Principles of Communications
ECS 332

Dr. Prapun Suksompong

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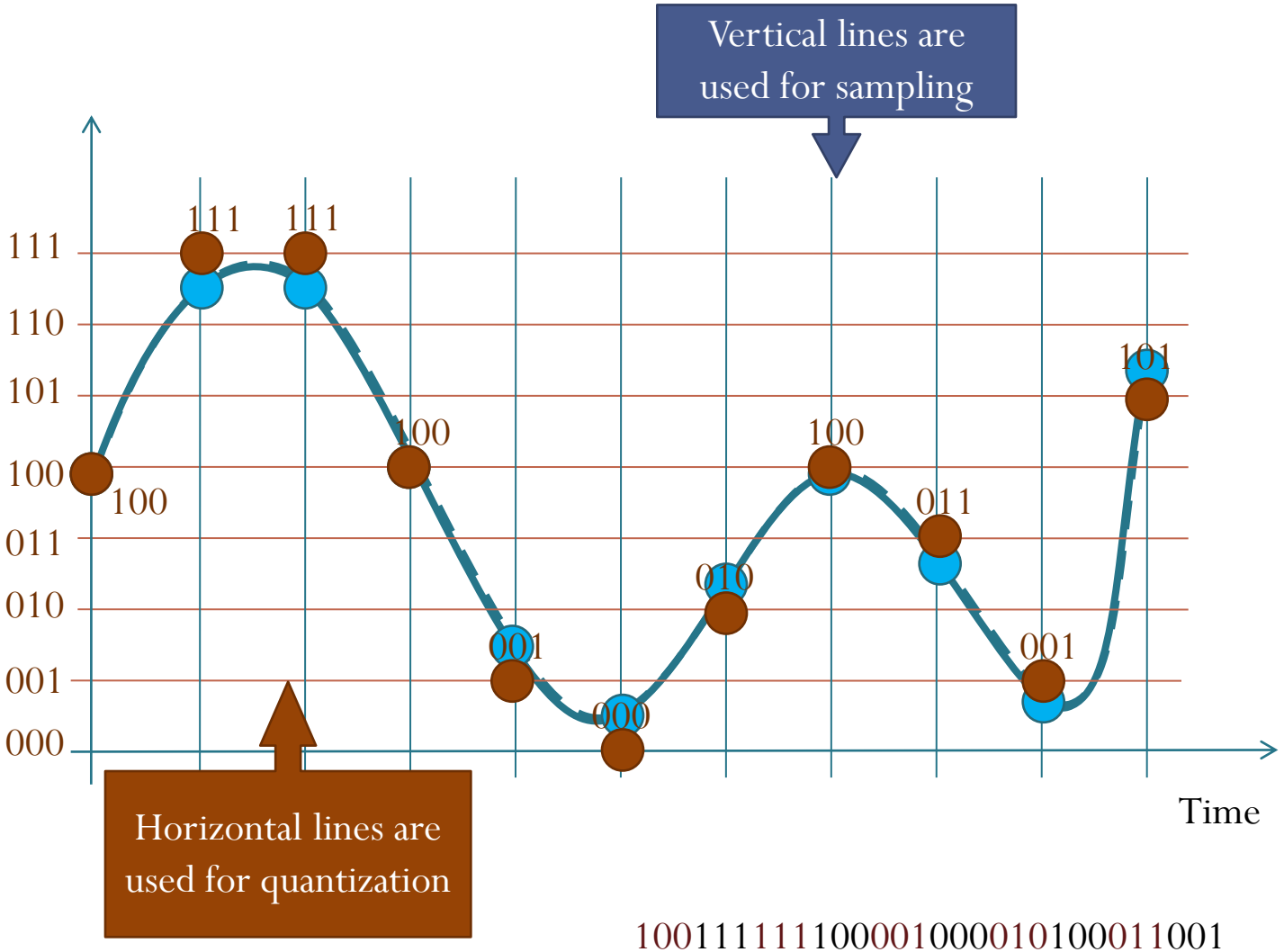
Digitization and PCM

Office Hours:
BKD 3601-7

Monday	**14:40-16:00**
Friday	**14:00-16:00**

Digitization (analog to digital)

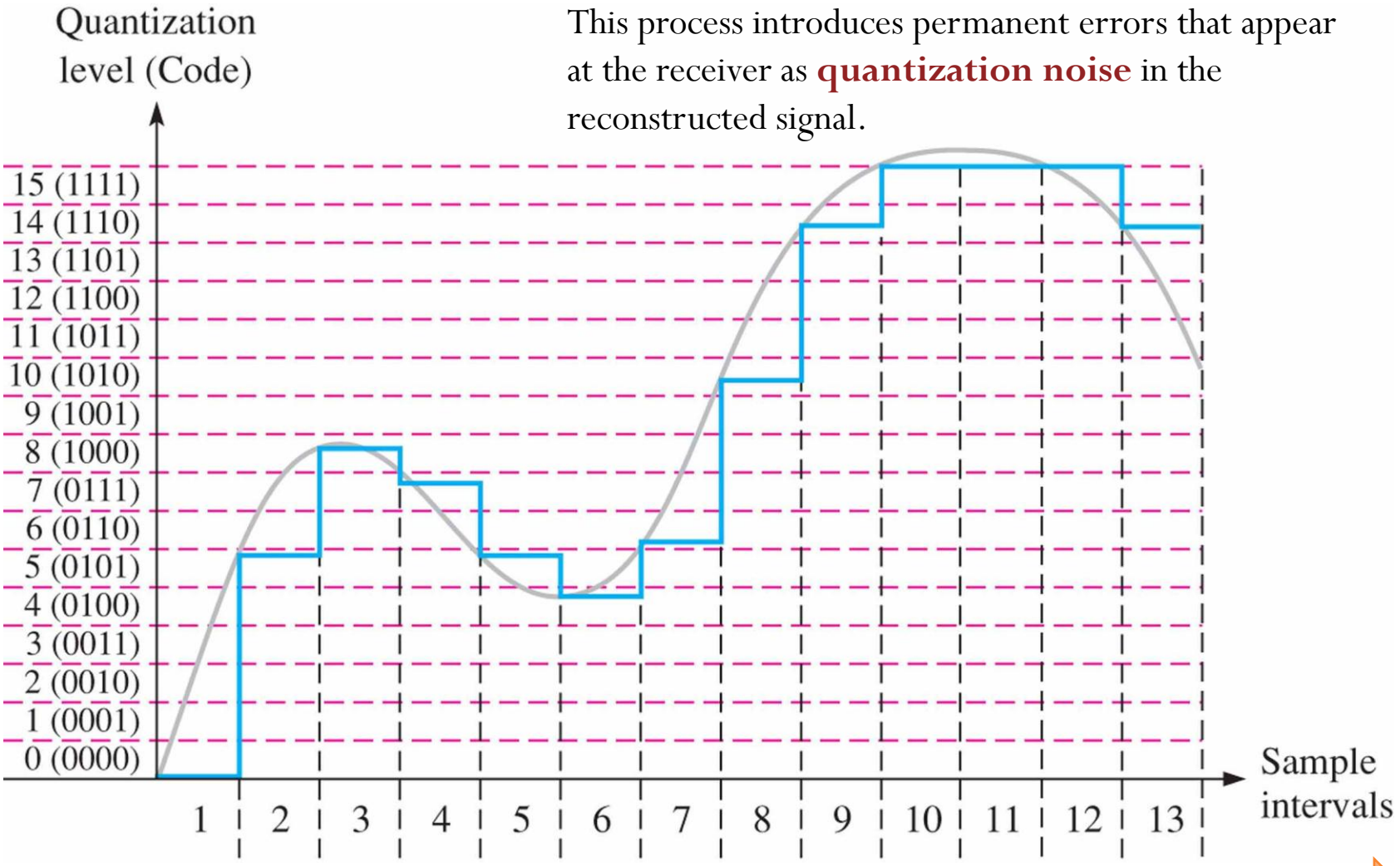


100111111100001000010100011001

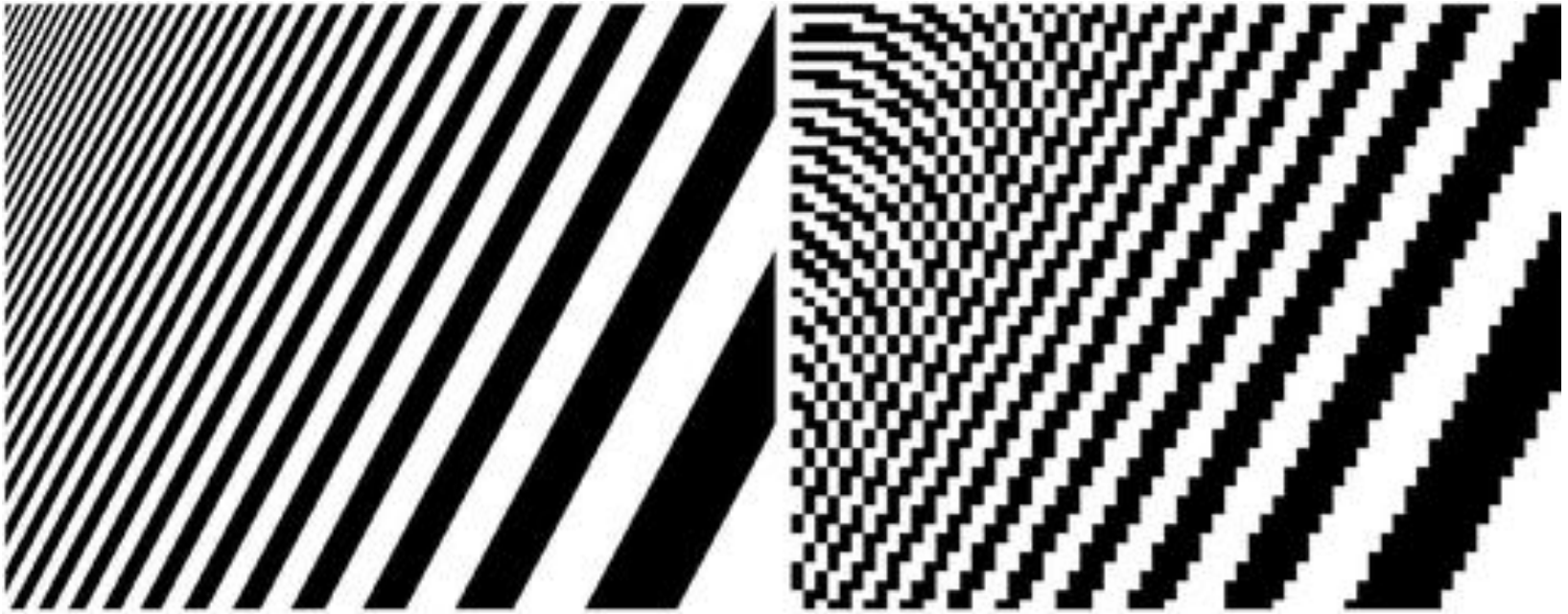
Quantization

Quantizer rounds off the sample values to the nearest discrete value in a set of q **quantum levels**.

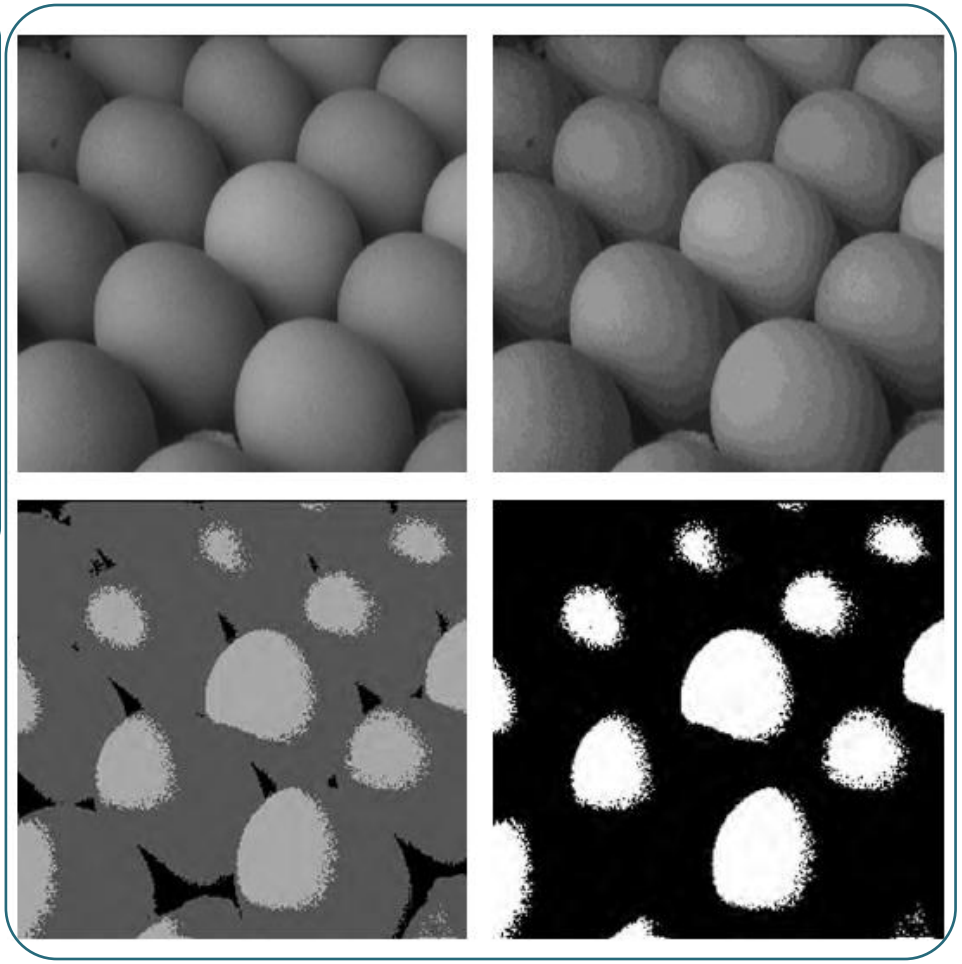
This process introduces permanent errors that appear at the receiver as **quantization noise** in the reconstructed signal.

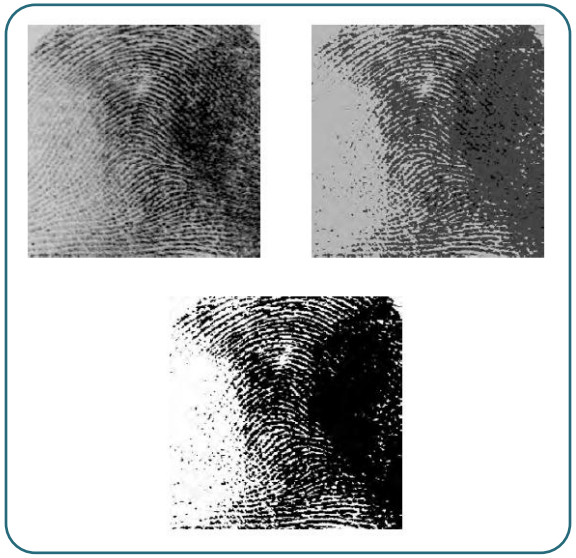


Aliasing in 2D



Quantization in 2D





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Digital PAM

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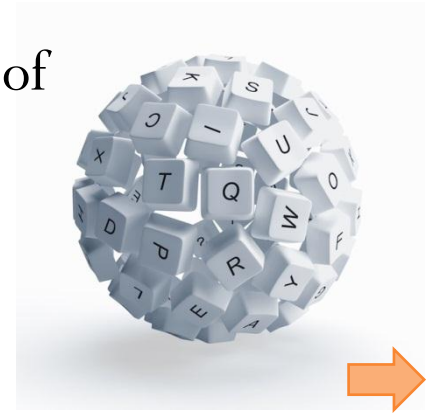
Digital Message

- An ordered sequence of **symbols** (or characters)
- Produced by a discrete information source.
- The source draws from an **alphabet** of $M \geq 2$ different symbols.
  - Ex. English text source: 26 (a to z) + 26 (A to Z) + 10 (0 to 9) + . , ! @ ( ) …
  - Ex. Thai text source: 44 consonants (พยัญชนะ) + 15 vowel symbols (สระ) + 4 tone marks (วรรณยุกต์) + …
  - Ex. A typical computer terminal has an alphabet of $M \approx 90$ symbols (the number of character keys multiplied by two to account for the shift key)



Ex. ASCII

- Text is commonly encoded using ASCII
- MATLAB automatically represents any string file as a list of ASCII numbers.

```
>> str='I love ECS332';
>> real(str)

ans =

    73    32   108   111   118   101    32    69    67    83    51    51    50

>> dec2base(str,2)

ans =

1001001
0100000
1101100
1101111
1110110
1100101
0100000
1000101
1000011
1010011
0110011
0110011
0110010
```

text string

(decimal) ASCII representation of the text string

binary (base 2) representation of the decimal numbers

Line Codes: PAM Format

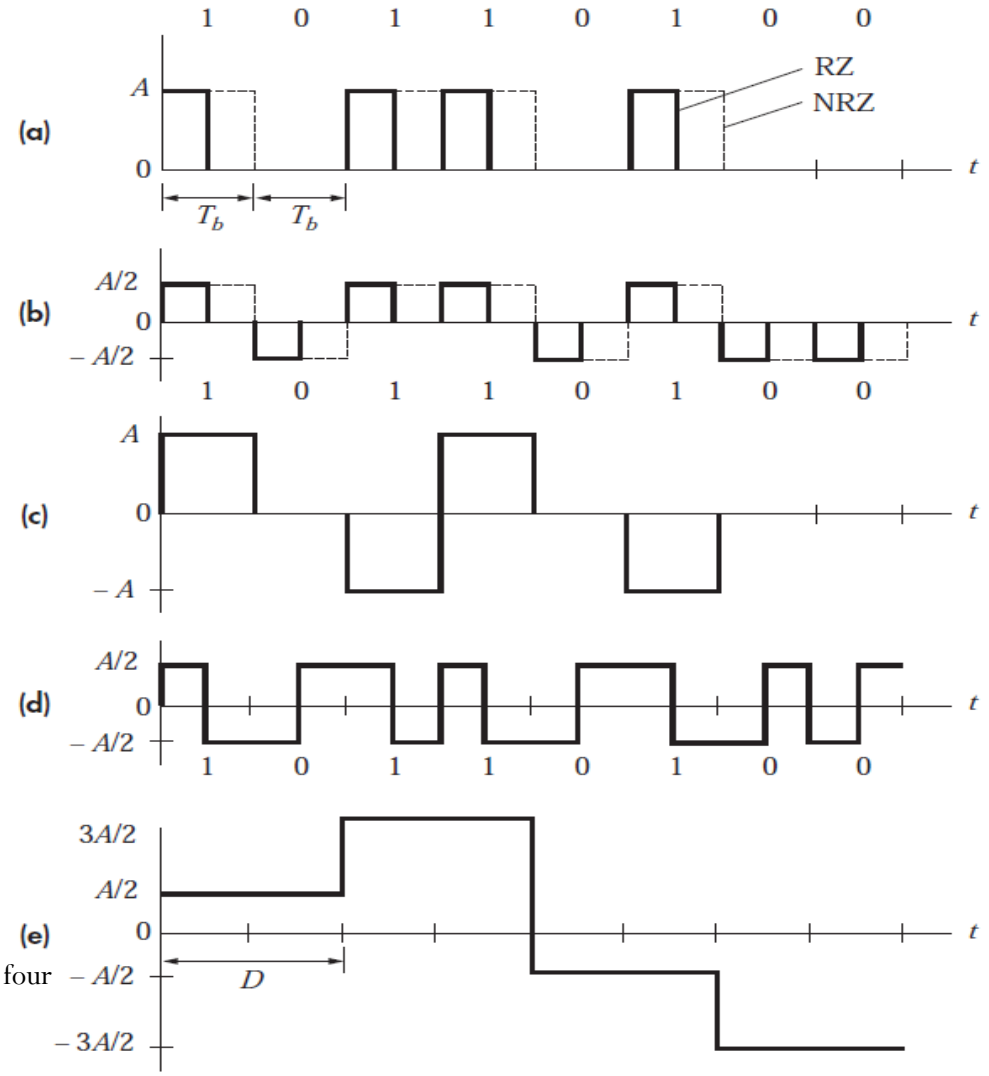
Unipolar RZ (return-to-zero)
Unipolar NRZ (nonreturn-to-zero)

Polar RZ
Polar NRZ

Bipolar NRZ
(successive 1s are represented by pulses with alternating polarity)

Split-phase Manchester (twinned binary)

Polar quaternary NRZ.
(Derived by grouping the message bits in blocks of two and using four amplitude levels to prepresent the four possible combinations)



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PAM with Noise

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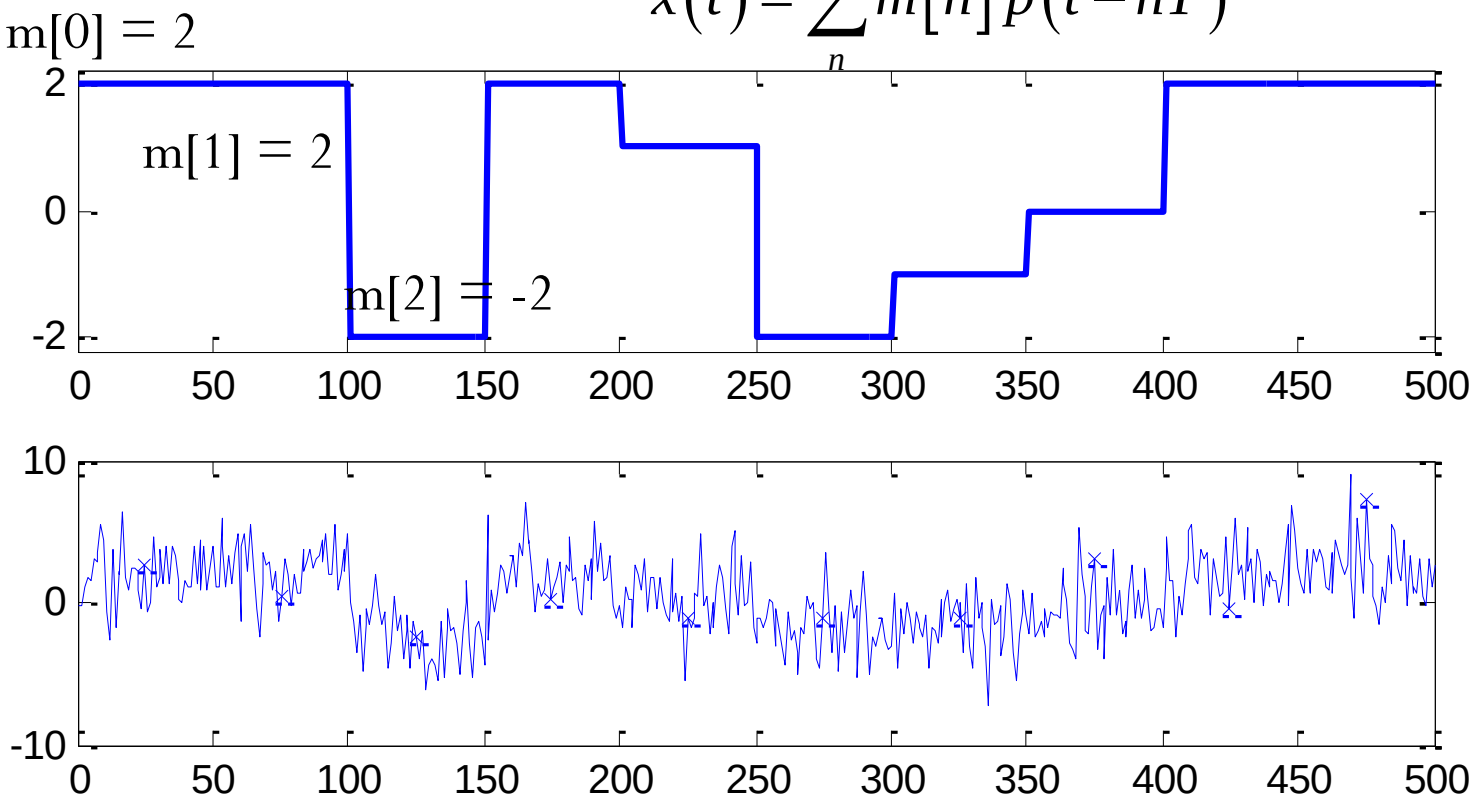
Noise: Ex 1

$$m[n] \in \{\overbrace{-2,-1,0,1,2}^{\mathcal{A}}\}$$

$$x(t) = \sum_n m[n]\, p(t - nT)$$

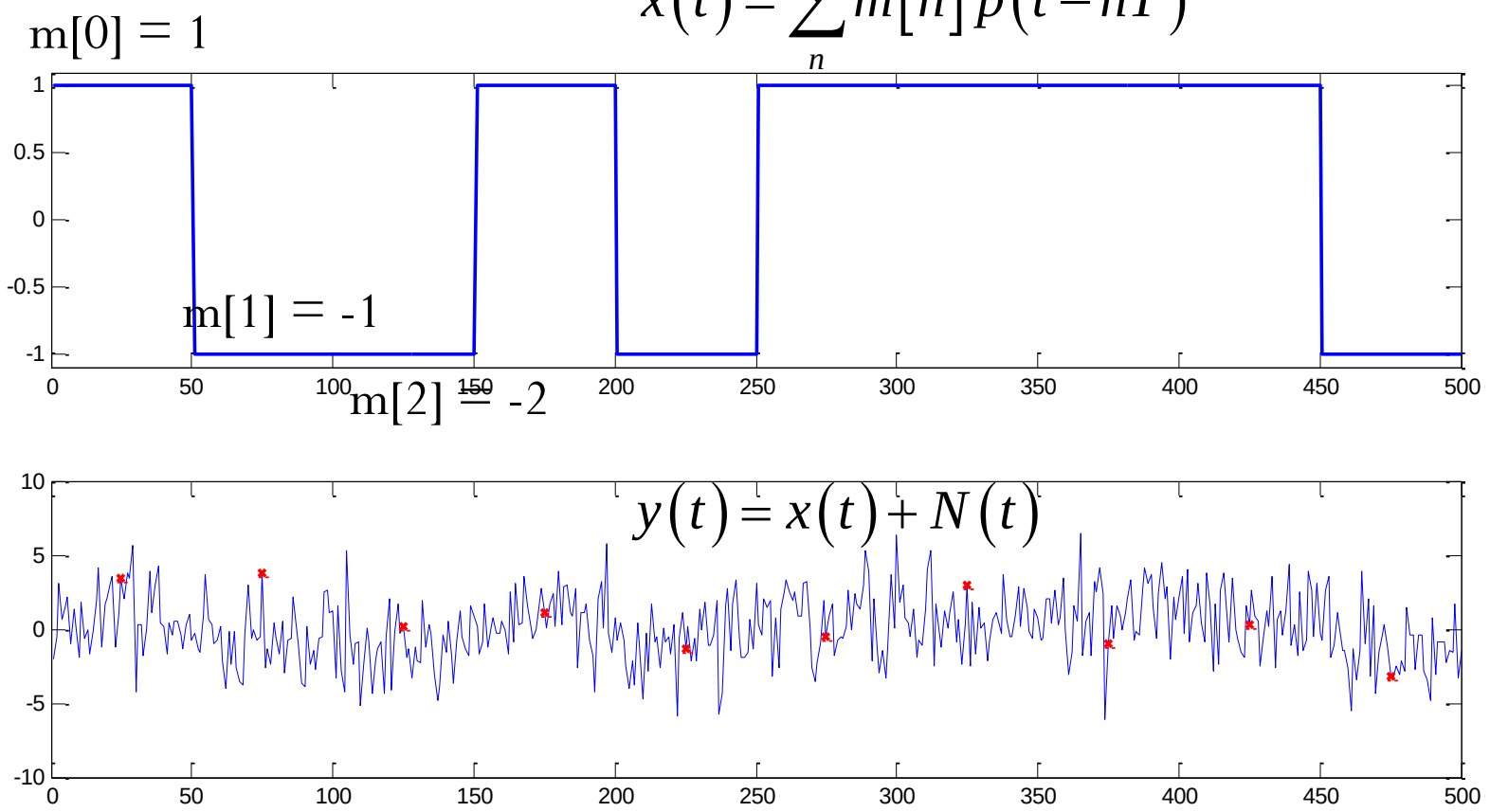


$$y(t) = x(t) + N(t)$$

Noise: Ex 2 (1/5)

$$m[n] \in \{\underbrace{-1, 1}_{\mathcal{A}}\}$$

$$x(t) = \sum_n m[n]\, p(t - nT)$$



To decode, consider

$$r[n] = y\left(nT + \frac{T}{2}\right)$$

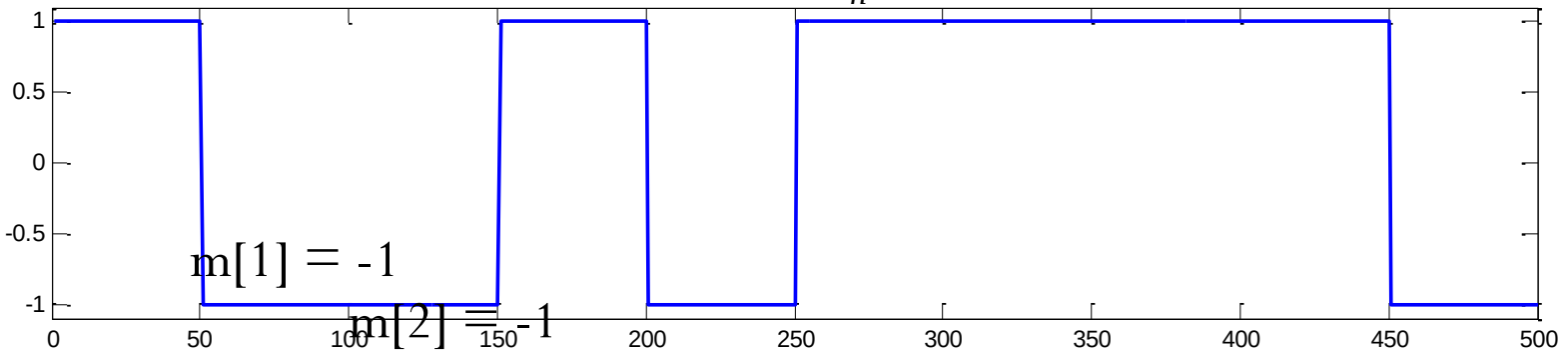
$$r[n] \geq 0 \Rightarrow \text{ decode as } \hat{m}[n] = 1$$

$$r[n] < 0 \Rightarrow \text{ decode as } \hat{m}[n] = -1$$

Noise: Ex 2 (2/5)

$$x(t) = \sum_n m[n]\, p(t - nT)$$

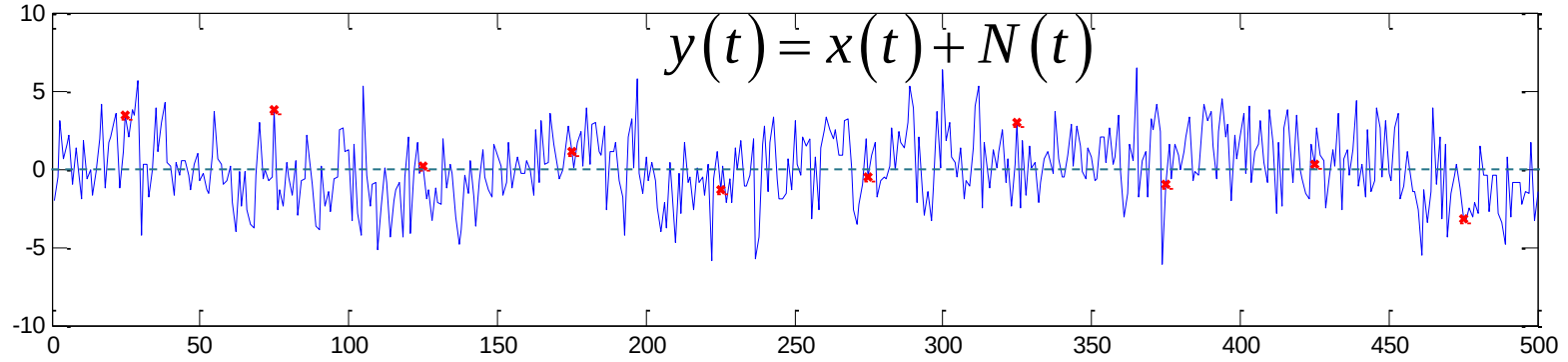
m[0] = 1



m[1] = -1

m[2] = -1

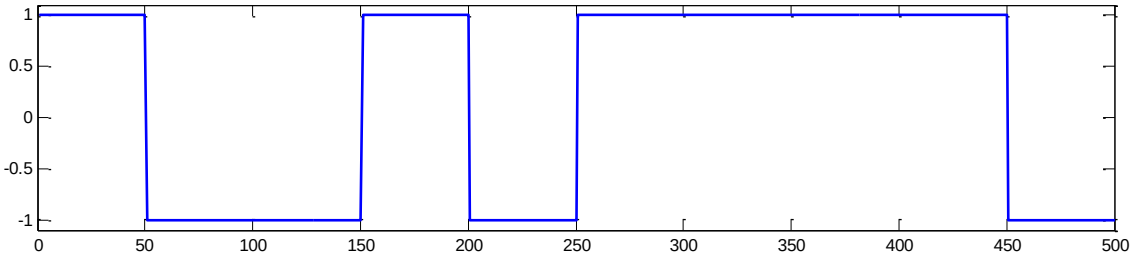
$$y(t) = x(t) + N(t)$$



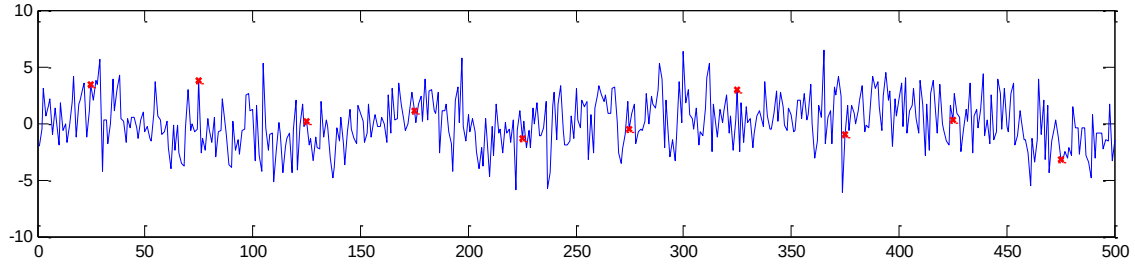
n	0	1	2	3	4	5	6	7	8	9
$m[n]$	1	-1	-1	1	-1	1	1	1	1	-1
$\hat{m}[n]$	1	1	1	1	-1	-1	1	-1	1	-1

Noise: Ex 2 (3/5)

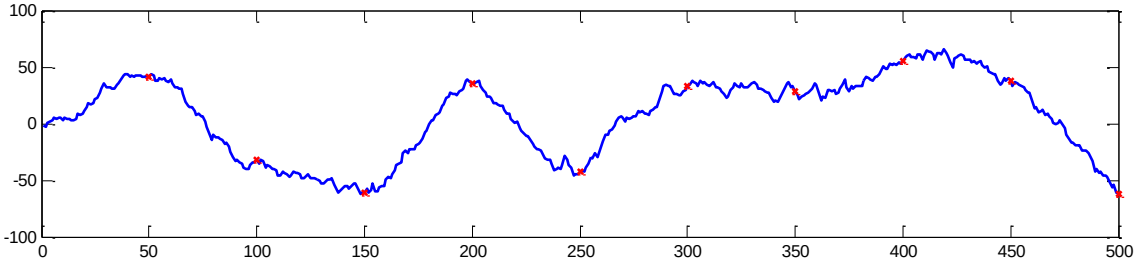
$x(t)$



$y(t)$



$r(t)$



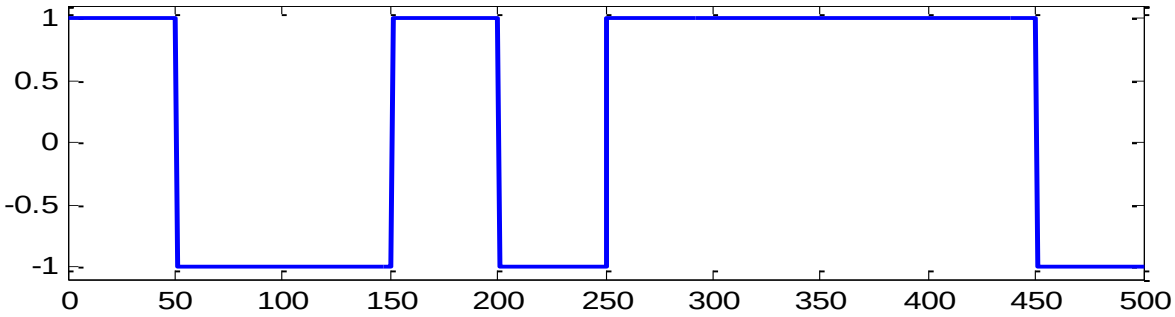
$$r(t) = \int_{t-T}^{t} y(\tau)d\tau = y(t) * \underbrace{h_r(t)}$$

$$h_r(t) = p^*(T-t)$$ **Matched filter**

Q: Where should we sample?

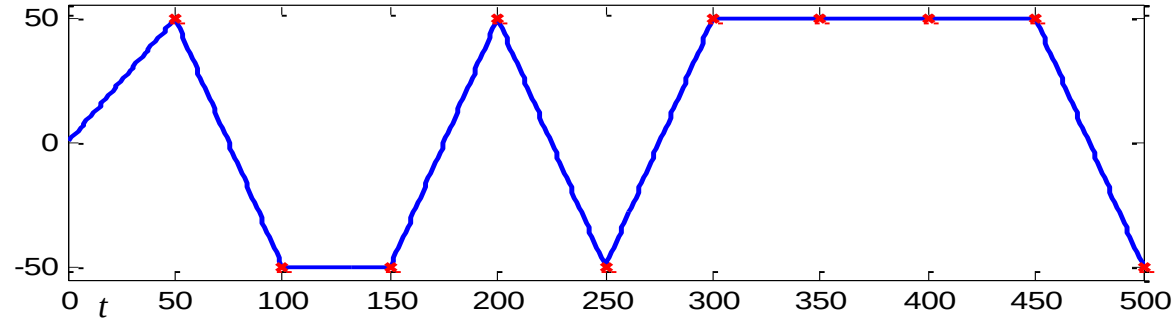
Noise: Ex 2 (4/5)

$x(t)$



$r(t)$

when there is no noise



$$r(t) = \int_{t-T} x(\tau)d\tau = x(t) * h_r(t) \qquad h_r(t) = p^*(T-t)$$

To decode, consider

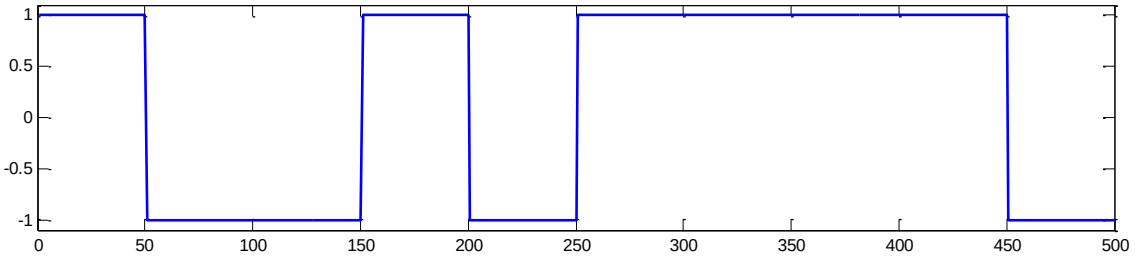
$$r[n] = y(nT+T)$$

$$r[n] \geq 0 \Rightarrow \text{ decode as } \hat{m}[n] = 1$$

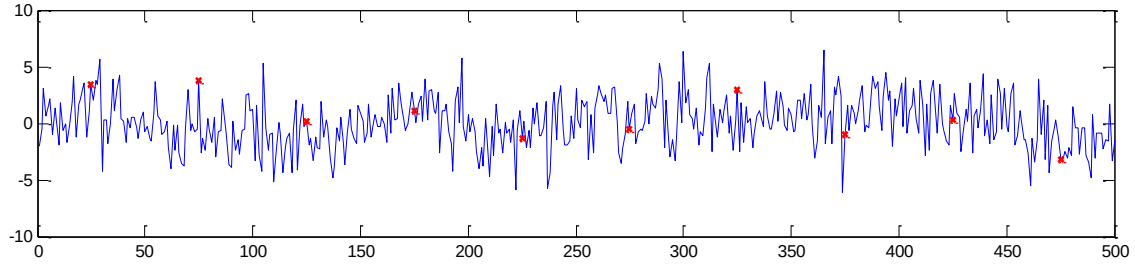
$$r[n] < 0 \Rightarrow \text{ decode as } \hat{m}[n] = -1$$

Noise: Ex 2 (5/5)

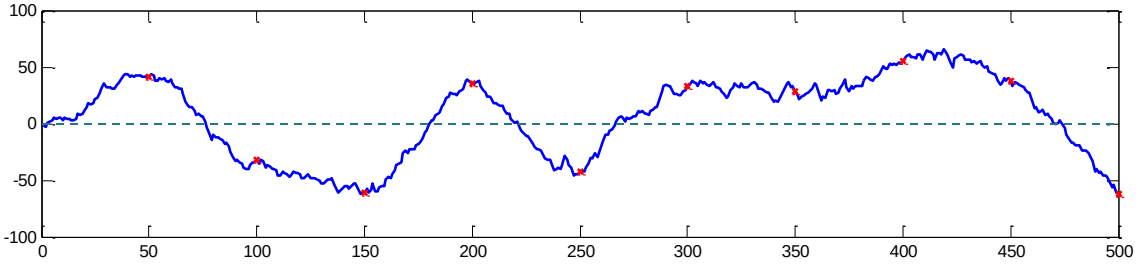
$x(t)$



$y(t)$



$r(t)$



n	0	1	2	3	4	5	6	7	8	9
$m[n]$	1	-1	-1	1	-1	1	1	1	1	-1
$\hat{m}[n]$	1	-1	-1	1	-1	1	1	1	1	-1

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Digital Modulation

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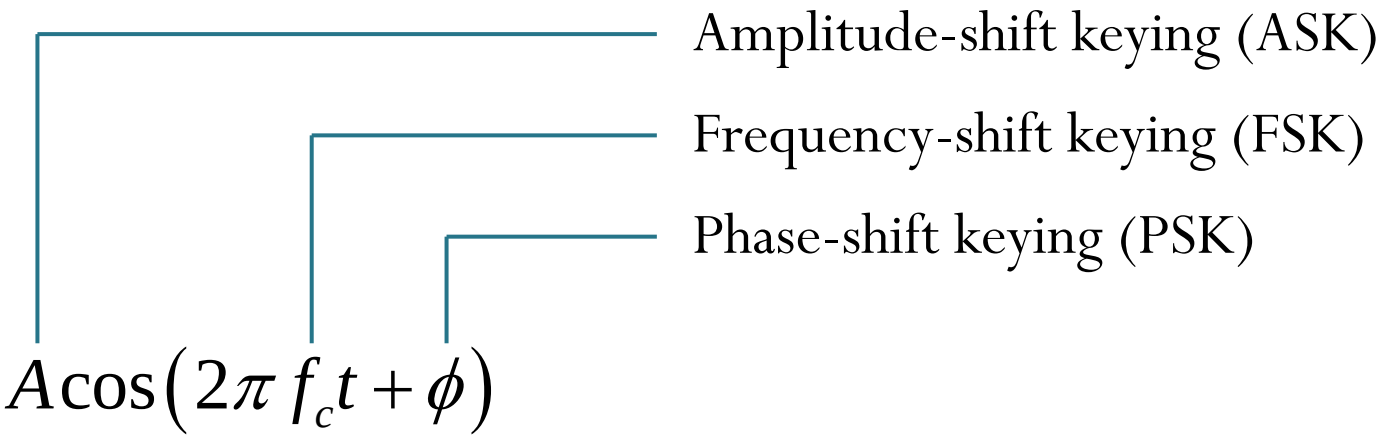
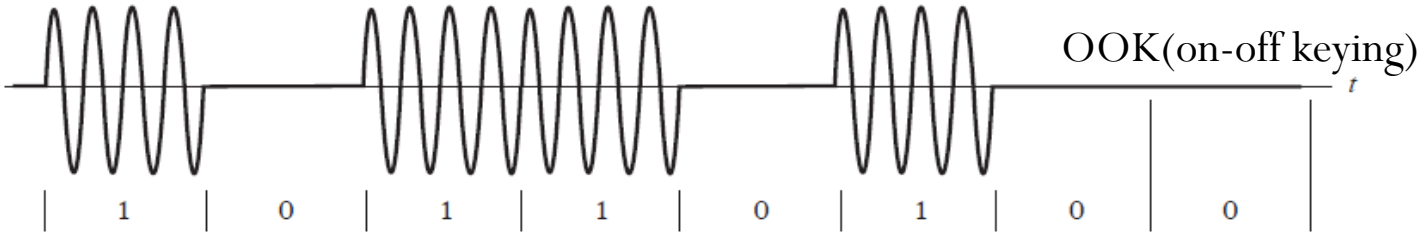
Digital Modulation

- A ***digital signal*** can modulate the amplitude, frequency, or phase of a sinusoidal carrier wave.
- If the modulating waveform consists of NRZ rectangular pulses, then the modulated parameter will be switched or ***keyed*** from one discrete value to another.

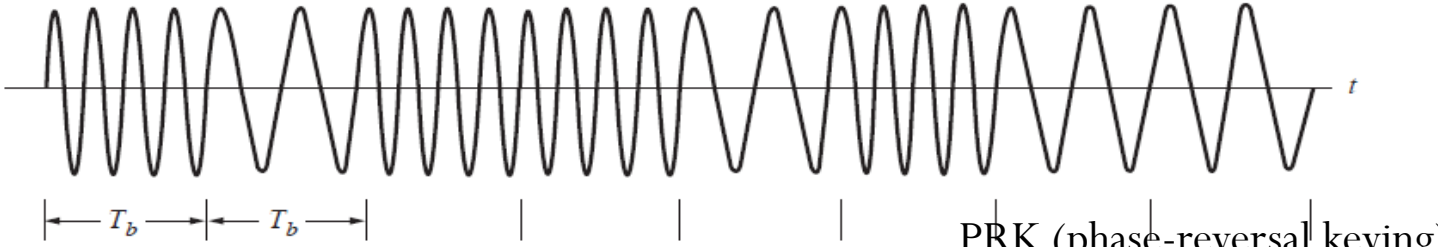


Digital Modulation: Binary Signaling

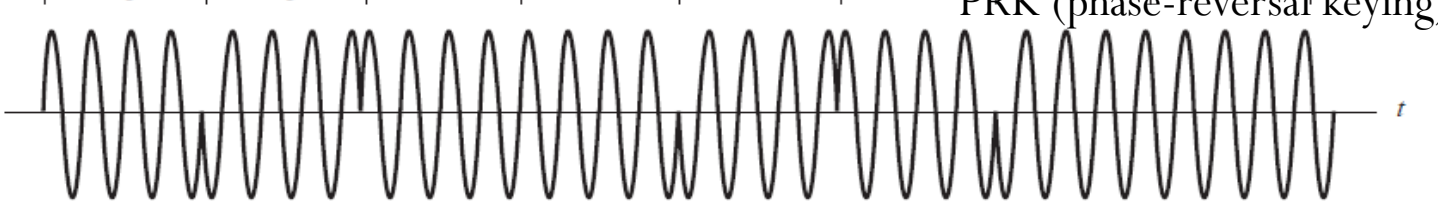
Binary ASK



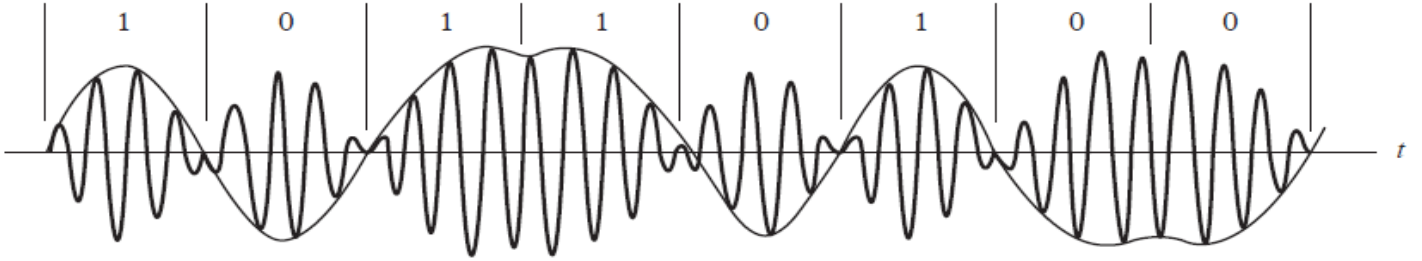
FSK



Binary PSK (BPSK)

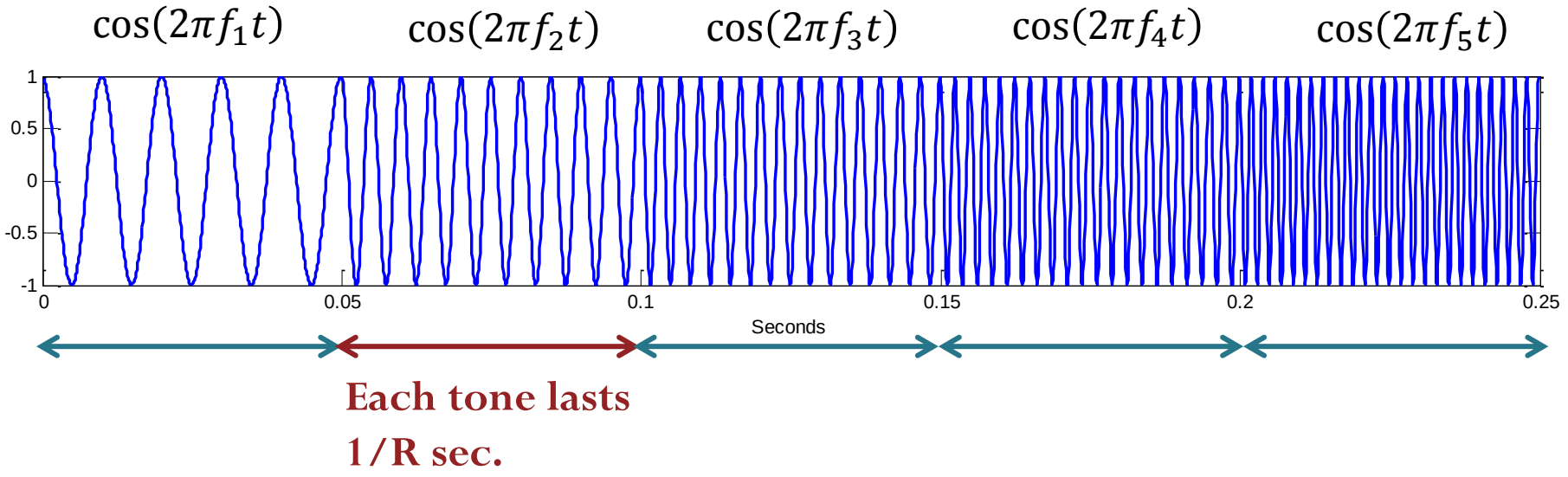


DSB mod. w/ Nyquist pulse shaping at baseband



[Carlson and Crilly, 2009, Fig 14.1-1]

FSK



Rate = R frequency-change per second