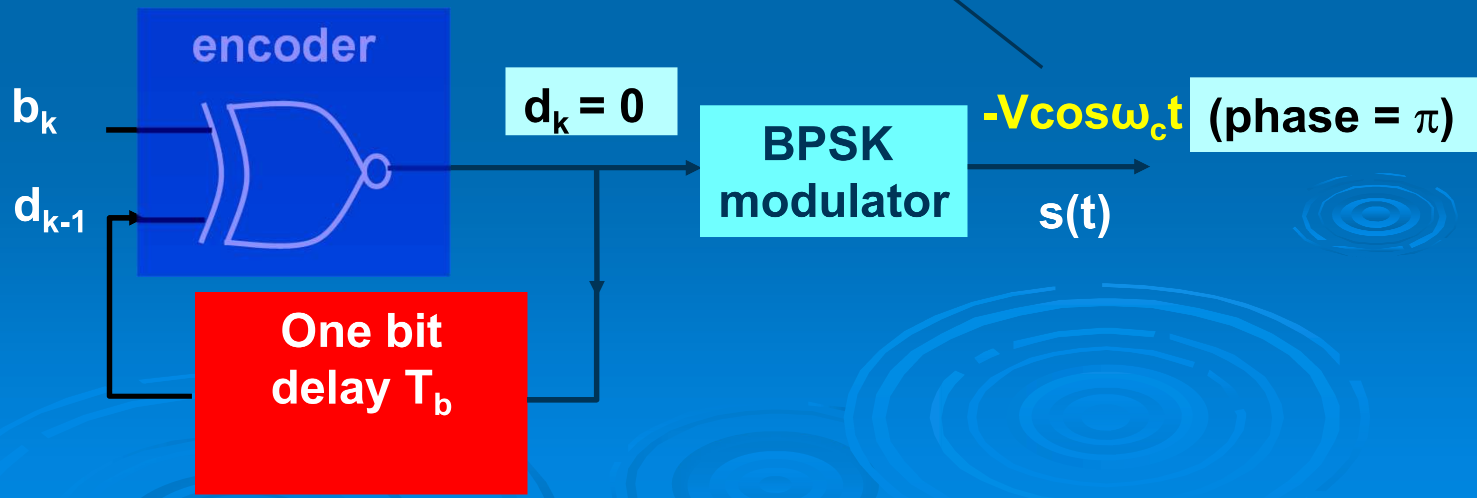
Differential encoding

Bit Time	0	1	2	3	4	5	6	7
Input sequence, b_k		1	1	0	1	0	0	0
Encoded sequence, d_k	1*	1	1	0				
Phase of transmitted s(t)	0	0	0	π				

*Arbitrary starting reference bit

Truth table for ex-NOR

Inputs		output
1	1	1
0	0	1
1	0	0
0	1	0



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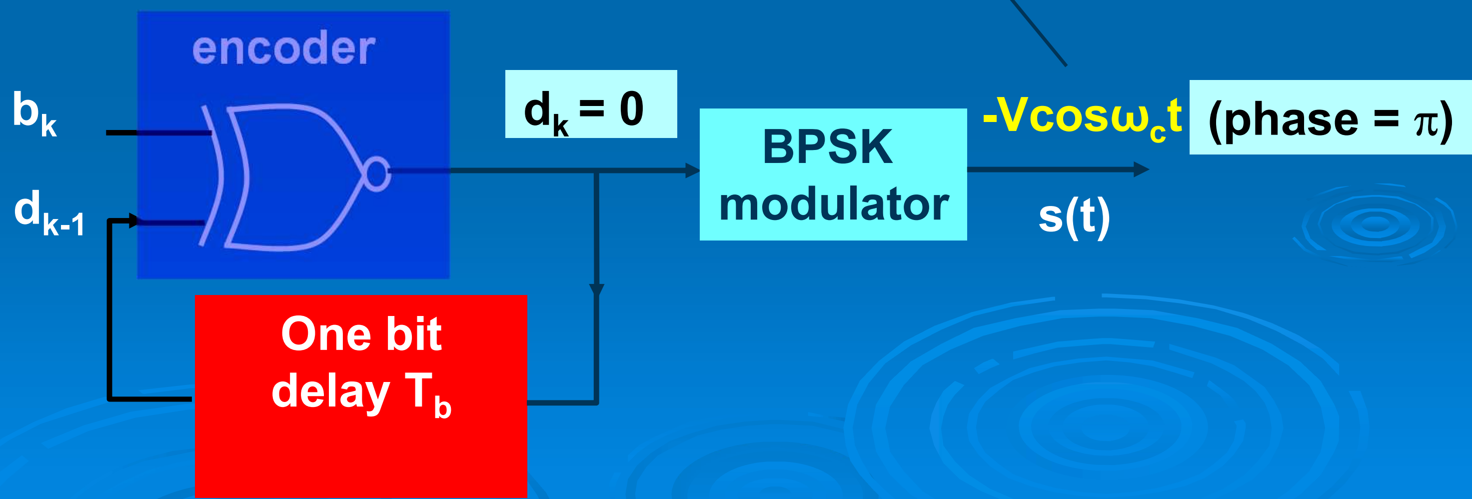
Input sequence, b_k		1	1	0	1	0	0	0
Encoded sequence, d_k	1*	1	1	0	0			
Phase of transmitted s(t)	0	0	0	π	π			

*Arbitrary starting reference bit

Truth table for ex-NOR

Inputs		output
1	1	1
0	0	1
1	0	0
0	1	0



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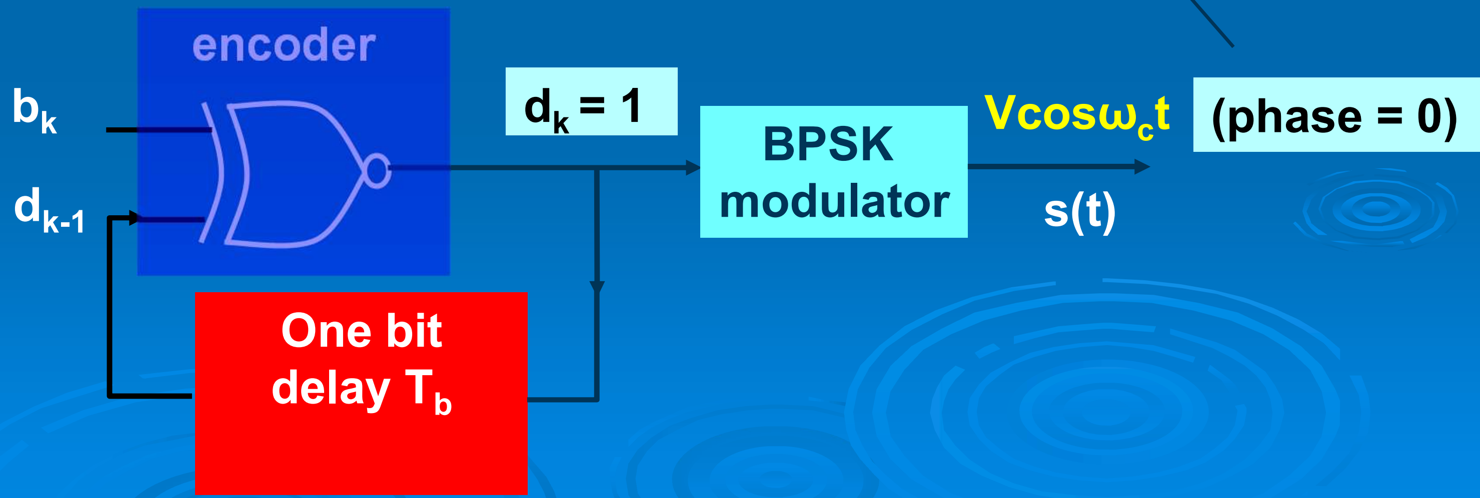
Differential encoding

Bit Time	0	1	2	3	4	5	6	7
Input sequence, b_k		1	1	0	1	0	0	0
Encoded sequence, d_k	1*	1	1	0	0	1		
Phase of transmitted s(t)	0	0	0	π	π	0		

*Arbitrary starting reference bit

Truth table for ex-NOR

Inputs		output
1	1	1
0	0	1
1	0	0
0	1	0



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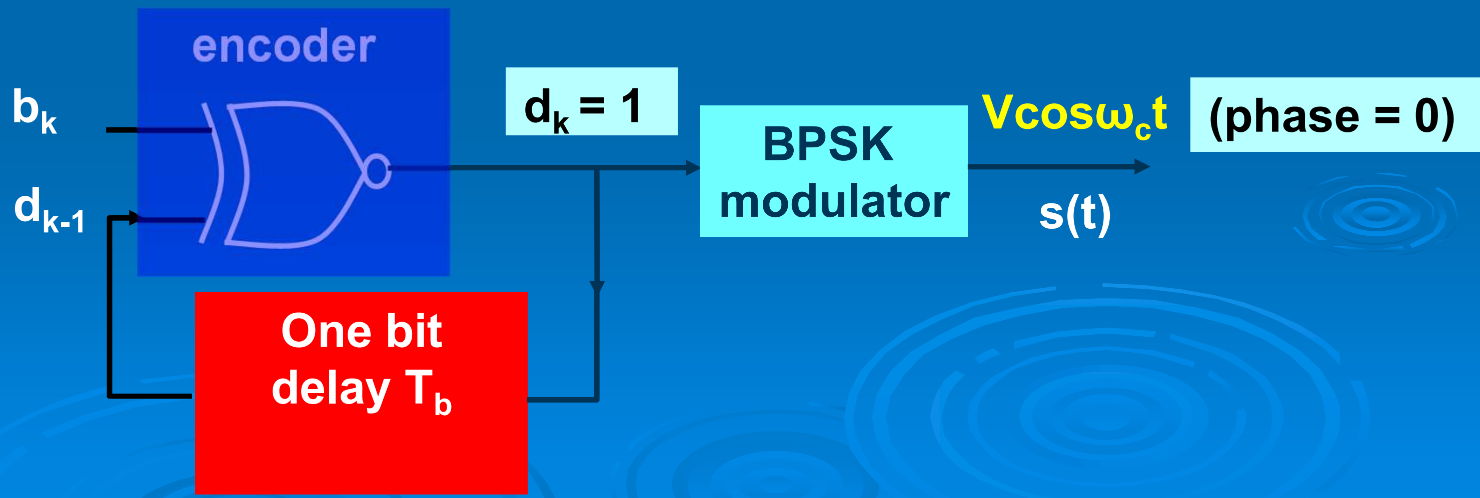
Differential encoding

Bit Time	0	1	2	3	4	5	6	7
Input sequence, b_k		1	1	0	1	0	0	0
Encoded sequence, d_k	1*	1	1	0	0	1	0	1
Phase of transmitted s(t)	0	0	0	π	π	0	π	0

*Arbitrary starting reference bit

Truth table for ex-NOR

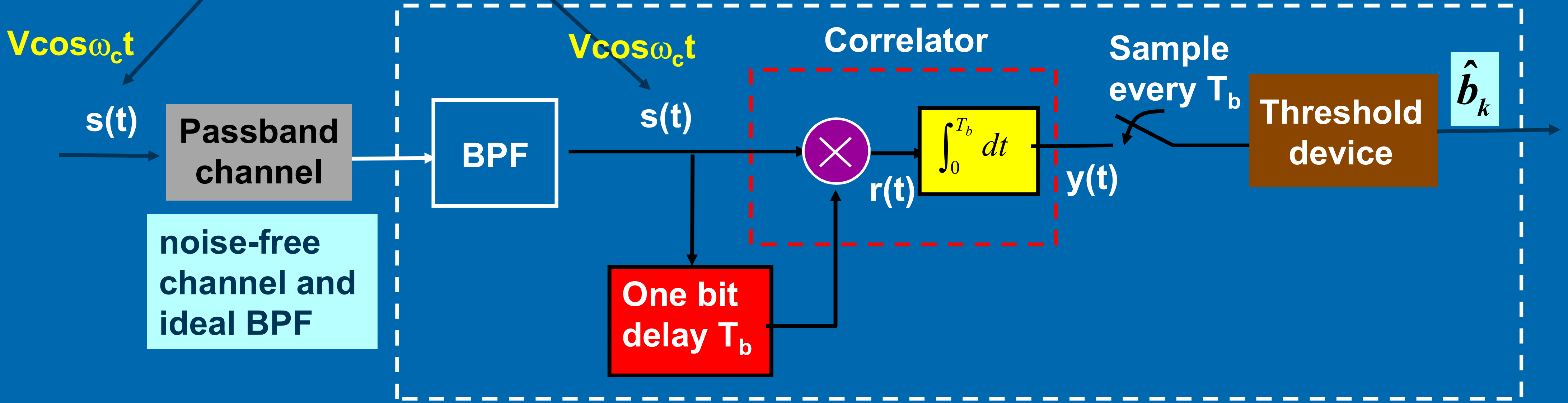
Inputs		output
1	1	1
0	0	1
1	0	0
0	1	0



10.5 Differential Phase-Shift Keying (DPSK)

Receiver

$$s(t) = \begin{cases} s_2(t) = V\cos\omega_c t & 0 < t < T_b; \quad d_k = 1; \\ s_1(t) = -V\cos\omega_c t & 0 < t < T_b; \quad d_k = 0; \end{cases}$$



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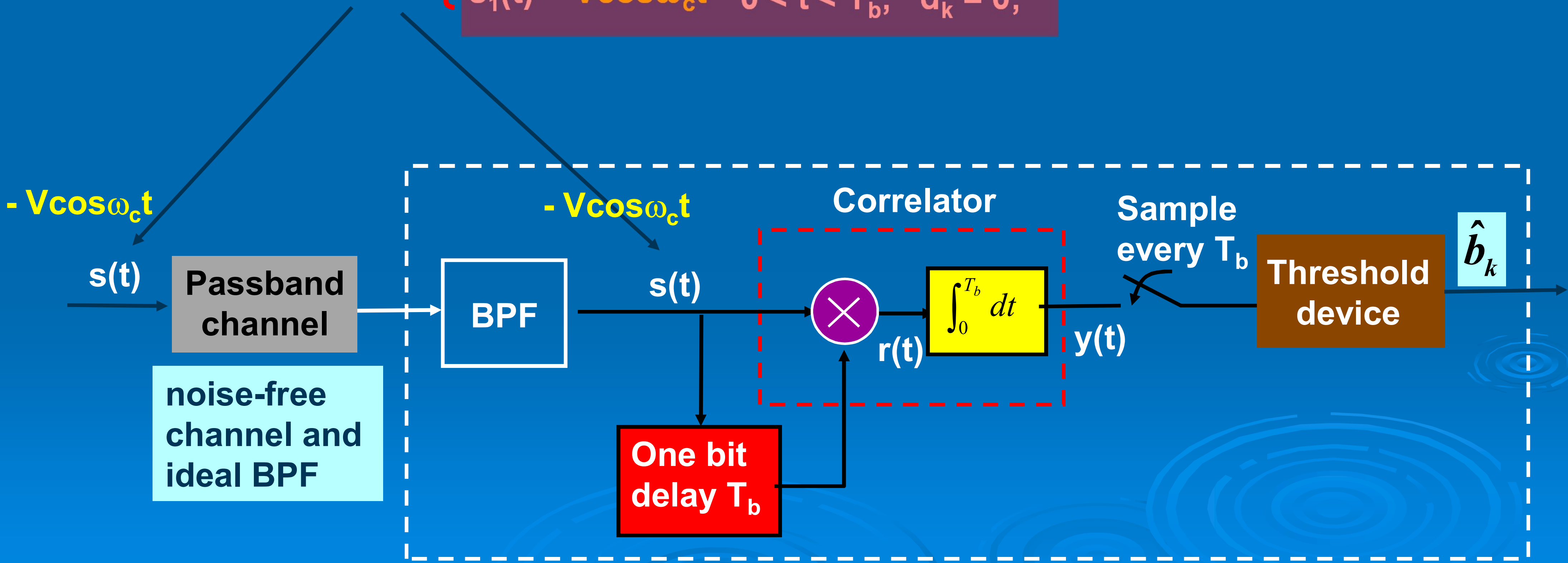
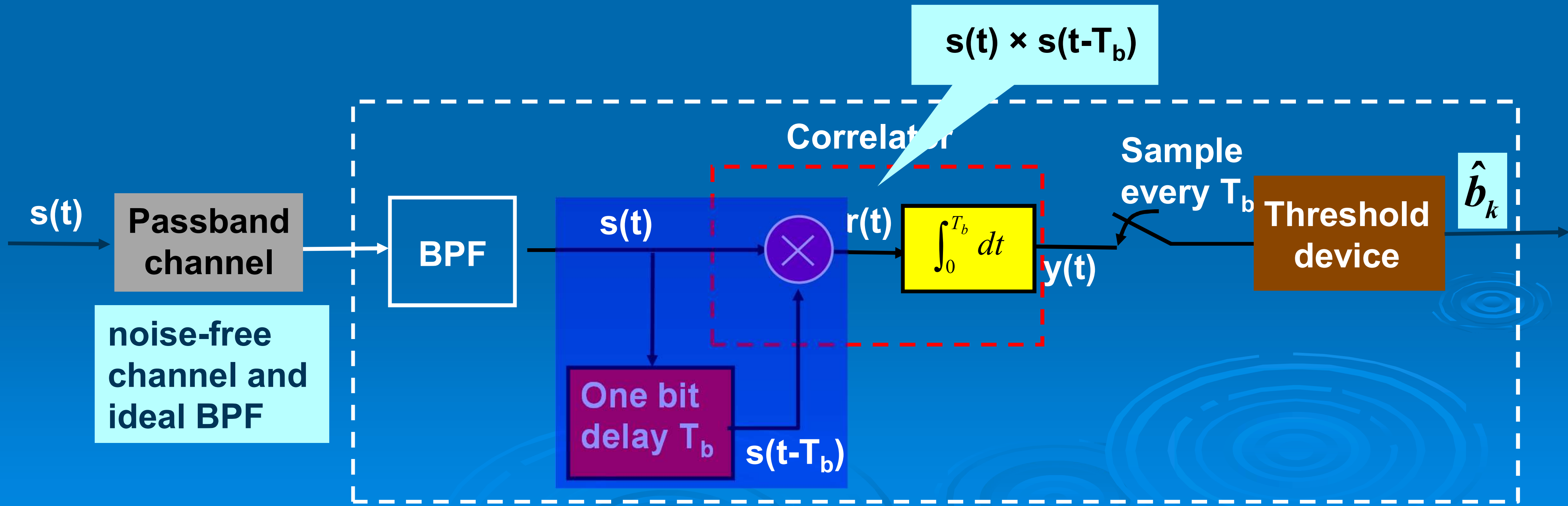


10.5 Differential Phase-Shift Keying (DPSK)

Receiver

$$r(t) = s(t) \times s(t-T_b) = \begin{cases} V^2 \cos^2 \omega_c t & \text{If } s(t) = s(t-T_b) \end{cases}$$



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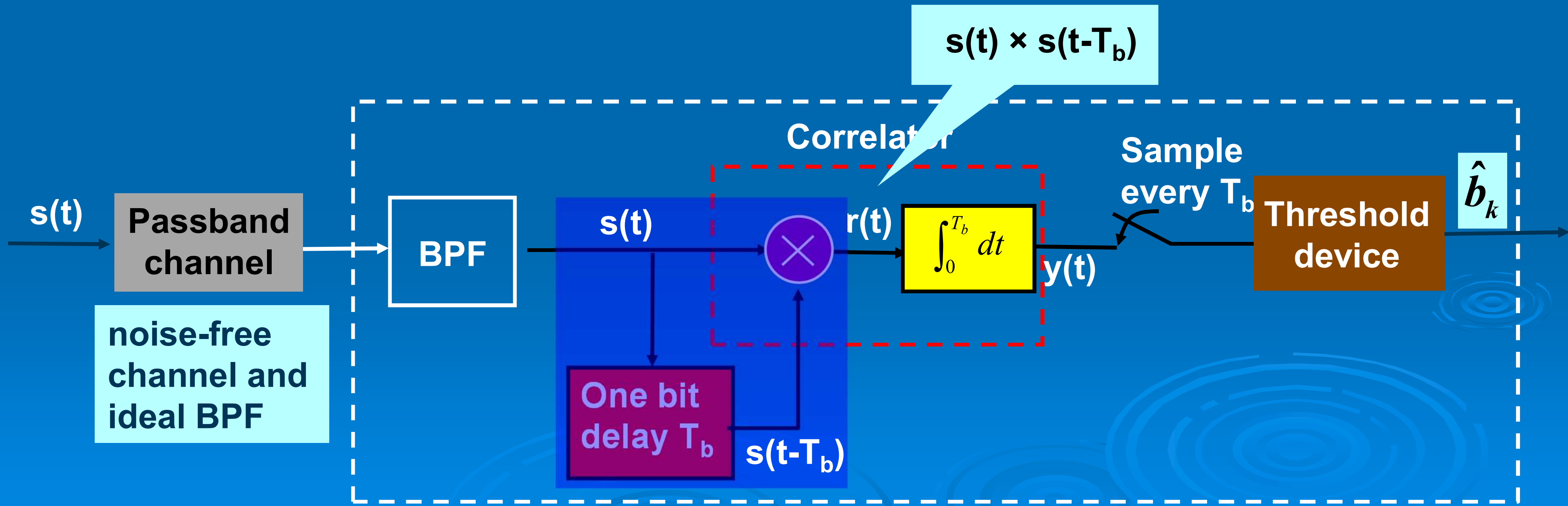
Receiver

$$r(t) = s(t) \times s(t-T_b) = \begin{cases} V^2 \cos^2 \omega_c t & \text{If } s(t) = s(t-T_b) \\ -V^2 \cos^2 \omega_c t & \text{If } s(t) \neq s(t-T_b) \end{cases}$$



10.5 Differential Phase-Shift Keying (DPSK)

- When $r(t) = V^2 \cos^2 \omega_c t$, after integration and dump,

$$y(Tb) = k\int_0^{T_b} V^2 \cos^2 \omega_c t \, dt = kV^2 \int_0^{T_b} \left(\frac{1}{2} + \frac{\cos 2\omega_c t}{2}\right) dt$$

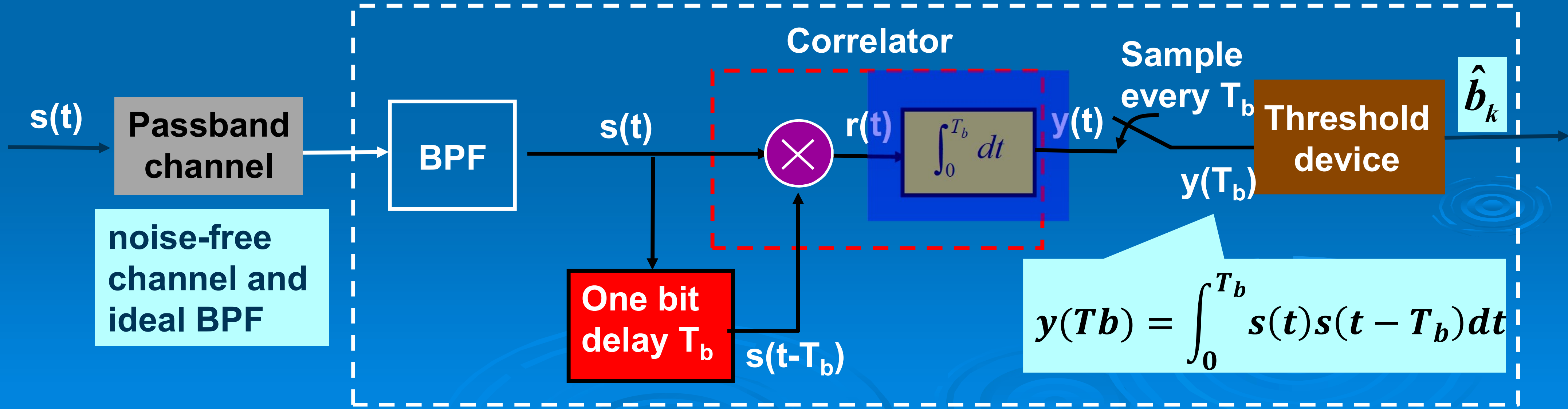
using $\cos 2\theta = 2\cos^2\theta - 1$

$\Rightarrow \cos^2\theta = \dfrac{1+\cos 2\theta}{2}$

$$= kV^2 \int_0^{T_b} \left(\frac{1}{2}\right) dt + kV^2 \int_0^{T_b} \left(\cancel{\frac{\cos 2\omega_c t}{2}}\right) dt$$

$$= \frac{kV^2 T_b}{2}$$

Assume ideal case: whole cycles within 1 bit.



10.5 Differential Phase-Shift Keying (DPSK)

- When $r(t) = -V^2 \cos^2 \omega_c t$, after integration and dump,

$$y(Tb) = k\int_0^{T_b} -V^2 \cos^2 \omega_c t \, dt = -kV^2 \int_0^{T_b} \left(\frac{1}{2} + \frac{\cos 2\omega_c t}{2}\right) dt$$

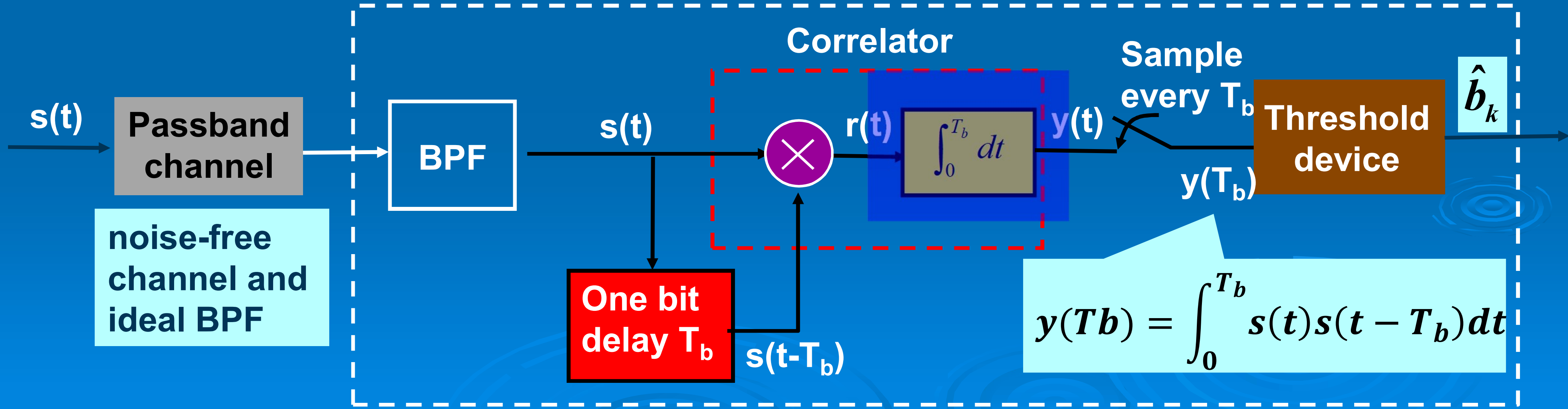
using $\cos 2\theta = 2\cos^2\theta - 1$

$$\Rightarrow \cos^2\theta = \frac{1+\cos 2\theta}{2}$$

$$= -kV^2 \int_0^{T_b} \left(\frac{1}{2}\right) dt - kV^2 \int_0^{T_b} \cancel{\left(\frac{\cos 2\omega_c t}{2}\right)} dt$$

$$= -\frac{kV^2 T_b}{2}$$

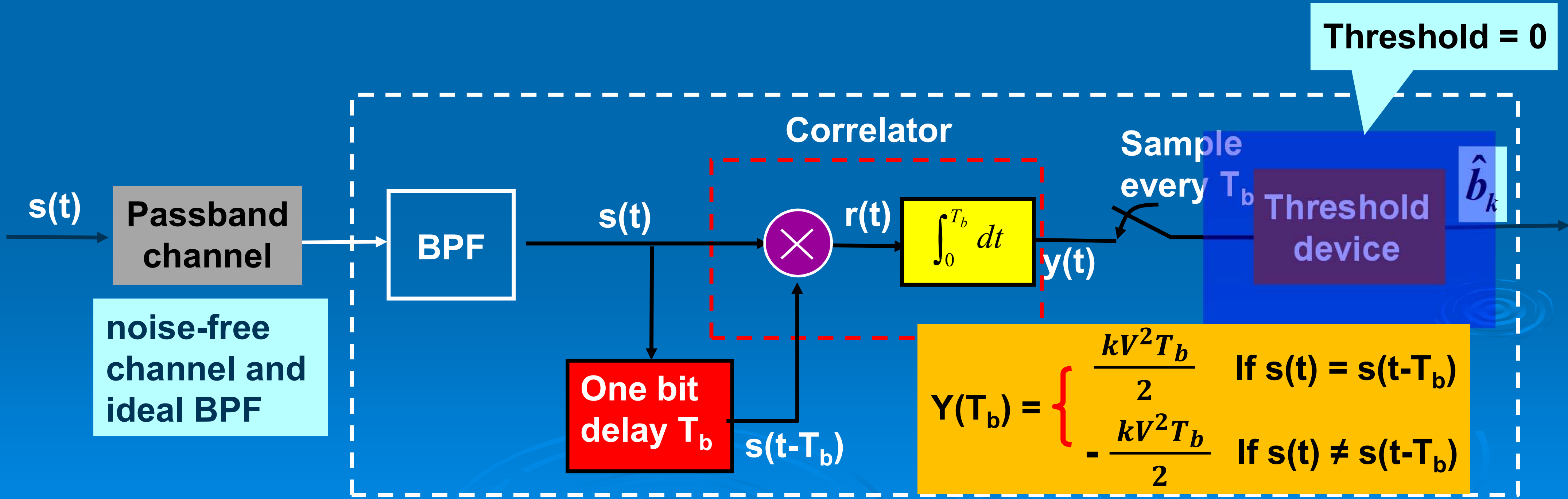
Assume ideal case: whole cycles within 1 bit.



10.5 Differential Phase-Shift Keying (DPSK)

Receiver

- Threshold level is therefore set at 0 V (middle value).
- Decision rule:
  - If the correlator output is positive, decode $b_k = 1$.
  - If the correlator output is negative, decode $b_k = 0$.



10.5 Differential Phase-Shift Keying (DPSK)

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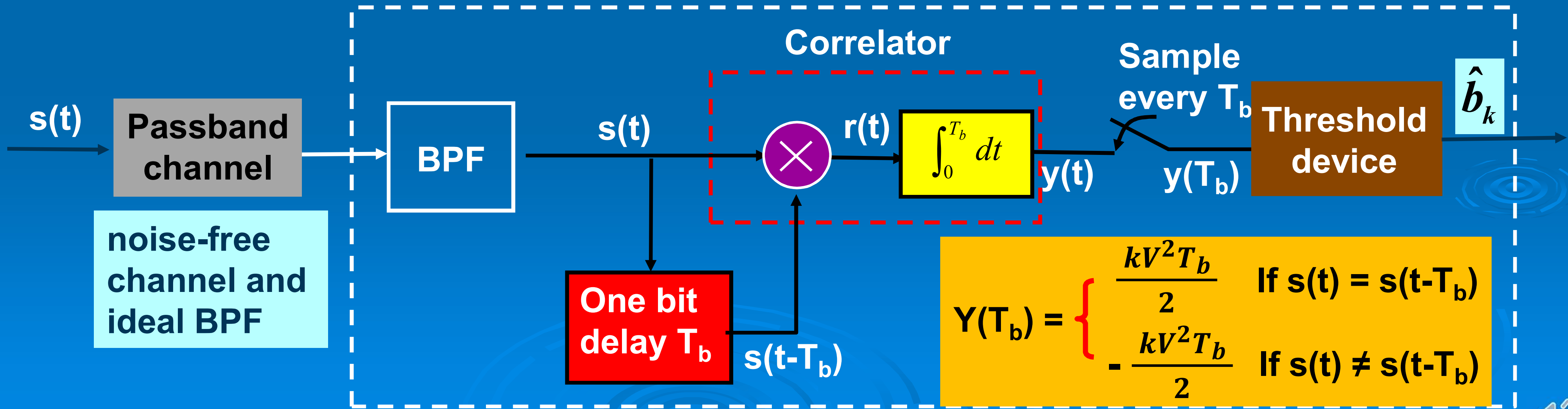
Differential decoding

Bit Time	0	1	2	3	4	5	6	7
Bit sequence sent		1	1	0	1	0	0	0
Phase of received s(t)	0	0	0	π	π	0	π	0
Correlator output (sampled value), $y(T_b)$		+	+	-	+	-	-	-
Output bit sequence recovered		1	1	0	1	0	0	0



$$Y(T_b) = \begin{cases} \dfrac{kV^2T_b}{2} & \text{If } s(t) = s(t-T_b) \\ -\dfrac{kV^2T_b}{2} & \text{If } s(t) \neq s(t-T_b) \end{cases}$$

10.5 Differential Phase-Shift Keying (DPSK)

- The probability of bit error for a DPSK system is found to be

$$P_e = \frac{1}{2}\exp\left(\frac{-V^2 T_b}{2\eta}\right) = \frac{1}{2}e^{-\left(\frac{V^2 T_b}{2\eta}\right)}$$

- Disadvantages of DPSK are:

  - For a given transmitted power, the DPSK system will give a higher error rate when compared with the coherent BPSK system.

  - Asynchronous transmission is not possible as the system need to be locked on a specific signalling speed.

  - An error will propagate to the adjacent bit. Hence higher error rate than coherent BPSK.

10.5 Differential Phase-Shift Keying (DPSK)

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Example 10.1

Figure E10.1 shows the block diagram of a DPSK transmitter. The binary input is in unipolar NRZ format of amplitude 2V volt, at a bit rate of 1200 b/s. The carrier is $\sin\omega_c t$ where $\omega_c t = 4800\pi$ rad/s. Assume that the input is a long series of …10101010… . Sketch the waveforms at points A to D as indicated in Figure E10.1 for a 1010 frame. Assume distortion-less transmission path. Also assume that the encoder output is binary 1 prior to the 1010 frame.

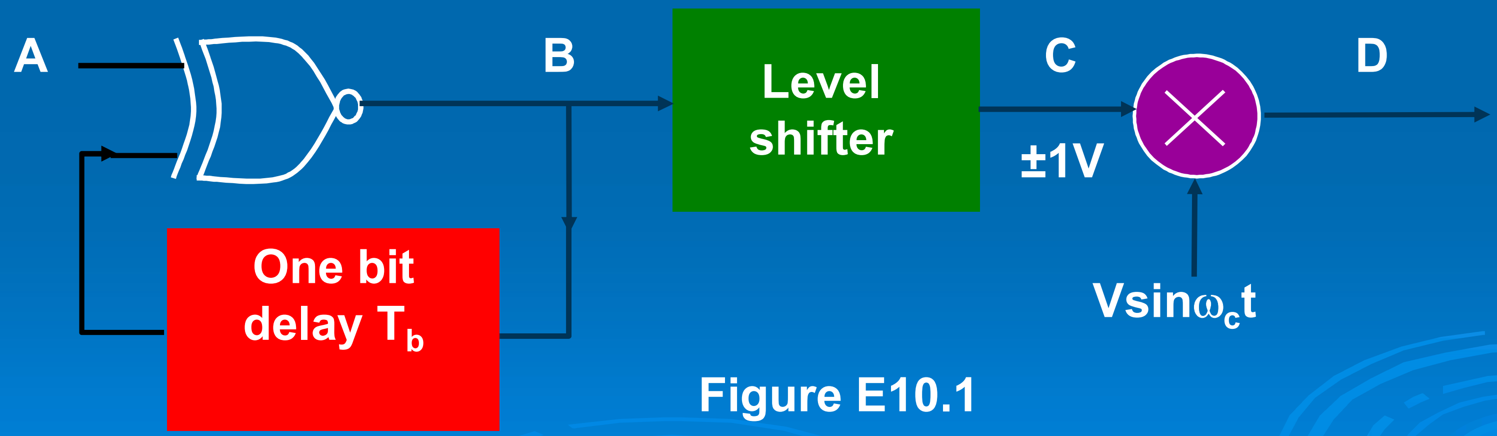


Figure E10.1

10.5 Differential Phase-Shift Keying (DPSK)

Solution:

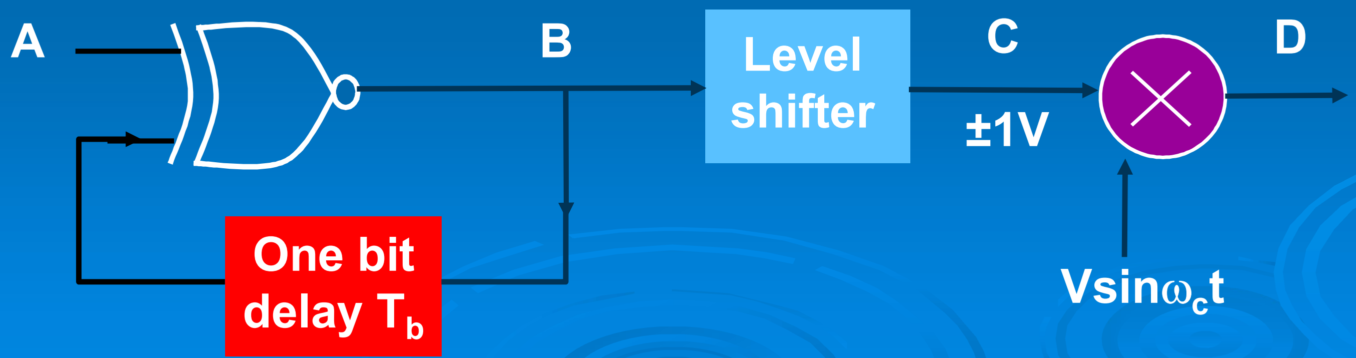
$\omega_c = 2\pi f_c = 4800\,\pi$ rad/s

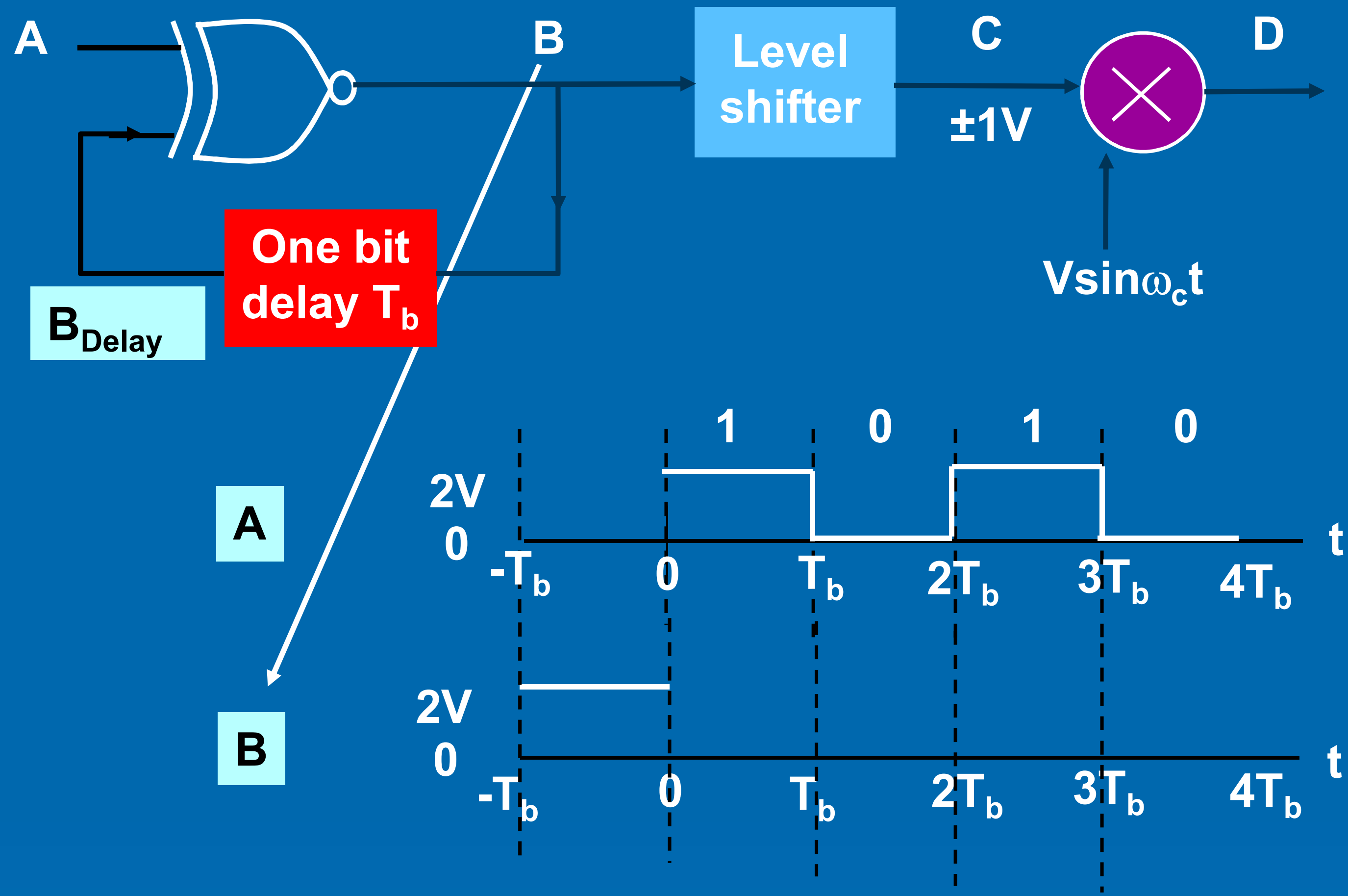
$2f_c = 4800 \longrightarrow f_c = 2400$ Hz $\longrightarrow$ Carrier Period $T_c = \dfrac{1}{2400}$ sec

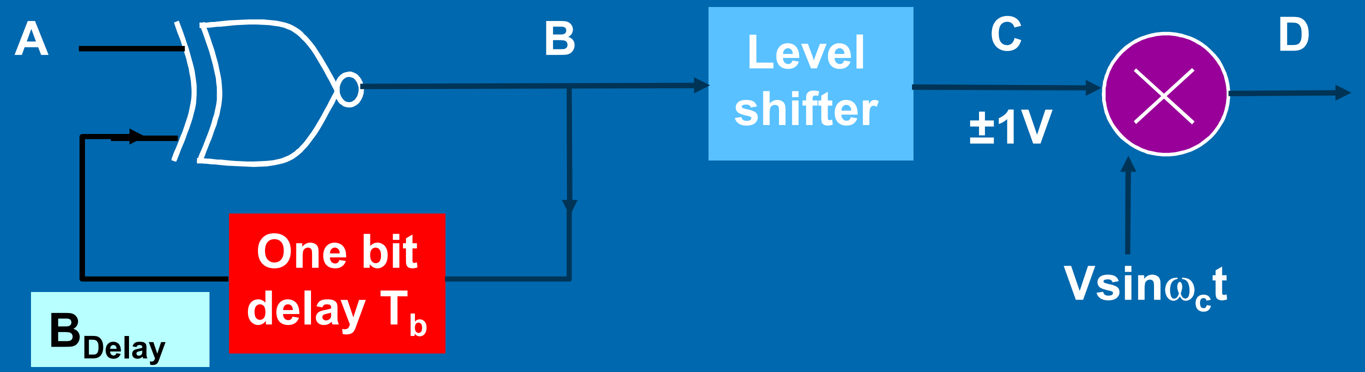
"A" has unipolar format; bit rate $r_b = 1200$ b/s

$T_b = \dfrac{1}{1200}$ sec

One bit duration $T_b = \dfrac{1}{r_b} = \dfrac{1}{1200} = 2T_c$ two carrier periods

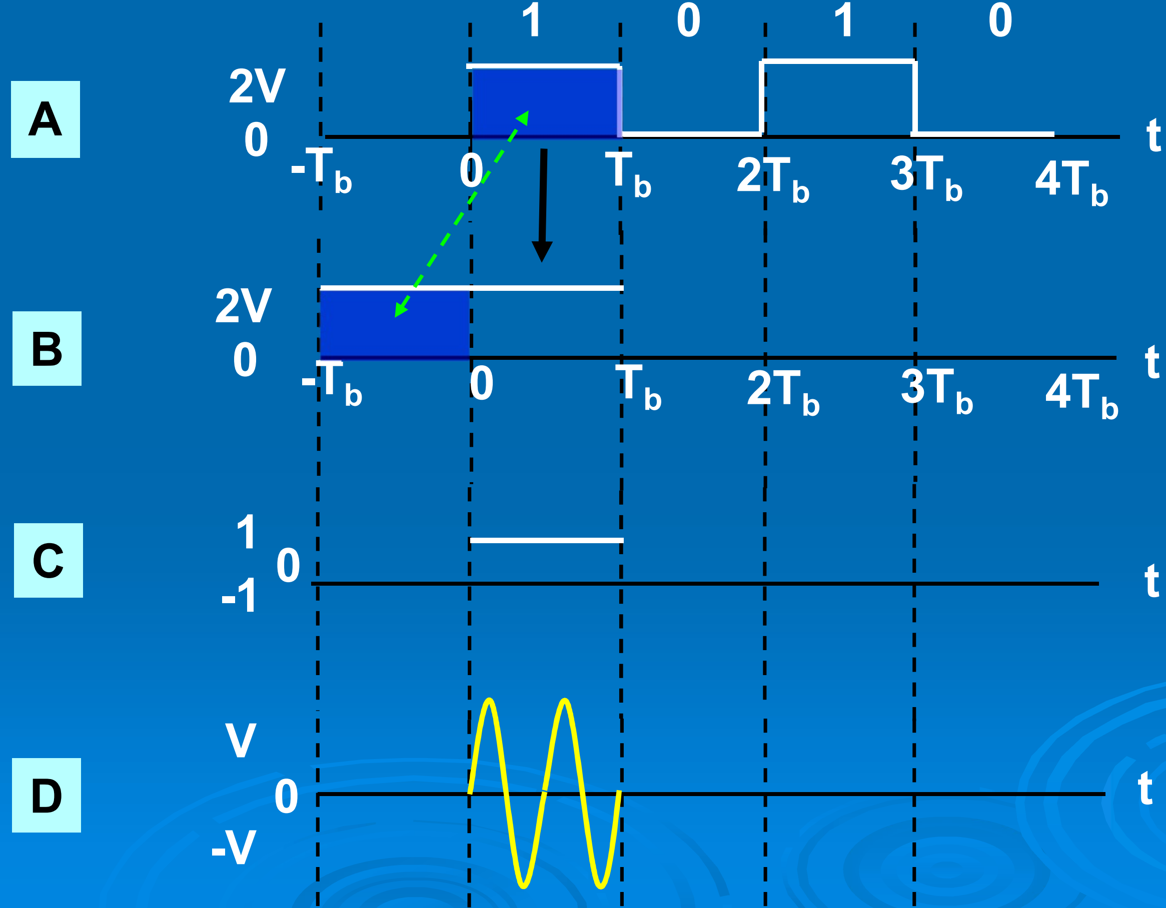


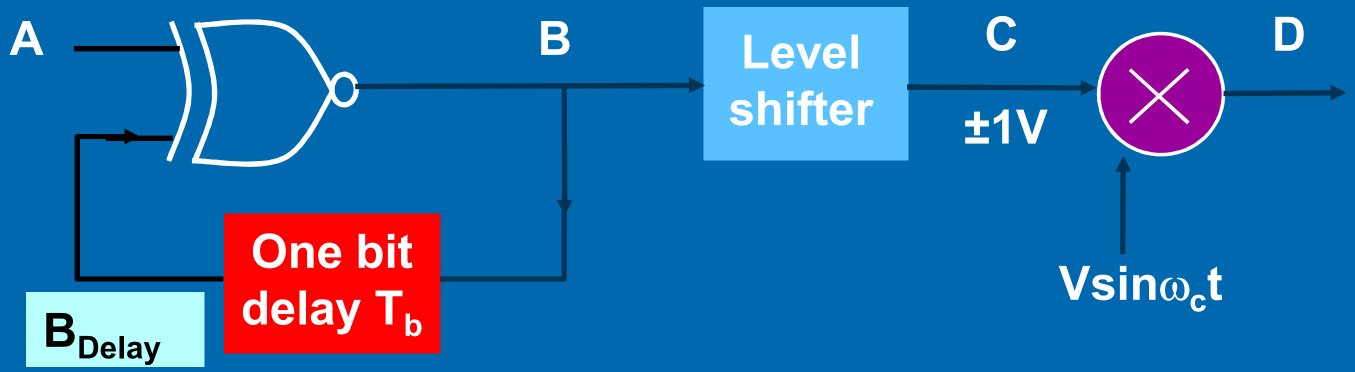

A
B
Level shifter
C
±1V
D
One bit delay T_b
B_{Delay}
$V\sin\omega_c t$
1
0
1
0
2V
0
A
$-T_b$
0
T_b
$2T_b$
$3T_b$
$4T_b$
t
B
2V
0
$-T_b$
0
T_b
$2T_b$
$3T_b$
$4T_b$
t



X-NOR

X	Y	Z(o/p)
0	0	1
0	1	0
1	0	0
1	1	1





X-NOR

X	Y	Z(o/p)
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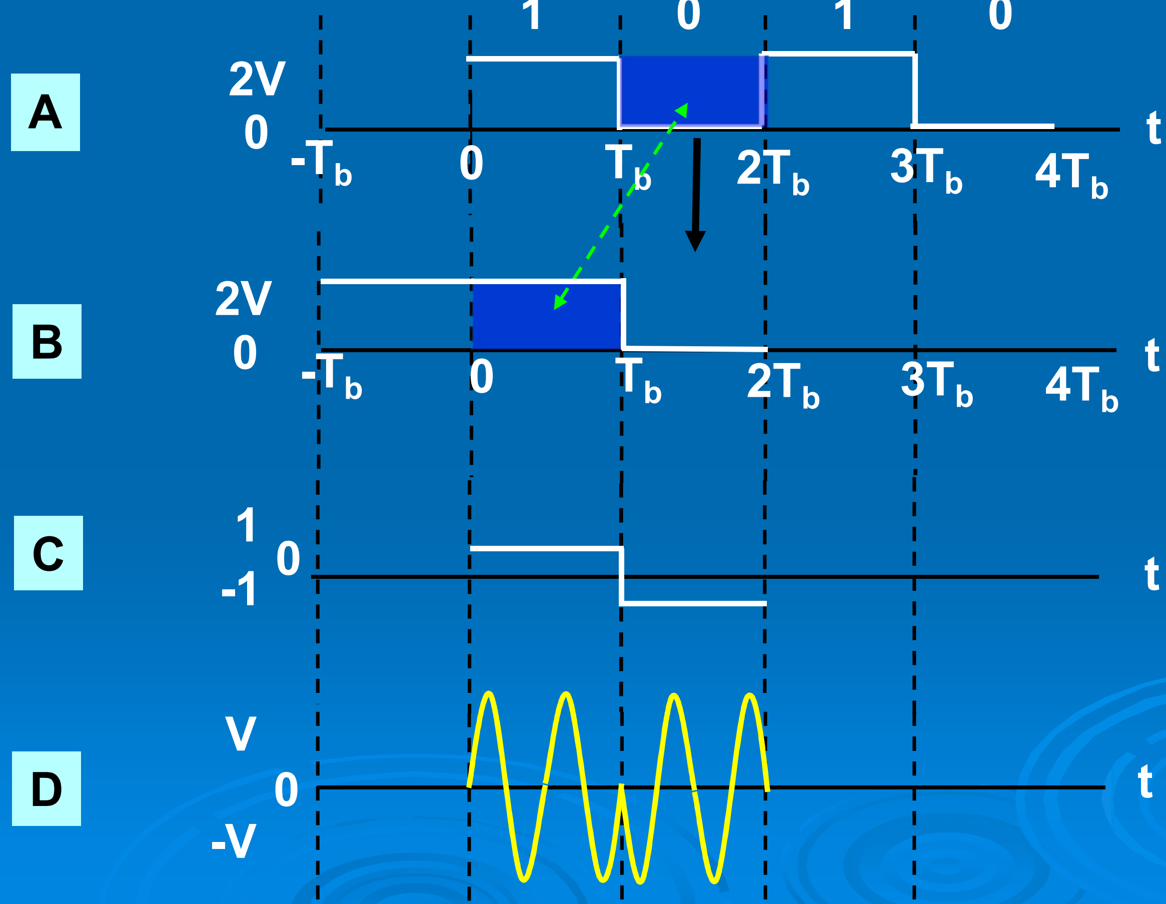
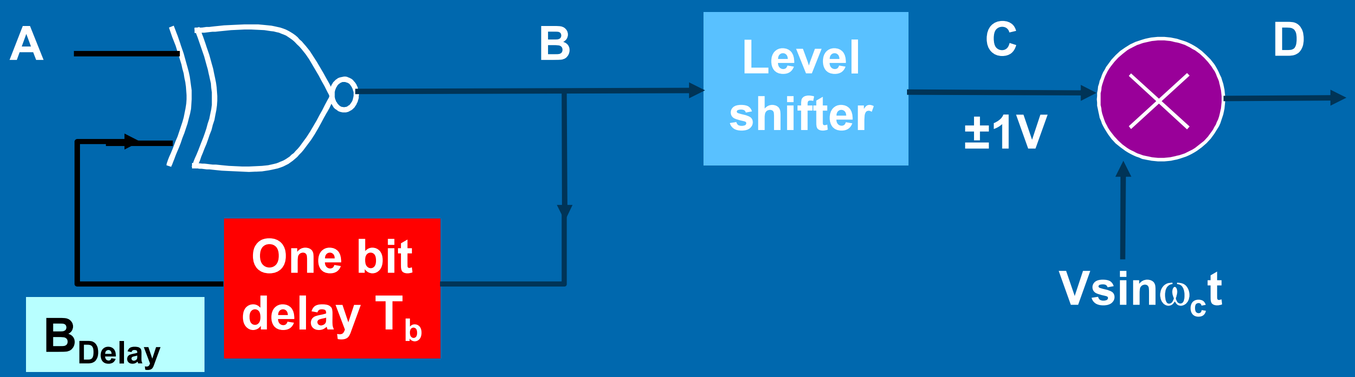
0	1	0
1	0	0
1	1	1





X-NOR

X	Y	Z(o/p)
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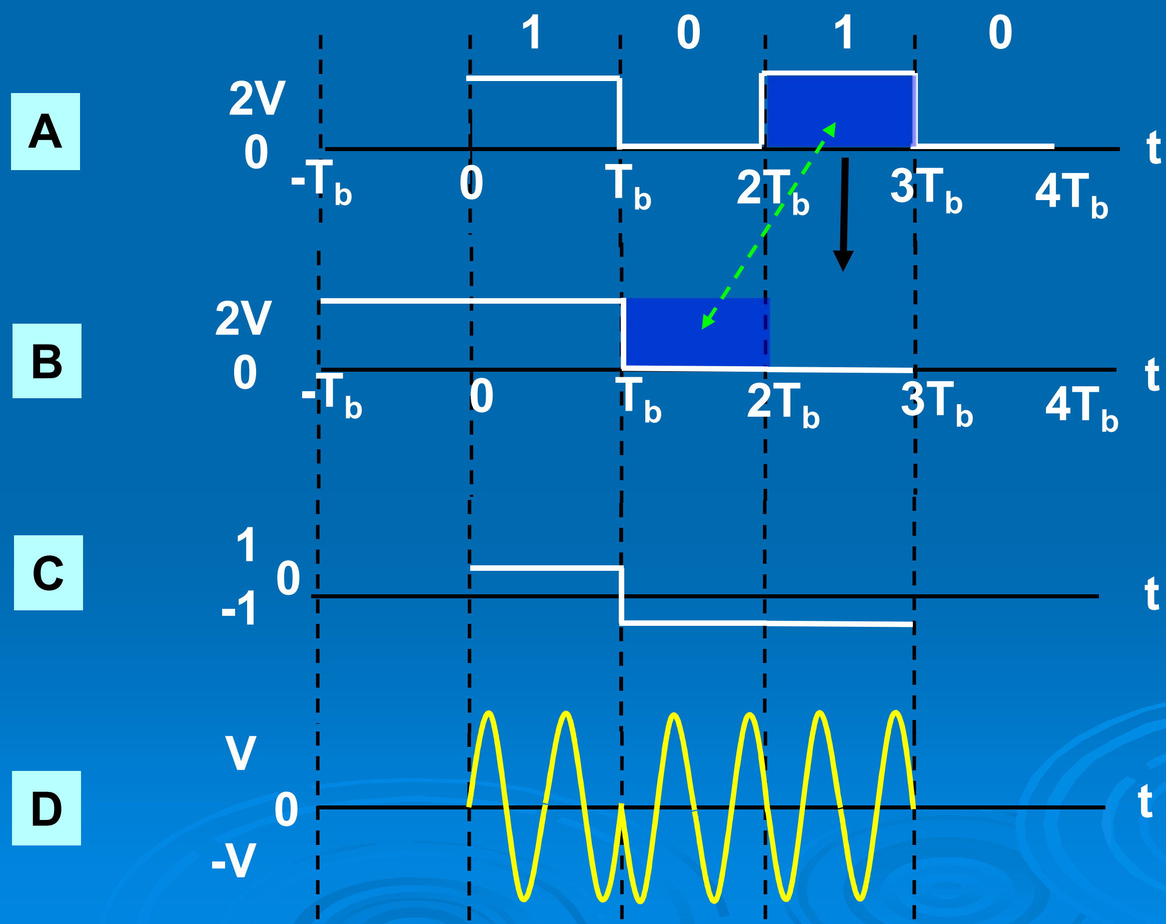
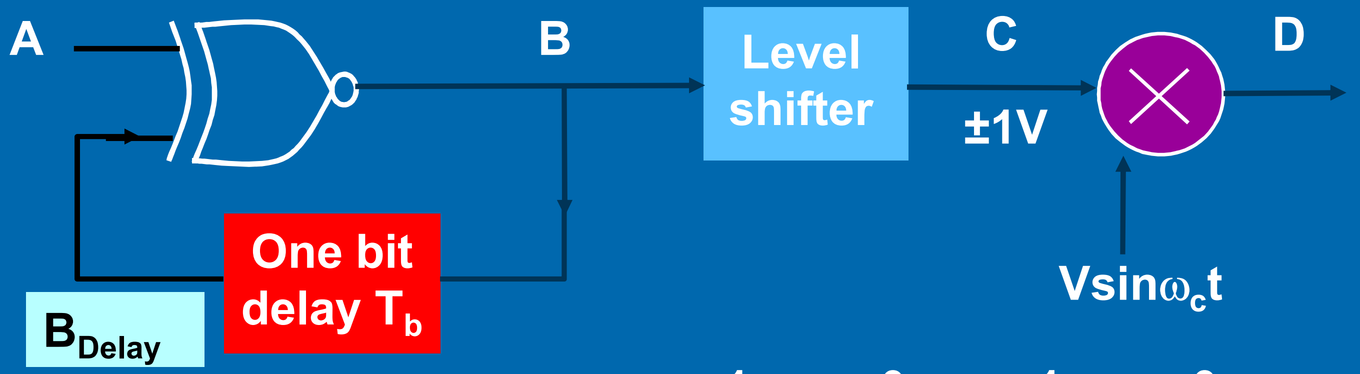
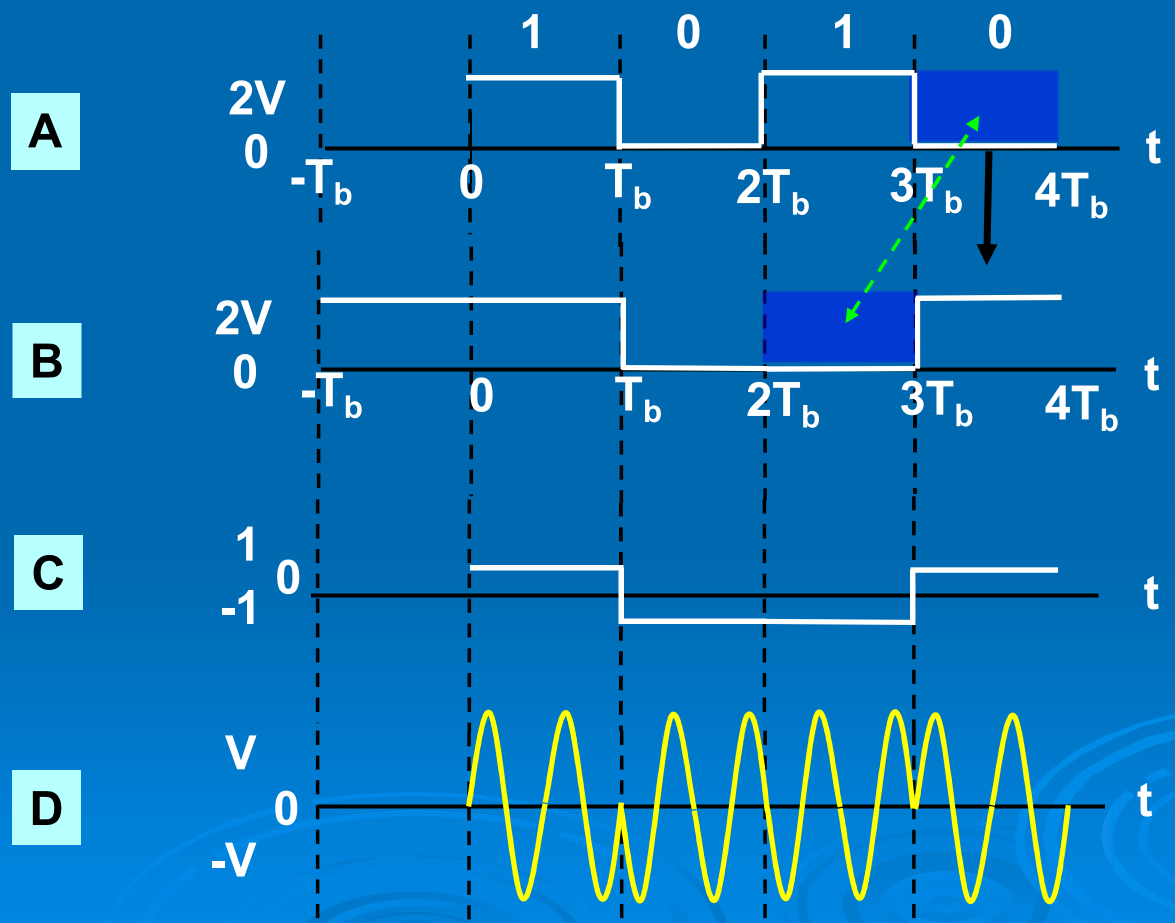




X-NOR

X	Y	Z(o/p)
0	0	1
0	1	0
1	0	0
1	1	1



10.6 Quadrature Phase Shift Keying (QPSK)

- **Limitation of binary modulation techniques - require high transmission bandwidth.**

  Each bit is transmitted individually

- **One way of improving bandwidth utilisation - use quadrature multiplexing e.g. *quadrature phase shift keying* (QPSK).**

- **In QPSK, two bits are lumped together to form a symbol.**

  - There are four distinct symbols corresponding to the two-bit sequences 00, 01, 10 and 11.

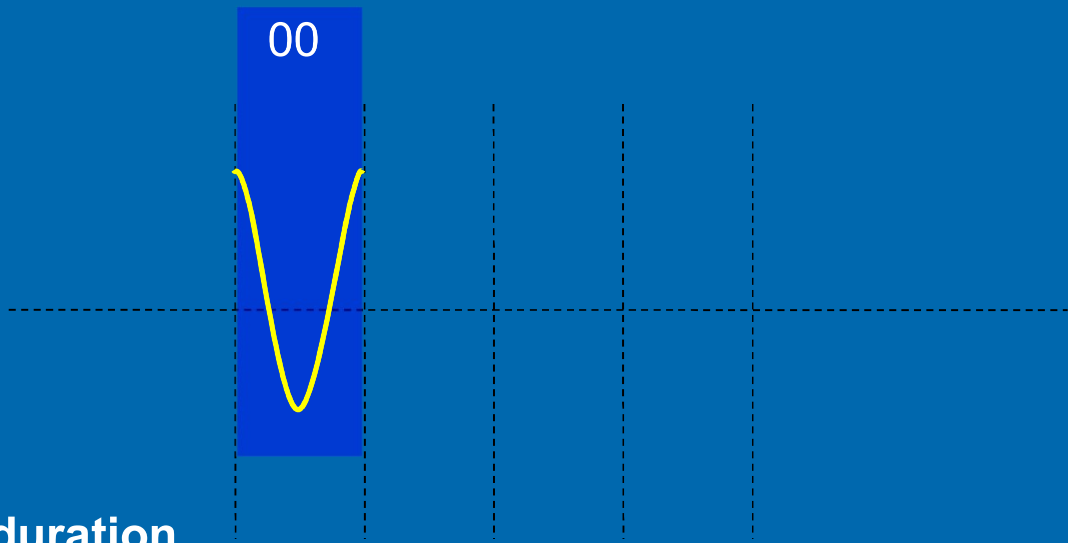
  - A symbol is transmitted as a carrier with an initial phase angle of four possible values.

10.6 Quadrature Phase Shift Keying (QPSK)

- **The four possible phase angles are the four equally spaced angles.**

e.g.

$$s_i(t) = \begin{cases} A\cos(2\pi f_c t + \phi_i) & 0 \le t \le T_s \\ \phi_i = \begin{cases} 0 & for\ "00" \\ 90^\circ & for\ "01" \\ 180^\circ & for\ "10" \\ 270^\circ & for\ "11" \end{cases} \end{cases}$$



where T_s ($T_s = 2T_b$) is the symbol duration.

10.6 Quadrature Phase Shift Keying (OPSK)

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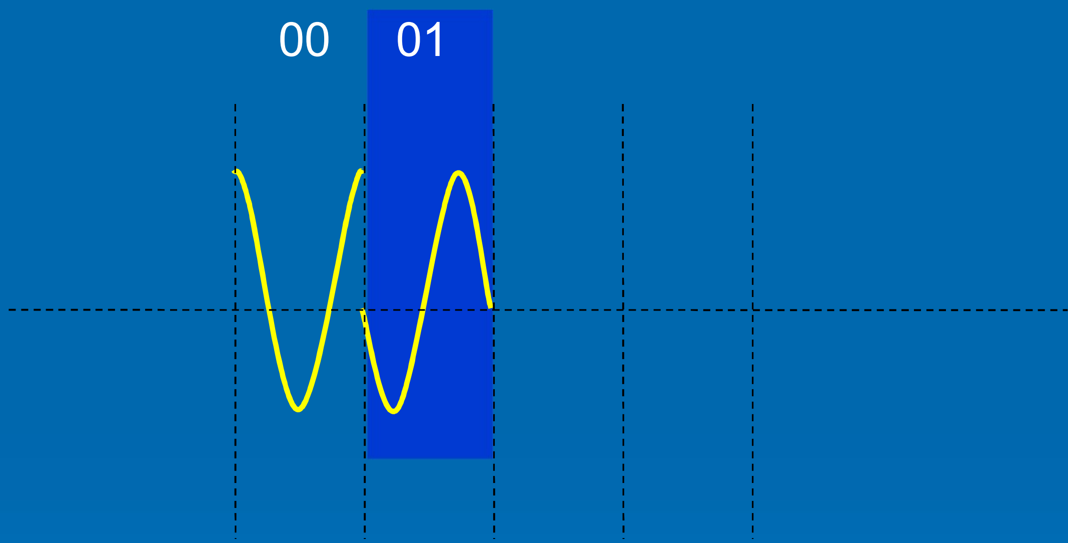
- Each symbol is a carrier that takes on one of the four equally spaced initial phase angles. e.g.

$$s_i(t) = \begin{cases} A\cos(2\pi f_c t + \phi_i) & 0 \le t \le T_s \\ \phi_i = \begin{cases} 0 & for\ "00" \\ 90^\circ & for\ "01" \\ 180^\circ & for\ "10" \\ 270^\circ & for\ "11" \end{cases} & \end{cases}$$



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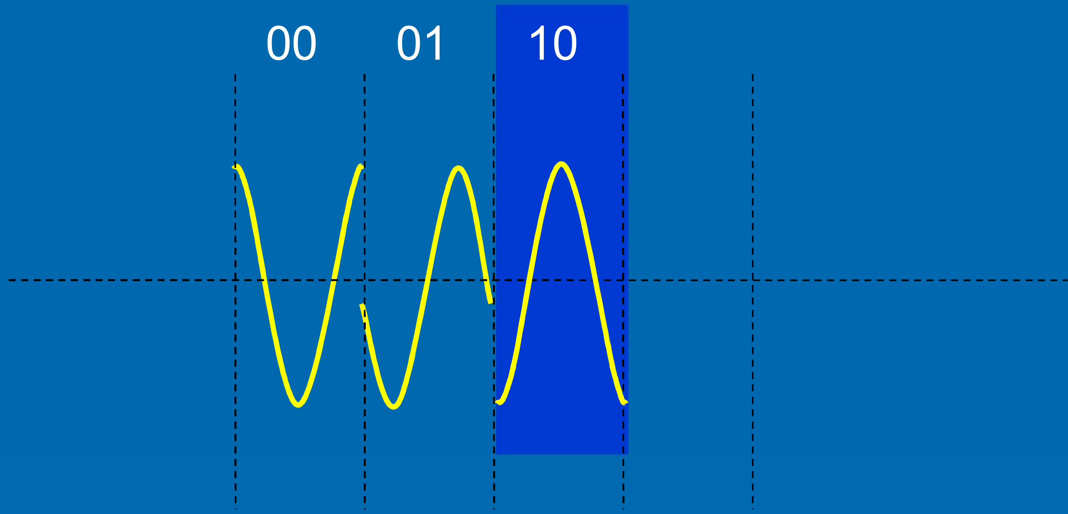
$$s_i(t) = \begin{cases} A\cos(2\pi f_c t + \phi_i) \quad 0 \le t \le T_s \\ \phi_i = \begin{cases} 0 \quad \textit{for}\ "00" \\ 90^\circ \quad \textit{for}\ "01" \\ 180^\circ \quad \textit{for}\ "10" \\ 270^\circ \quad \textit{for}\ "11" \end{cases} \end{cases}$$



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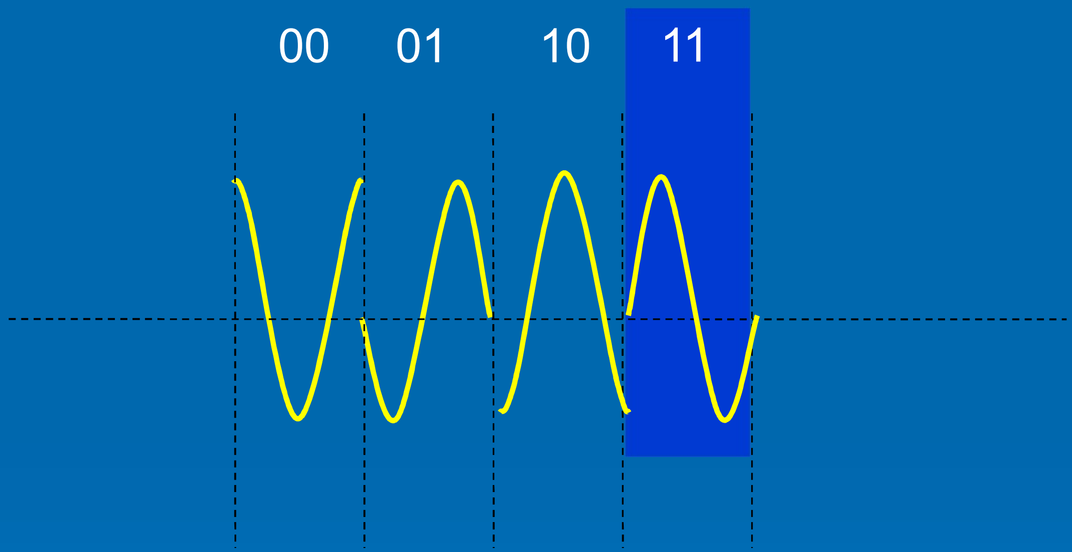


where T_s is the symbol duration.

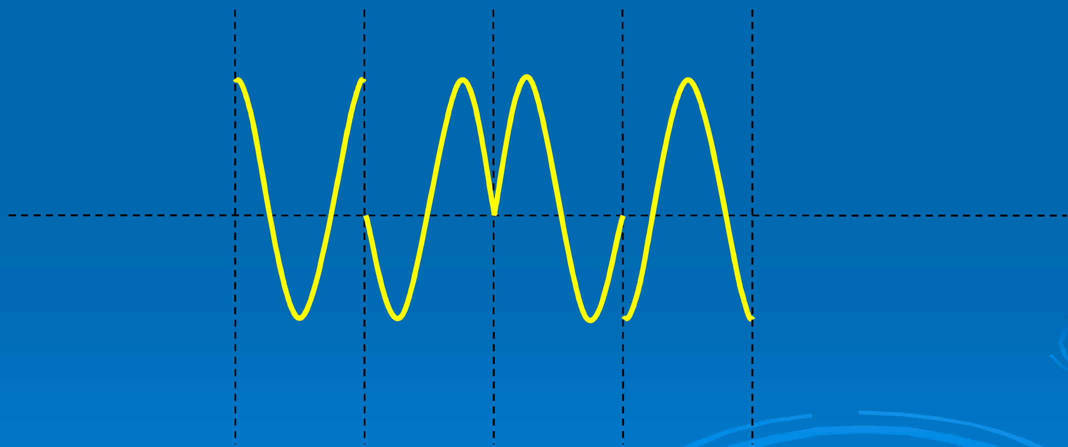
10.6 Quadrature Phase Shift Keying (OPSK)

- **The QPSK waveform of a bit stream of 01111000 generated by a QPSK modulator (LSB at the right most). Note: LSB is transmitted first.**

01 11 10 00

LSB is transmitted first

00 01 11 10



$$s_i(t) = \begin{cases} A\cos(2\pi f_c t + \phi_i) \quad 0 \le t \le T_s \\ \phi_i = \begin{cases} 0 & for\ "00" \\ 90^\circ & for\ "01" \\ 180^\circ & for\ "10" \\ 270^\circ & for\ "11" \end{cases} \end{cases}$$

10.6 Quadrature Phase Shift Keying(QPSK)

- The probability of bit error for a QPSK system is given by

$$P_e = \frac{1}{2} erfc\left(\sqrt{\frac{V^2 T_b}{2\eta}}\right)$$

Same P_e as in BPSK

- QPSK has the same probability of bit error as that of BPSK.
  But the bandwidth required by OPSK is half of that is required by BPSK.

- QPSK is the preferred system if smaller channel bandwidth is desired.

10.7 M-ary PSK (MPSK)

- In MPSK, the initial phase angle of the carrier takes on one of M possible values:

  $S_i(t) = A \cos(2\pi f_c t + \phi_i)$ ϕ_i = 360i/M, where i = 0, 1, …, M-1.

- During each symbol interval T_s, one of M possible symbols is sent.

$$s_i(t) = A\cos\left(2\pi f_c t + \frac{360i}{M}\right) \qquad i = 0, 1, \ldots, M-1$$

- QPSK is an example of MPSK with M = 4.

10.7 M-ary PSK (MPSK)

- In MPSK, as M is increased, bandwidth efficiency is improved.
  - Trade-off is increase in transmitted power or an increase in P_e.

- Among MPSK, QPSK offers the best trade-off between power and bandwidth requirements. Thus, QPSK is the first to be widely used in practice.

- For M > 8,
  - Higher transmitted power is required.
  - More complex equipment is required.

10.8 Quadrature Amplitude Modulation (QAM)

Singapore Polytechnic

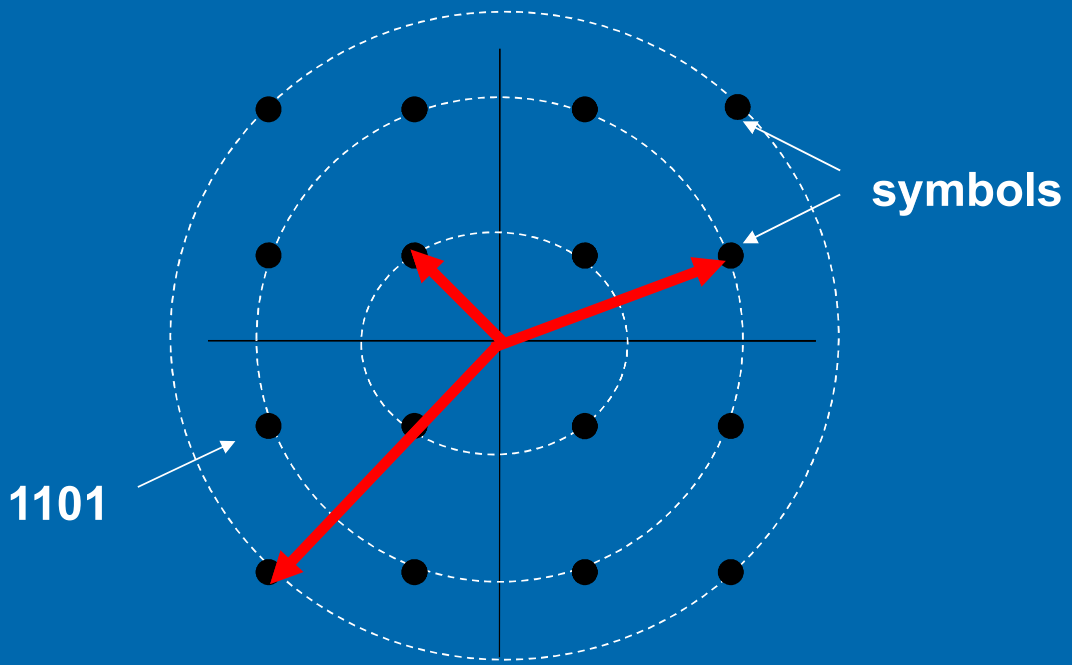
- Channel bandwidth utilisation can be improved further by the hybrid use of amplitude and phase modulation.
- A common form of this hybrid scheme is QAM. The principle of QAM is illustrated using 16-QAM.
- In 16-QAM there are 16 possible symbols, each representing a 4-bit data.

10.8 Quadrature Amplitude Modulation (QAM)

- A possible way to represent these 16 symbols is by a constellation diagram shown.

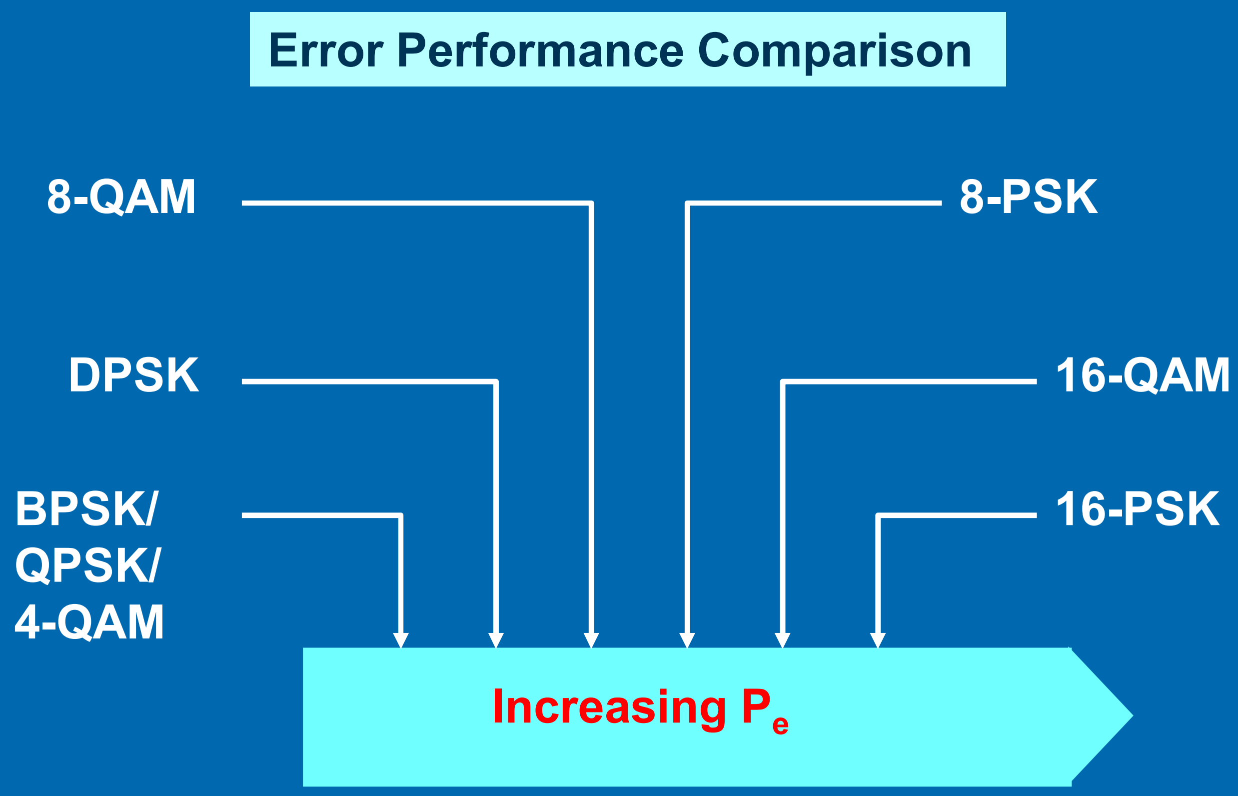
- The constellation uses three different amplitudes, two with four phases and one with eight phases.

Used in 9600 bits/s modems

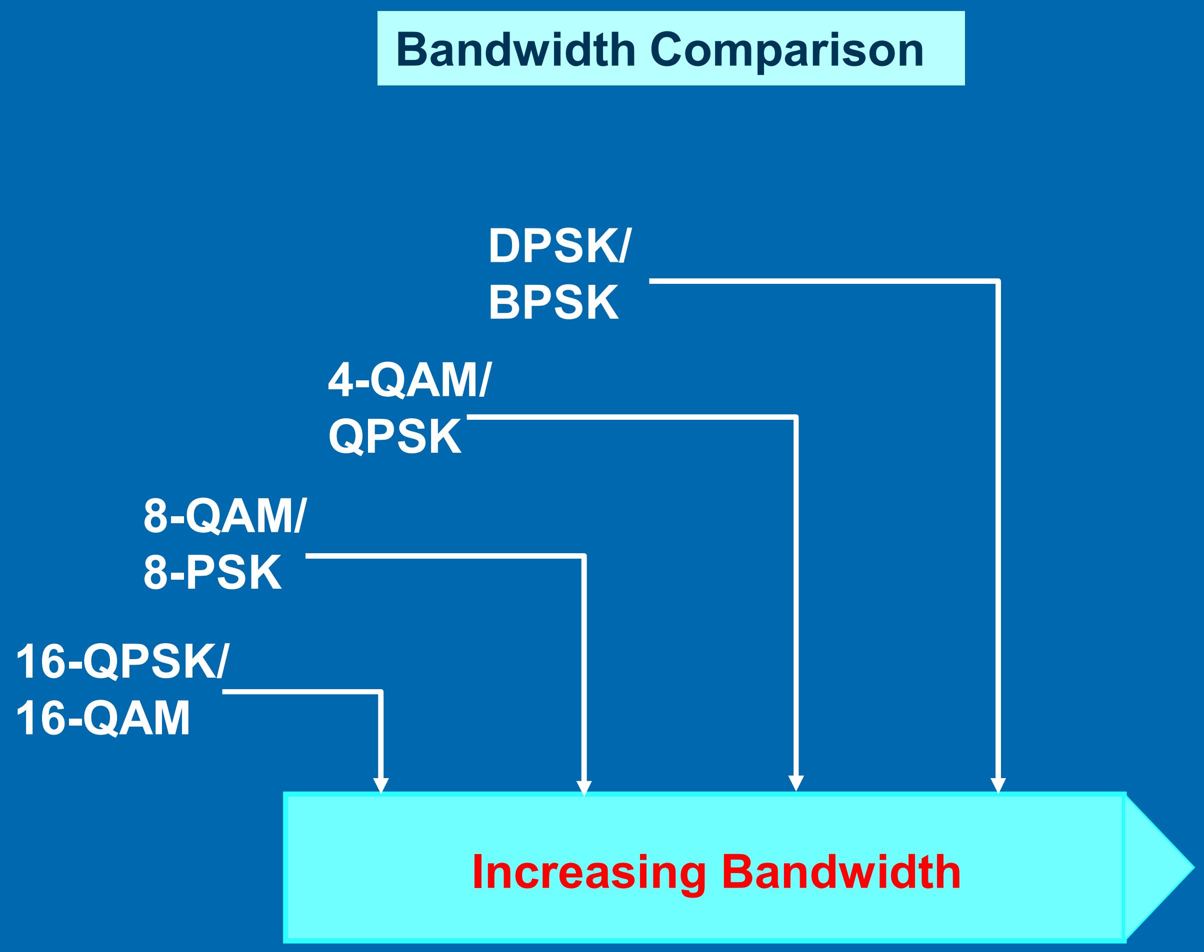


10.9 Comparison of digital modulation systems

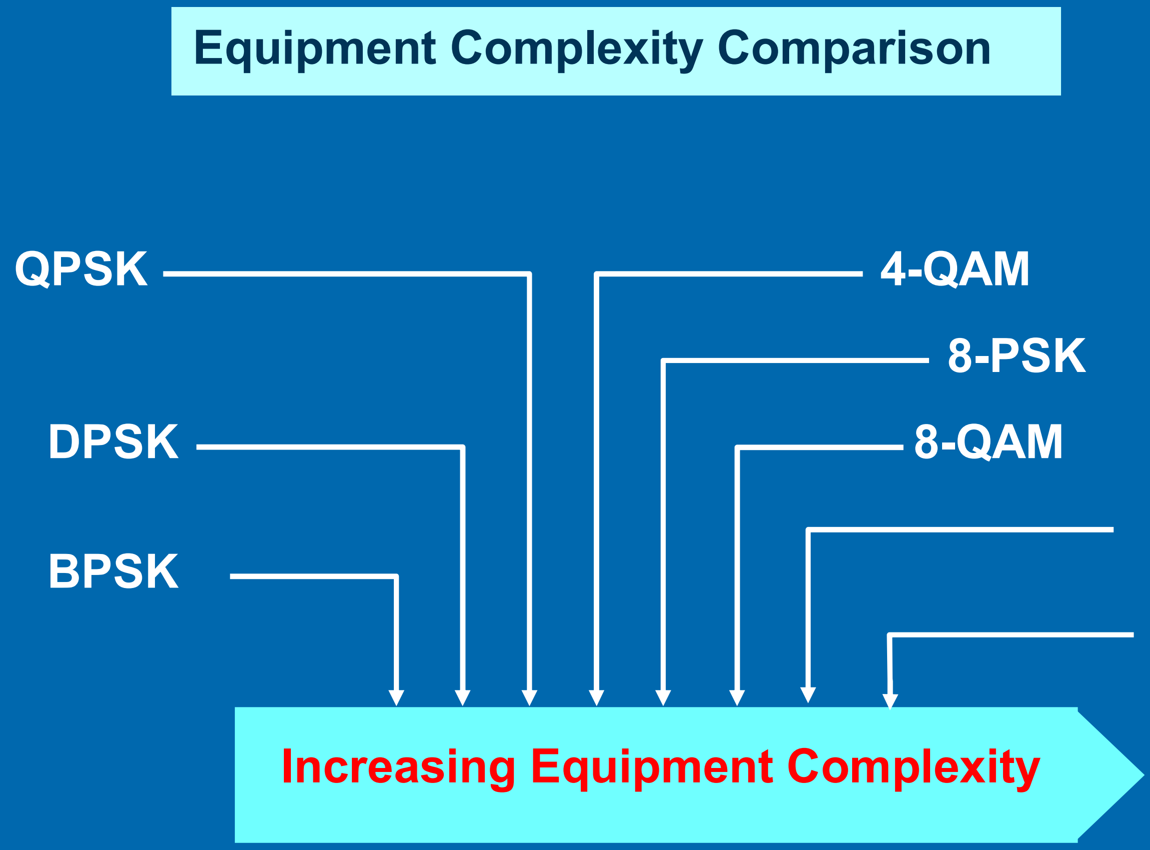
- Choice of digital modulation methods depends on
  - error performance,
  - bandwidth efficiency (in bps/Hz)
  - equipment complexity.



10.9 Comparison of digital modulation systems



10.9 Comparison of digital modulation systems

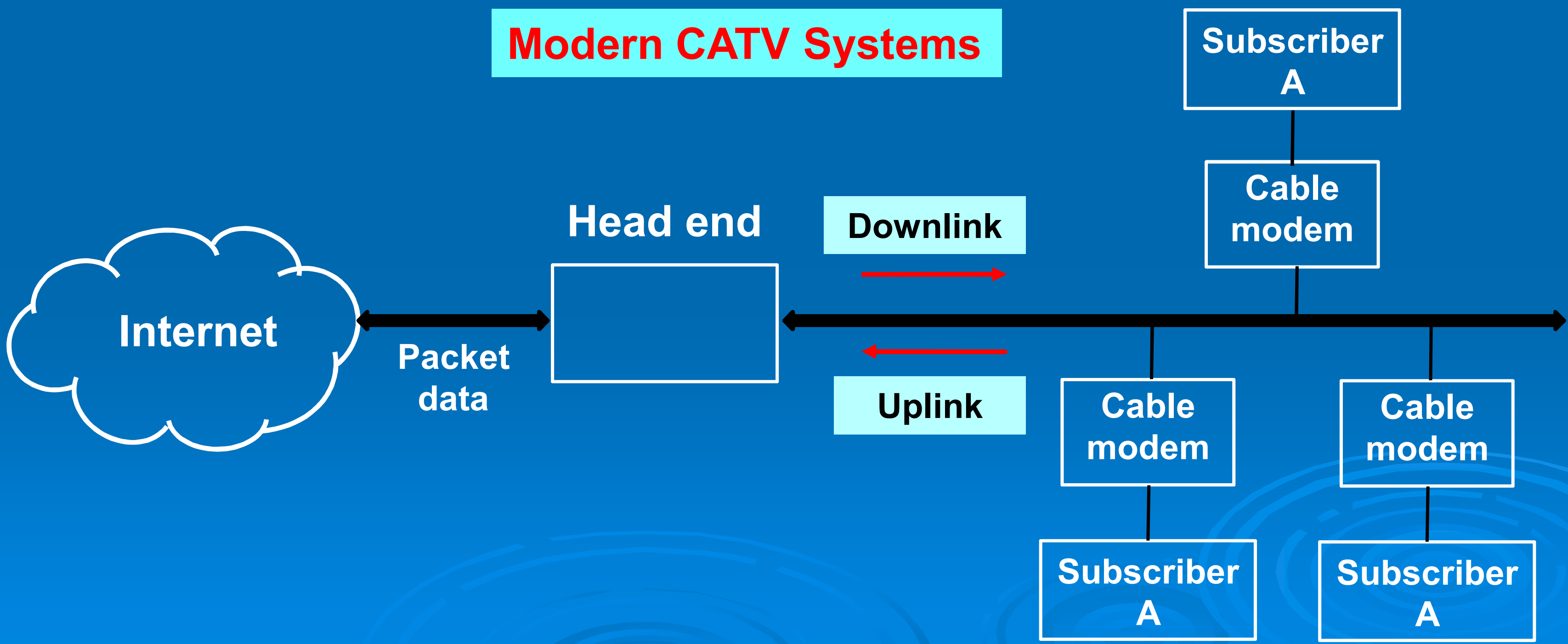


10.10 Applications

Cable Data Modem

- Modern CATV systems provides a high-speed internet connection via a cable modem distributing the TV and data signals from the CATV head end to the neighbourhood of customer.
- The signals are converted from light to RF signal and transmitted to individual home via coaxial cable.

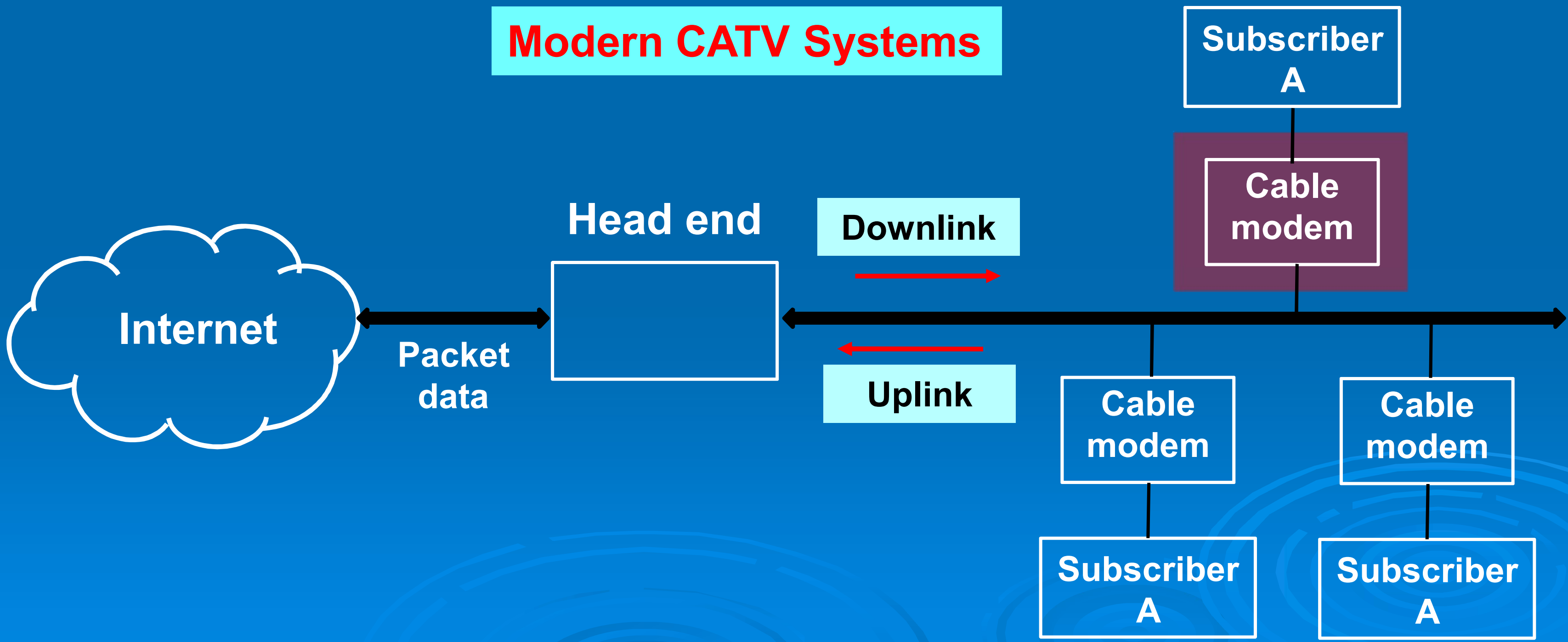
Operate up to 800 MHz



10.10 Applications

Cable Data Modem

- The cable modem, usually connected to a PC or in-house data network via an Ethernet line, demodulates the downlink data and modulates the uplink data:
  - The downlink is usually around 3 Mega bits/s
  - The uplink speed is around 500 kbits/s.



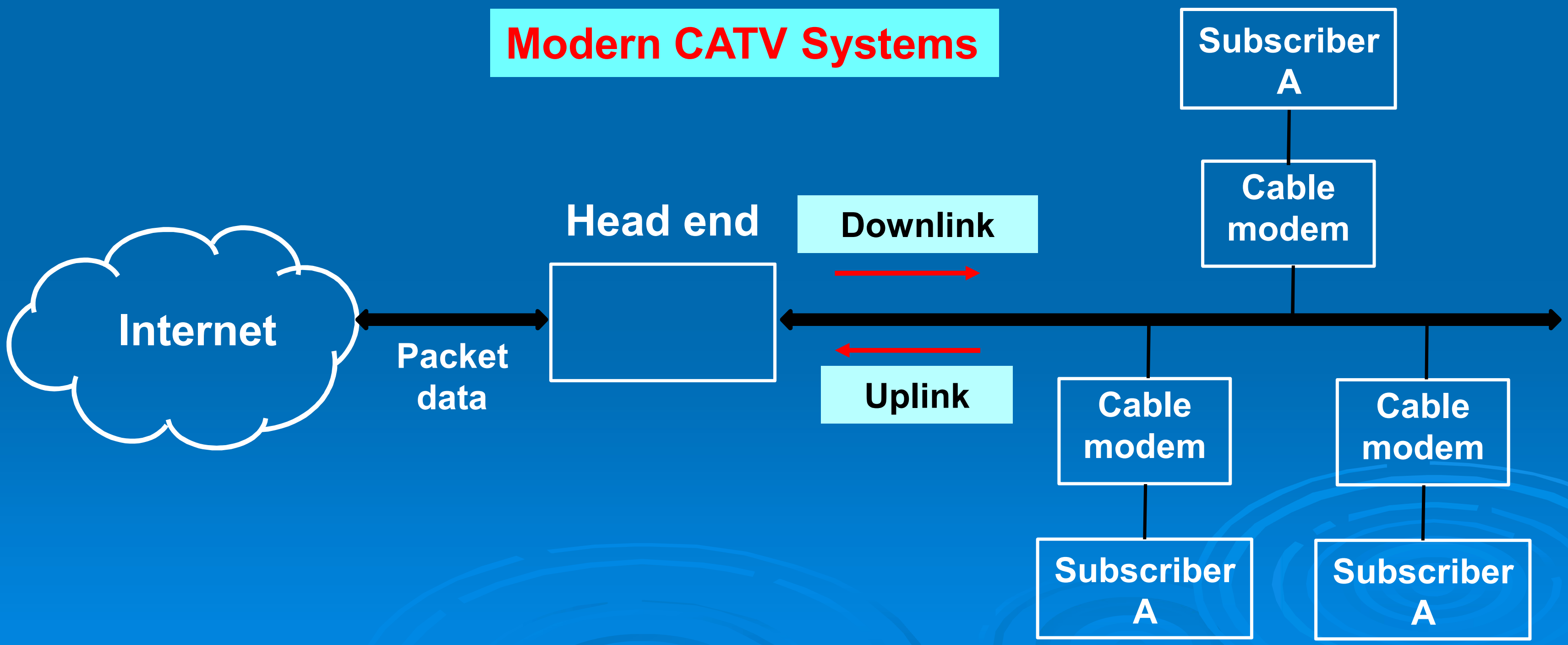
10.10 Applications

Cable Data Modem

- A single downlink 6 Mega hertz-wide channel can support a combined downstream data rate:

27 Mbits/s if 64 QAM is used.

36 Mbits/s if 256 QAM is used.



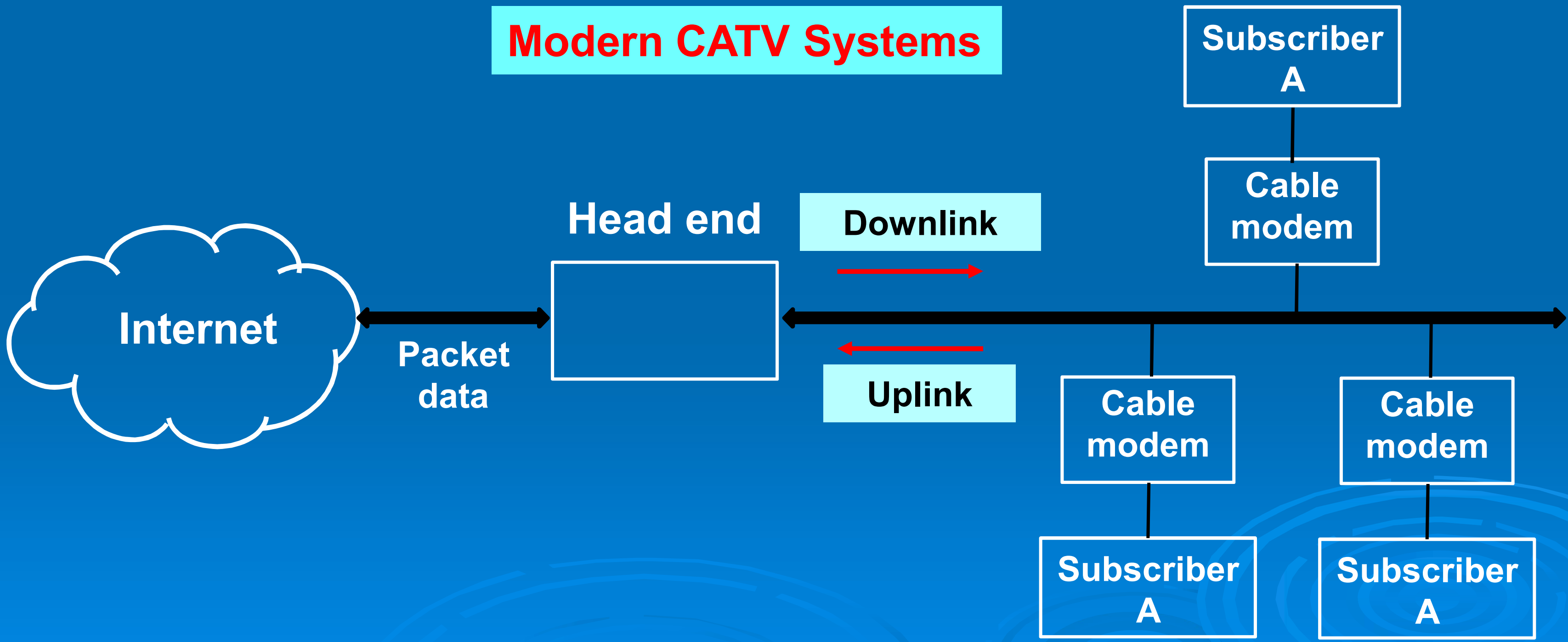
10.10 Applications

Cable Data Modem

- One uplink channel supports a combined data rate:

10 Mbits/s if QPSK is used

30 Mbits/s if 16QAM is used



10.10 Applications

- **Cable Modem Standards**

Component	Downstream	Upstream
Carrier frequency range	50 - 750 MHz	5 – 42 MHz
Channel bandwidth	6 MHz	6 MHz or 2 MHz
Modulation	64-QAM or 256-QAM	QPSK or 16-QAM
Composite data rate	27 Mb/s or 36 Mb/s	10 – 30 Mb/s
Subscriber data rate	1.5 – 6 Mb/s	256 kb/s – 1.5 Mb/s
Coding	Block code (Reed Solomon)	Block code (RS)
Encryption	DES	DES

Photo courtesy Motorola, Inc.
Motorola SURFboard modem

10.10 Applications

- **Digital Radio**

  Microwave radio links using multilevel QAM.

- **Digital Communications by satellite**

  QPSK is often used.

U.S. military WGSS communications satellite

Relay towers on Frazier Mountain, Southern California

End

CHAPTER 10

(Part 2 of 2)