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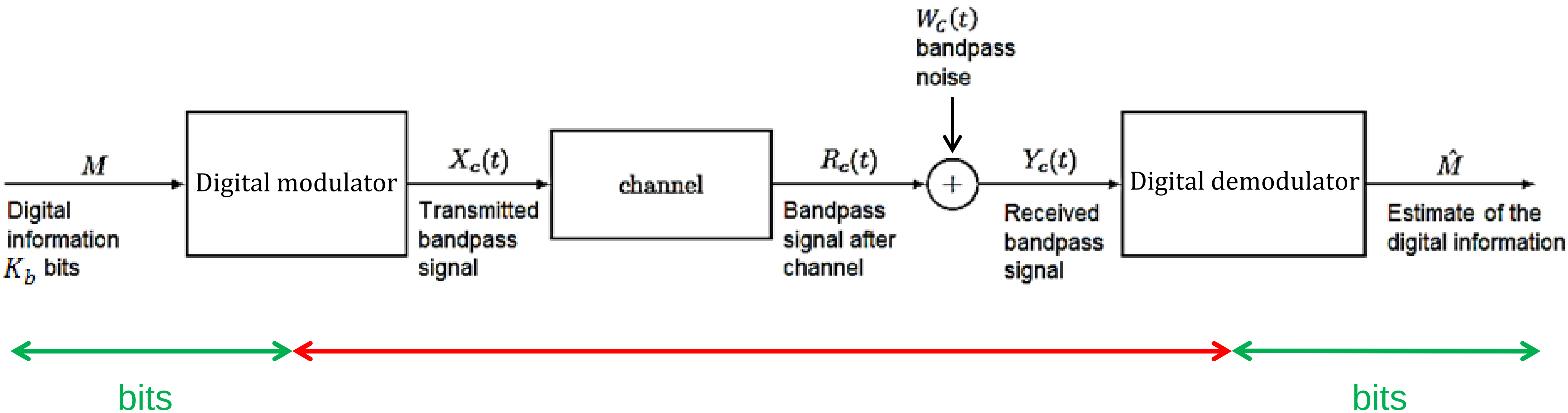
THE EDGE IN KNOWLEDGE

Digital Communication Part I: Basics

(Chapter 12)

- Block diagram:



$$\boxed{R_b = Bit\ rate\ = \frac{K_b}{duration\ of\ the\ transmission}\quad bits/s}$$

Digital Communication Part I: Basics

Remark: The digital information M consists of K_b bits.

it can be equivalently seen as consisting of 2^{K_b} different messages (i.e., strings of K_b bits), each with probability $\pi_i, i = 0,1, \ldots 2^{K_b} - 1$

Ex.: $K_b = 2 \Rightarrow \; M \in \{00, 01, 10, 11\}$ ($2^{K_b} = 4$ possible messages)

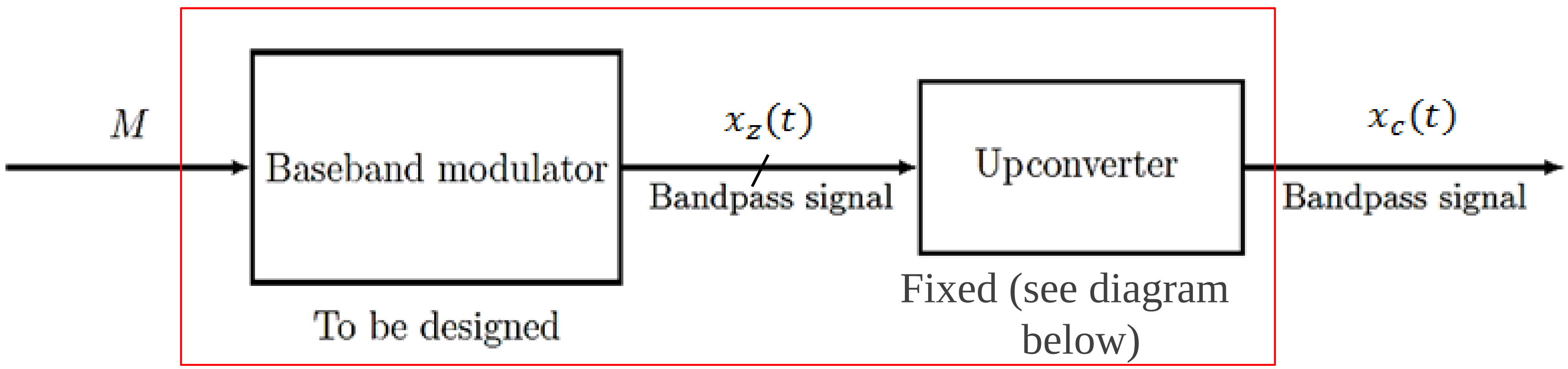
with probability $\underset{\pi_0}{00}, \underset{\pi_1}{01}, \underset{\pi_2}{10}, \underset{\pi_3}{11}$

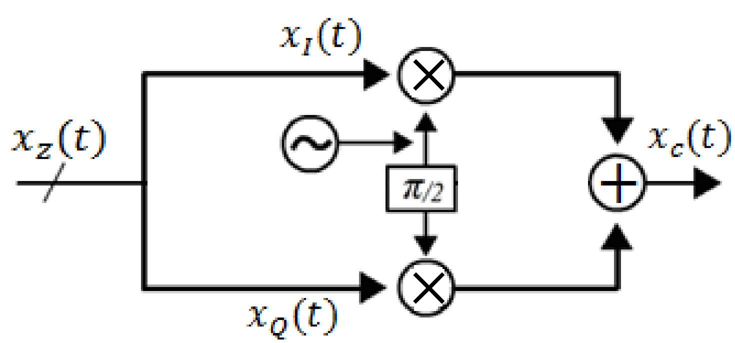
Digital Communication Part I: Basics

- Goal: Design digital modulator and digital demodulator so that $\Pr[\widehat{M} \neq M]$ is small.
- Constraints: Transmission power and bandwidth, bit rate

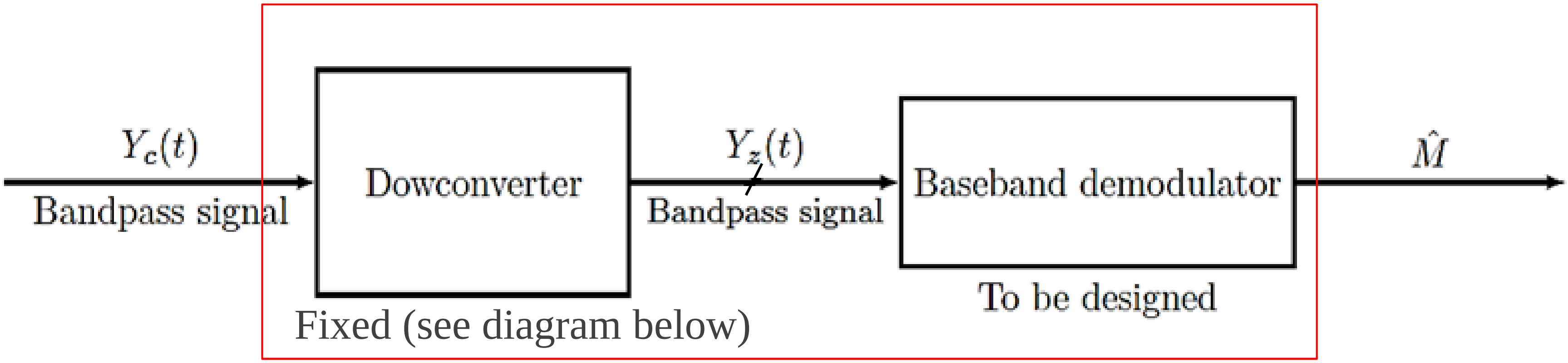
Digital Communication Part I: Basics

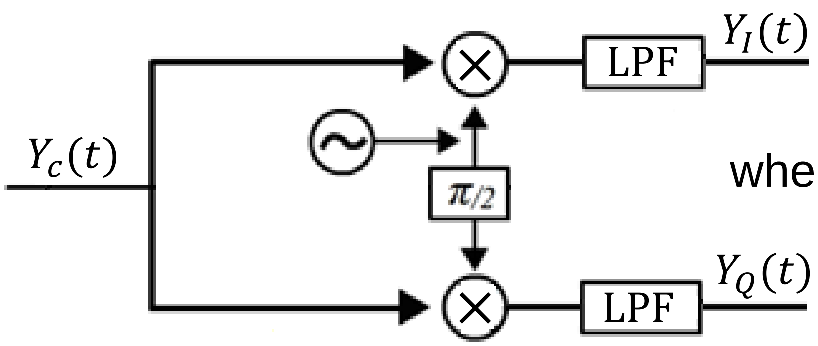
- Modulator:





Demodulator

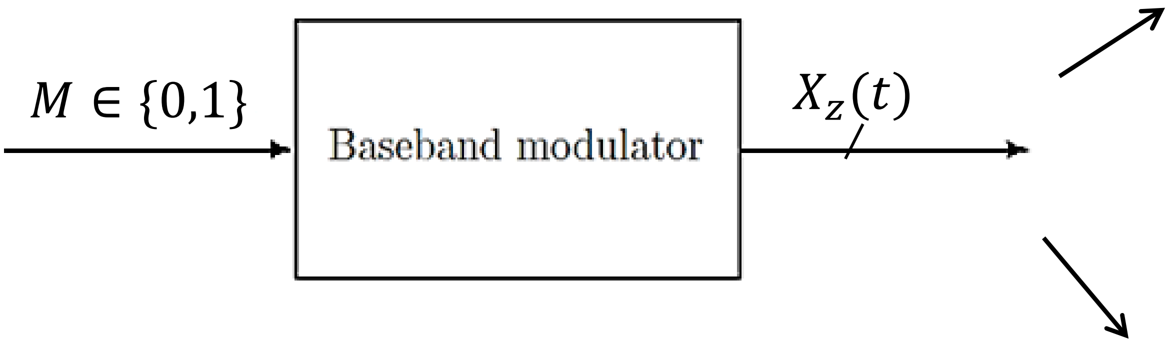


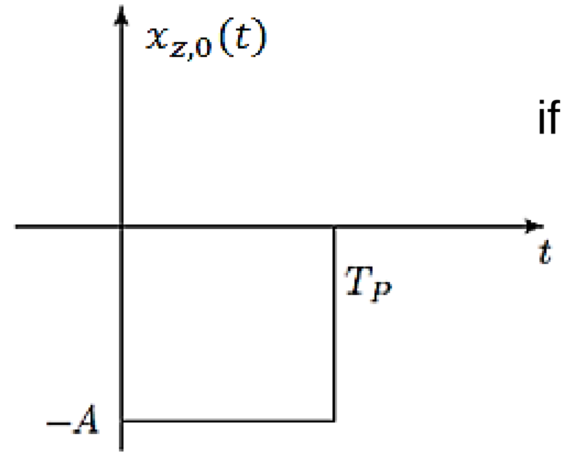


where $Y_z(t) = Y_I(t) + jY_Q(t)$

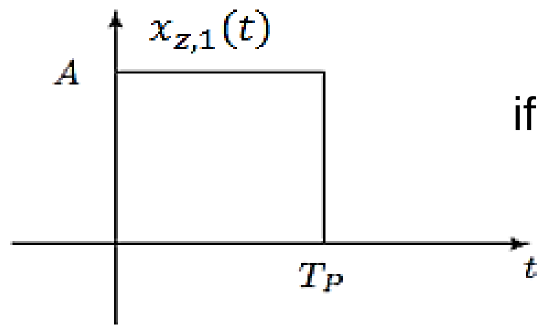
Example

a) $K_b = 1$





if $M = 0$



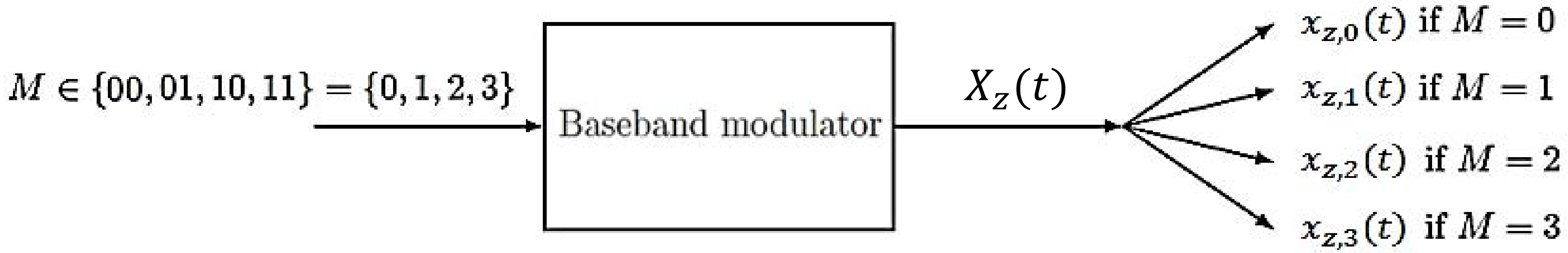
if $M = 1$

$$x_{z,0}(t) = \begin{cases} -A & \text{for } 0 \leq t \leq T_p \\ 0 & \text{otherwise} \end{cases}$$

$$x_{z,1}(t) = \begin{cases} A & \text{for } 0 \leq t \leq T_p \\ 0 & \text{otherwise} \end{cases}$$

Example

b) $K_b = 2$



$$x_{z,i}(t) = x_{I,i}(t) + j\,x_{Q,i}(t),\; i = 0, 1, 2, 3$$

$$x_{I,i}(t) = \begin{cases} -A & \text{if } 0 \le t \le T_p \\ 0 & \text{otherwise} \end{cases} \quad \text{for } i = 00 \text{ and } i = 01$$

$$x_{I,i}(t) = \begin{cases} A & \text{if } 0 \le t \le T_p \\ 0 & \text{otherwise} \end{cases} \quad \text{for } i = 10 \text{ and } i = 11$$

$\Longrightarrow$ $x_I(t)$ encodes the first bit. Similarly $x_Q(t)$ encodes the second bit.

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Performance Metrics

- Complexity: affects cost of implementation
- Fidelity
  - Word, or message, Error Probability (WEP)

$$P_w(E) = \Pr[\widehat{M} \neq M]$$

  - If $K_b = 1$, then the WEP is referred to as Bit Error Probability (BEP)

$$P_B(E) = \Pr[\widehat{M} \neq M]$$

- Spectral efficiency

$$\eta_B = \frac{R_b}{B_T} \quad \text{bits/s/Hz}$$

for wired or fixed wireless

Ex.: $\eta_B = 0.01 - 15$

for mobile wireless

Transmission SNR

- $$\mathrm{SNR} = \frac{\text{power received signal } X_c(t) \text{ (or } X_z(t))}{\text{power received noise } W_c(t) \text{ (or } W_z(t))}$$
- Energy / power of $X_z(t)$:

$E_i = \int \left| x_{z,i}(t) \right|^2 \, dt$ energy of signal $x_{z,i}(t)$

$E_s = \sum_i \pi_i E_i$ average energy of $X_z(t)$

$P_s = \frac{E_s}{\text{duration of transmission}}$ average power of $X_z(t)$

$$\Rightarrow \mathrm{SNR} = \frac{P_s}{N_0 B_T}$$

$\Rightarrow$ Performance defined by $(\eta_B, P_W(E), \mathrm{SNR})$

Performance bounds

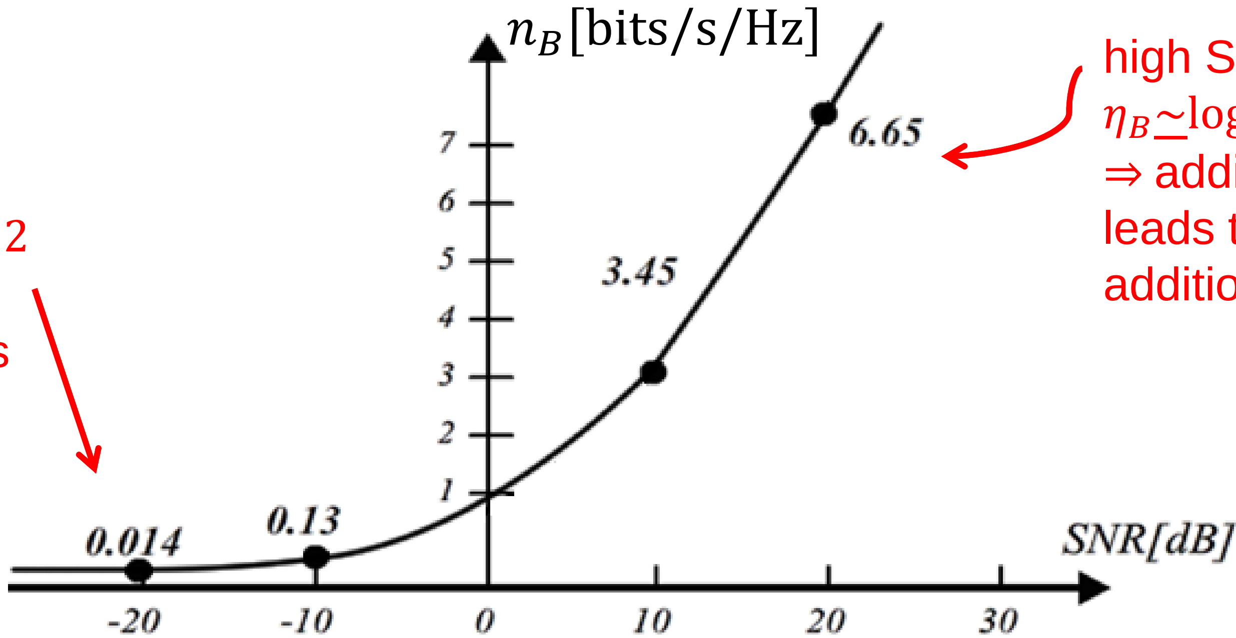
- Claude Shannon in 1948 developed a fundamental theory that allows to derive the maximum achievable spectral efficiency η_B given $SNR = \frac{P_s}{N_0 B_T}$ under the condition that $P_W(E)$ can be made as small as desired.

- View this documentary about Claude Shannon: http://www.youtube.com/watch?v=z2Whj_nL-x8

Performance bounds

- Shannon bound, also known as capacity
  - maximum $\eta_B = \log_2(1 + \text{SNR})$

low SNR:
$\eta_B \simeq \text{SNR} \log_e 2$
⇒ adding 10dB to the SNR multiplies the bit rate by 10.



high SNR:
$\eta_B \simeq \log_2 \text{SNR}$
⇒ adding 10dB to the SNR leads to $\log_2 10 = 3.3$ additional bits/s/Hz

See also Fig. 12.5 in the textbook

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