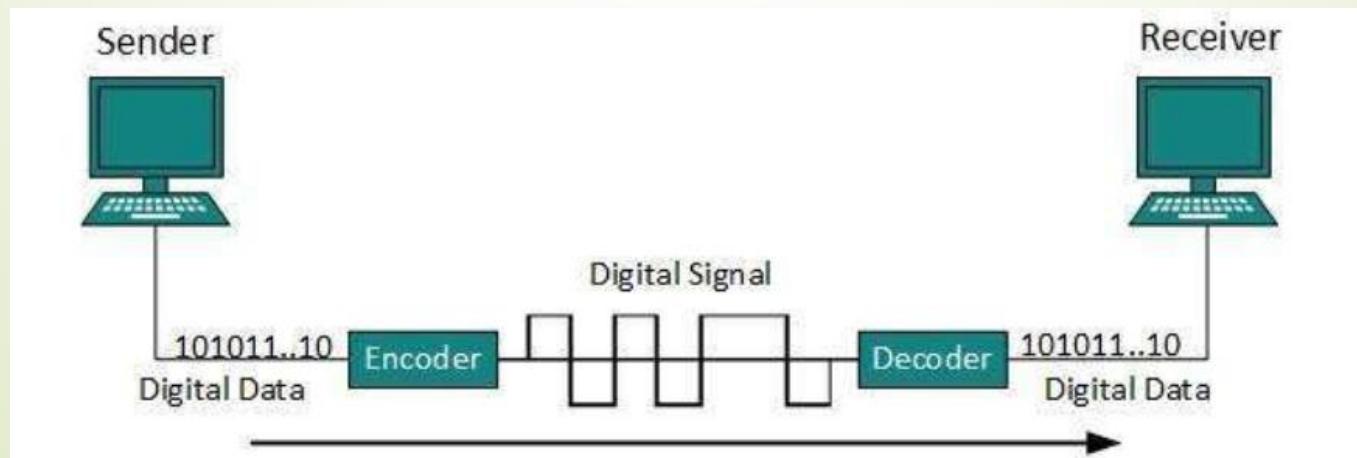


Communication Theory II

Lecture 1: Digital Baseband Transmission and Match Filter

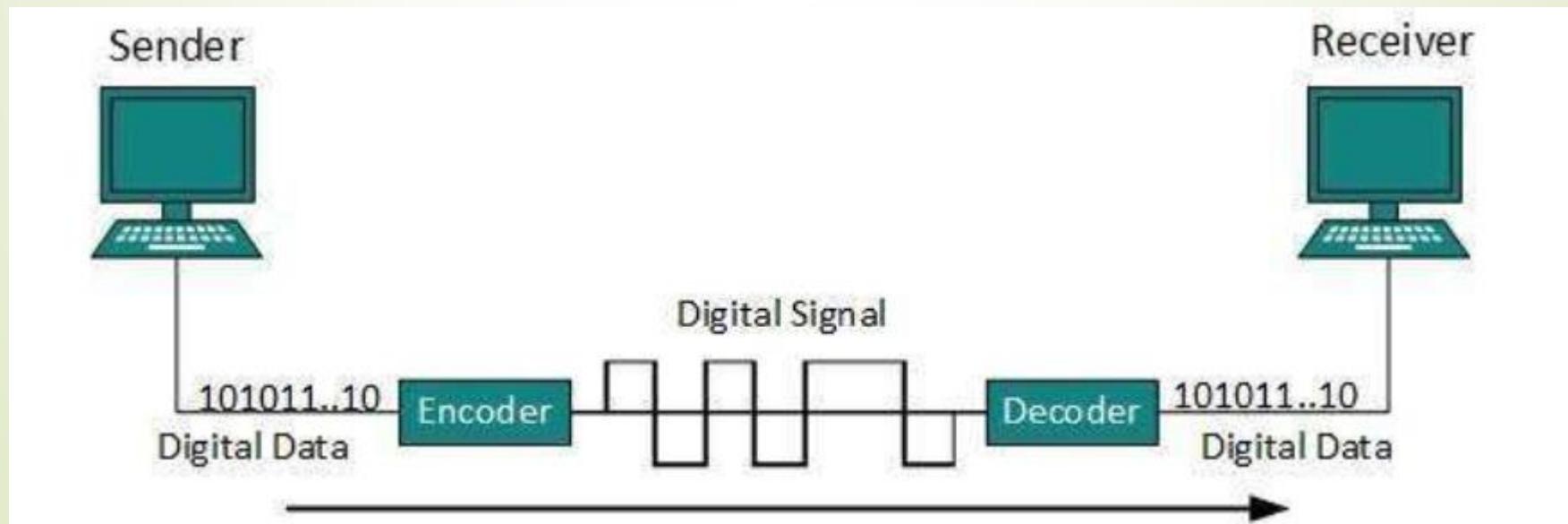
Digital Baseband Transmission

- ❑ Baseband transmission is used in various applications where the original baseband signal is directly transmitted without modulation to a higher frequency.
 - ❑ Local Area Networks (LANs)
 - ❑ Local Digital Audio/Video Transmission (HDMI)
 - ❑ Wired Communication Systems
 - ❑ Data Storage (where the digital data is transmitted at the baseband frequency onto the storage medium)



Digital Baseband Transmission

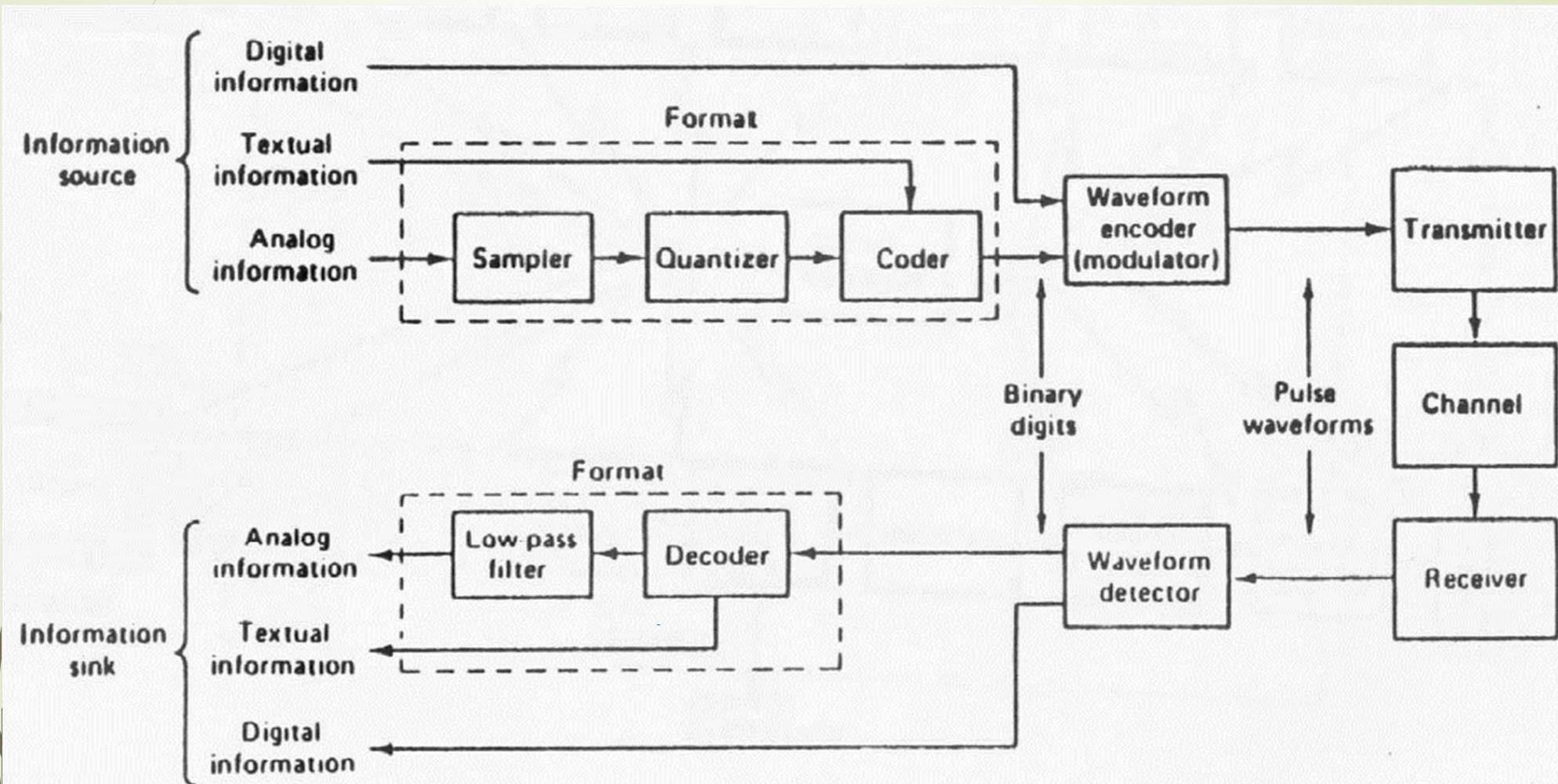
- In **digital baseband** transmission, a **bit stream** (e.g. a PCM signal) is encoded into **pulses** without modulating a high-frequency carrier.
- The **digital pulses** are then transmitted directly over a *baseband* or *lowpass* channel.



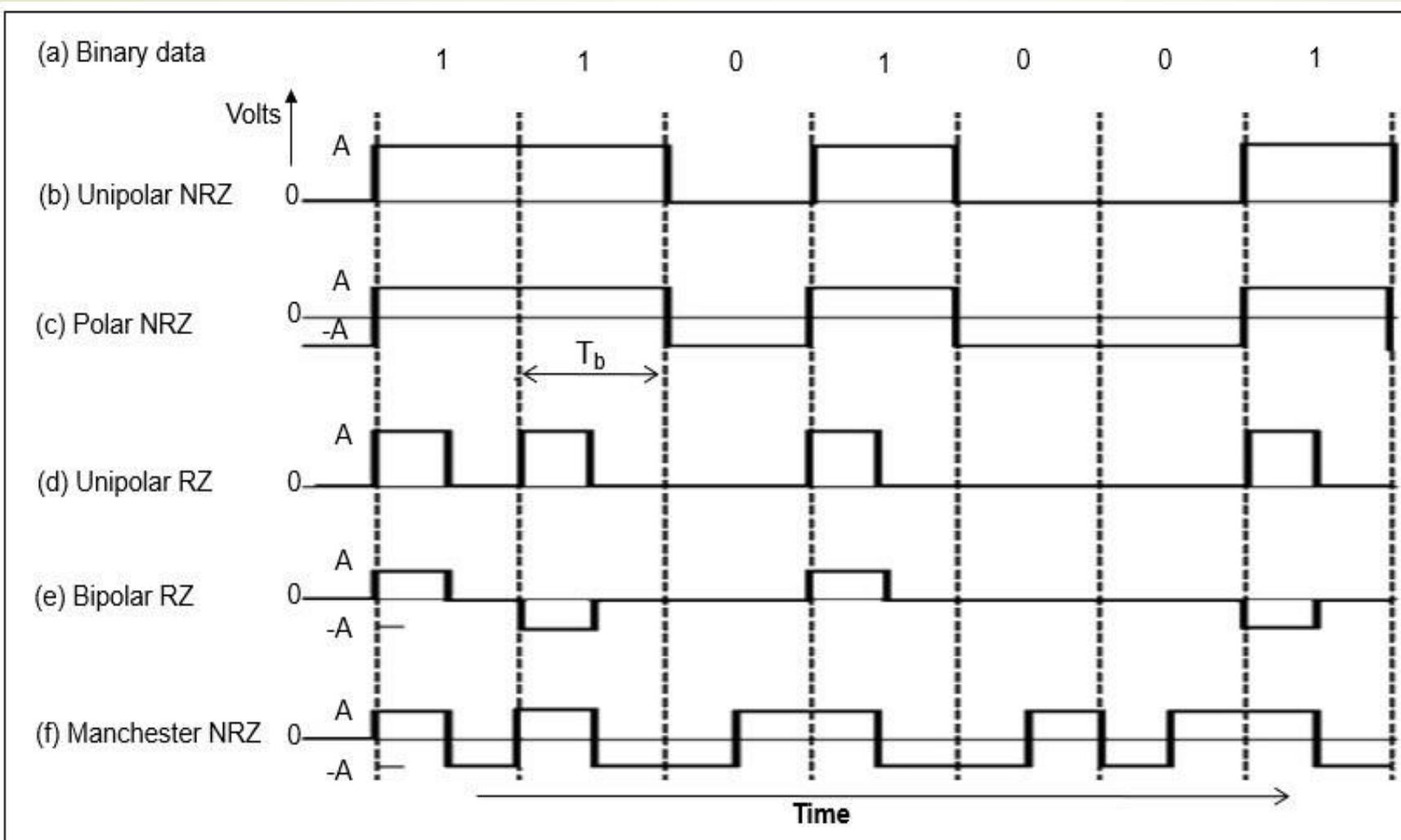
Digital Baseband Transmission

- A baseband signal refers to a signal that has not been modulated or translated to a higher frequency for transmission over a communication channel. It is typically a low-frequency signal that represents the original information or data to be transmitted.
- Digital baseband signals typically have a limited bandwidth, which contains the essential frequency components representing the transmitted data (significantly low frequency components)

Baseband Pulse Transmission

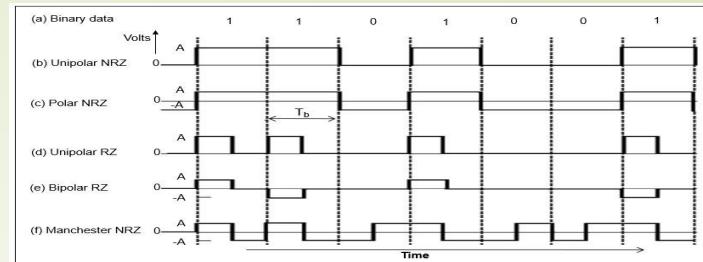


- Binary pulse format:



*Bipolar RZ :- A type of bipolar encoding known as paired disparity code, exemplified by **alternate mark inversion**, is utilized. This encoding scheme represents a binary 0 as zero volts, similar to unipolar encoding, while a binary 1 is encoded by alternating between positive and negative voltages.

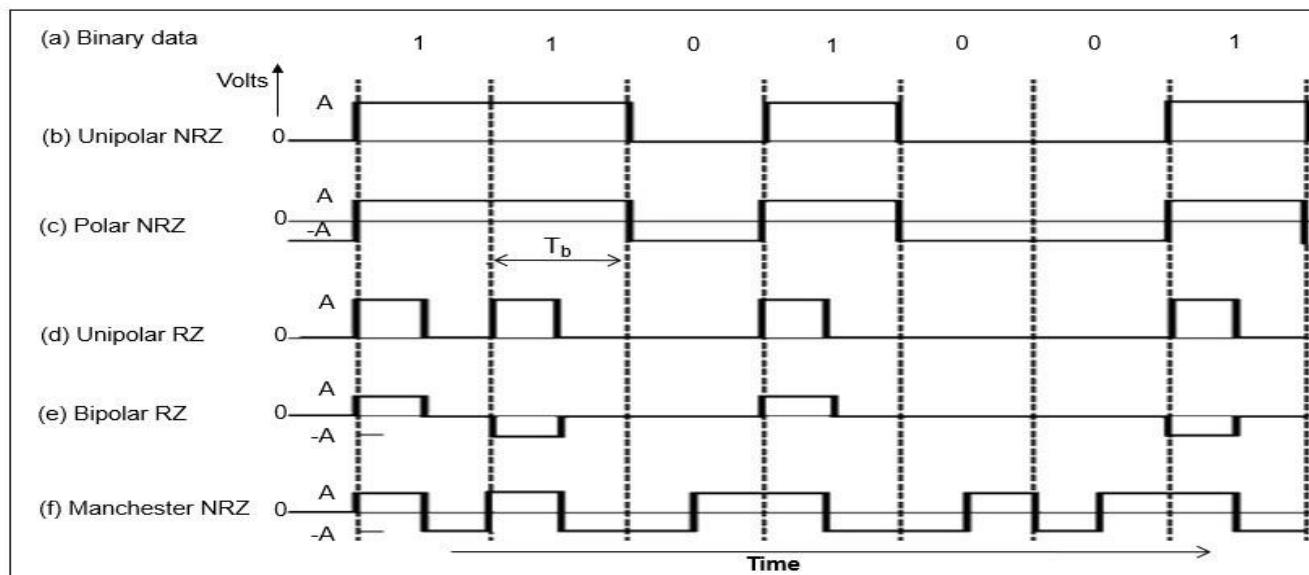
• Binary pulse format:



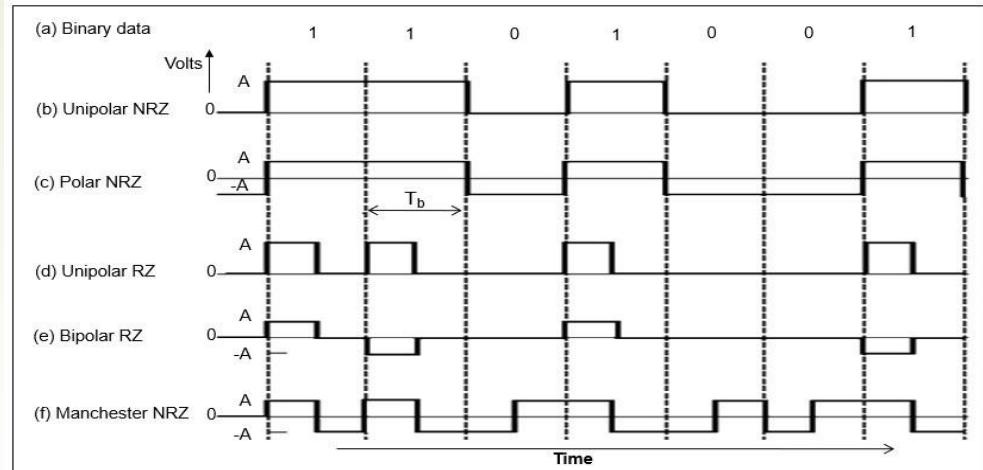
- **NRZ unipolar** encoding represents binary 0 and binary 1 using only one polarity of voltage. In this scheme, a binary 0 is encoded as zero volts, indicating the absence of a signal. A binary 1 is encoded using a positive voltage level, indicating the presence of a signal.
- **NRZ bipolar encoding**, also known as polar NRZ, represents binary 0 and binary 1 using two opposite polarities of voltage.
- **RZ unipolar encoding**, represents binary 0 and binary 1 using only one polarity of voltage. In RZ unipolar, the voltage returns to zero within each bit interval. A binary 0 is encoded as zero volts, indicating the absence of a signal. A binary 1 is encoded using a positive voltage level, but the voltage returns to zero (at middle) before the next bit.
- **RZ bipolar encoding**, also known as polar RZ, represents binary 0 and binary 1 using two opposite polarities of voltage. In RZ bipolar, the voltage returns to zero within each bit interval. A type of bipolar encoding known as paired disparity code, exemplified by **alternate mark inversion**, is utilized. This encoding scheme represents a binary 0 as zero volts, similar to unipolar encoding, while a binary 1 is encoded by alternating between positive and negative voltages.

Binary pulse format:

- ❑ Timing Recovery: Both bipolar NRZ and RZ line coding schemes can pose challenges in timing recovery, particularly when there are long runs of consecutive bits of the same value. These long runs can lead to clock skew and difficulties in maintaining accurate clock synchronization at the receiver.
- ❑ To overcome these limitations, other line coding schemes have been developed, such as Manchester encoding, Differential Manchester encoding, and more advanced modulation techniques like Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM). These schemes provide better noise immunity, clock recovery, and improved spectral efficiency compared to unipolar and bipolar NRZ and RZ coding.

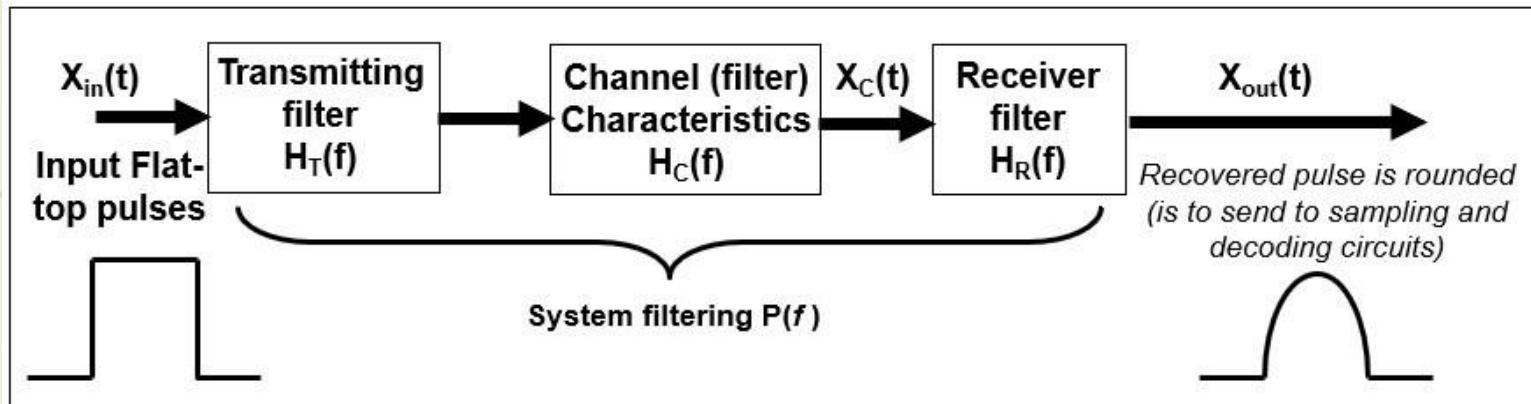


• Binary pulse format:



- In Manchester coding, each bit of the input data is divided into two equal time intervals. The value of the bit is represented by the transition of the signal within each interval.
- The key feature of Manchester coding is that each bit has a transition in the middle of its interval, which helps in achieving clock synchronization between the sender and receiver. This self-clocking property of Manchester coding eliminates the need for a separate clock signal.
- It also provides a balanced spectrum with equal energy in the low and high frequency components, which can be advantageous in certain communication environments.

Baseband Pulse Transmission



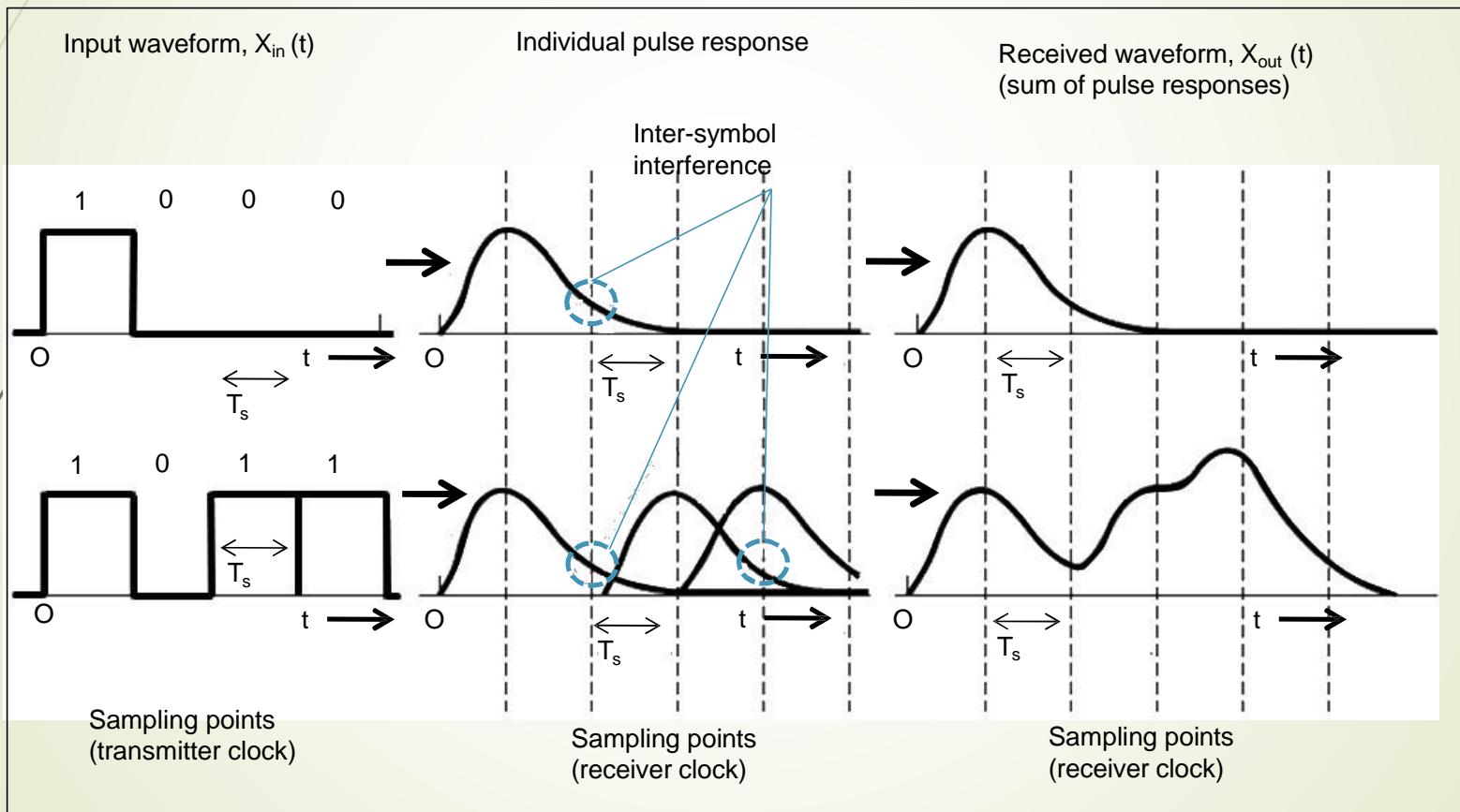
- ❑ A baseband pulse transmission system consists of three lowpass filtering at transmitter, channel, and receiver, respectively. The combined effect is called system lowpass filtering.
- ❑ When line code flat-top pulses are transmitted over the system, the system filtering will cause the pulses to have rounded tops at system output.

Channel Filters are not ideal, its response is diverted from ideal low pass filter. Frequency Components of Flat-Top Pulses: Flat-top pulses contain a wide range of frequency components, including high-frequency components that contribute to the sharp edges of the pulses.

Inter-Symbol Interference

- ❑ If these flat-top pulses are filtered improperly by the system, they will spread in time to form so-called the tails or ripples.
- ❑ These tails spread into adjacent bit intervals to interfere with the interpretation of the adjacent symbols. This interference is known as ISI (inter-symbol interference).
- ❑ If an ISI causes a wrong interpretation of a symbol (e.g. a pulse symbol is interpreted as binary “0” instead of binary “1”, and a zero- level symbol is interpreted as binary “1” instead of binary “0”), then a bit error arises.
- ❑ ISI is a major source of bit errors in the receivers.

Inter-Symbol Interference





Baseband Pulse Transmission : Match Filter



Match Filter

- The matched filter is the optimal linear filter for maximizing the signal to noise ratio (SNR) in the presence of additive stochastic noise.
- Matched filters are commonly used in radar, in which a signal is sent out, and we measure the reflected signals, looking for something similar to what was sent out.
- Two-dimensional matched filters are commonly used in image processing, e.g., to improve SNR for X-ray pictures

Match Filter

- Optimal detector system of a known pulse in an additive white Gaussian noise.

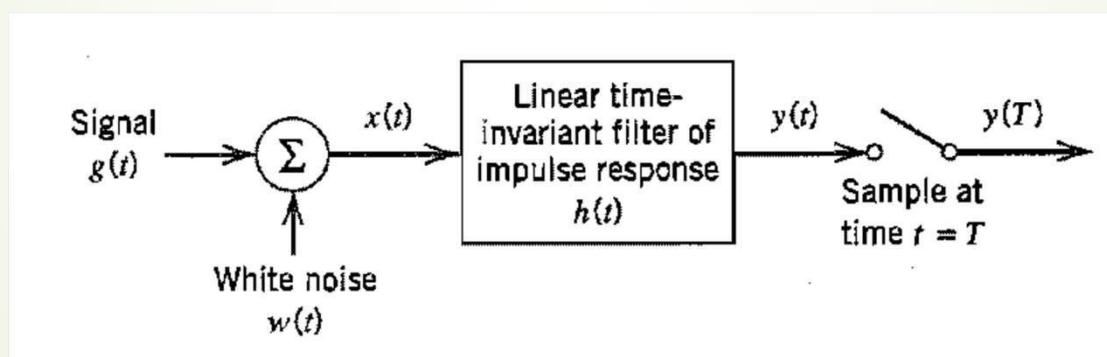


FIGURE 1-1 Linear Receiver

Match Filter

- The filter input $x(t)$ consists of a pulse signal $g(t)$ corrupted by additive channel noise $w(t)$, as shown by

$$x(t) = g(t) + w(t), \quad 0 \leq t \leq T \quad (1.1)$$

where T is an arbitrary observation interval. The pulse signal $g(t)$ may represent a binary symbol I or 0 in a digital communication system.

- The $w(t)$ is the sample function of a white noise process of zero density mean and power spectral No/2.
- The source of uncertainty lies in the noise $w(t)$.
- The function of the receiver is to detect the pulse signal $g(t)$ in an optimum manner, given the received signal $x(t)$.
- To satisfy this requirement, we have to optimize the design of the filter so as to minimize the effects of noise at the filter output in some statistical sense, and thereby enhance the detection of the pulse signal $g(t)$.

- Since the filter is linear, the resulting output $y(t)$ may be expressed as
- $$y(t) = g_o(t) + n(t) \quad (1.2)$$
- where $g_o(t)$ and $n(t)$ are produced by the signal and noise components of the input $x(t)$, respectively.
- A simple way of describing the requirement that the output signal component $g_o(t)$ be considerably greater than the output noise component $n(t)$ is to have the filter make the instantaneous power in the output signal $g_o(t)$, measured at time $t = T$, as large as possible compared with the average power of the output noise $n(t)$. This is equivalent to maximizing the peak pulse signal-to-noise ratio, defined as

$$\eta = \frac{|g_o(T)|^2}{E[n^2(t)]} \quad (1.3)$$

White Noise

- For the case of white noise, the description of the matched filter is simplified as follows: For white noise, Spectral density= $N_0 / 2$, $H(f)$ is given by

$$H(f) = \frac{2K}{N_0} S^*(f) e^{-j\omega t_0} \quad (1.4)$$

- From this equation, the following theorem is obtained

Example 1.1:

THEOREM. When the input noise is white, the impulse response of the matched filter becomes

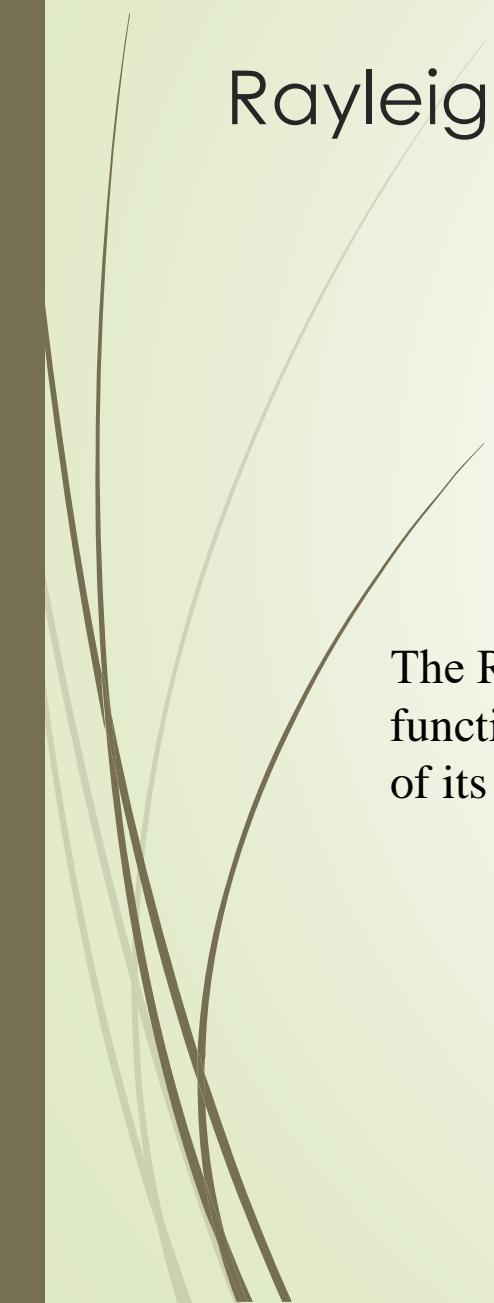
$$h(t) = Cs(t_0 - t) \quad (1.5)$$

where C is an arbitrary real positive constant, t_0 is the time of the peak signal output, and $s(t)$ is the known input-signal waveshape.

Proof

$$\begin{aligned} h(t) &= \mathcal{F}^{-1}[H(f)] = \frac{2K}{N_0} \int_{-\infty}^{\infty} S^*(f) e^{-j\omega t_0} e^{j\omega f} df \\ &= \frac{2K}{N_0} \left[\int_{-\infty}^{\infty} S(f) e^{j2\pi f(t_0 - t)} df \right]^* \\ &= \frac{2K}{N_0} [s(t_0 - t)]^* \end{aligned}$$

- But $s(t)$ is a real signal; hence, let $C=2K/N_o$ so that the impulse response is equivalent to equation (1.5).
- Equation (1.5) shows that the impulse response of the matched filter (white-noise case) is simply the known signal waveshape that is "played backward" and translated by an amount τ_0 . Thus, the filter is said to be "matched" to the signal.



Rayleigh's Energy Theorem

$$E = \int_{-\infty}^{\infty} g^2(t) dt = \int_{-\infty}^{\infty} |G(f)|^2 df$$

The Rayleigh's energy theorem states that the integral of the square of magnitude of a function (i.e., energy of the function) is equal to the integral of the square of magnitude of its Fourier transform

Impulse Response of Optimum Filter

$$h_{\text{opt}}(t) = kg(T - t)$$

The peak pulse signal-to-noise ratio of a matched filter depends only on the ratio of the signal energy to the power spectral density of the white noise at the filter input.

$$\eta_{\max} = \frac{(kE)^2}{(k^2N_0E/2)} = \frac{2E}{N_0}$$

$$h_{\text{opt}}(t) = kg(T - t)$$

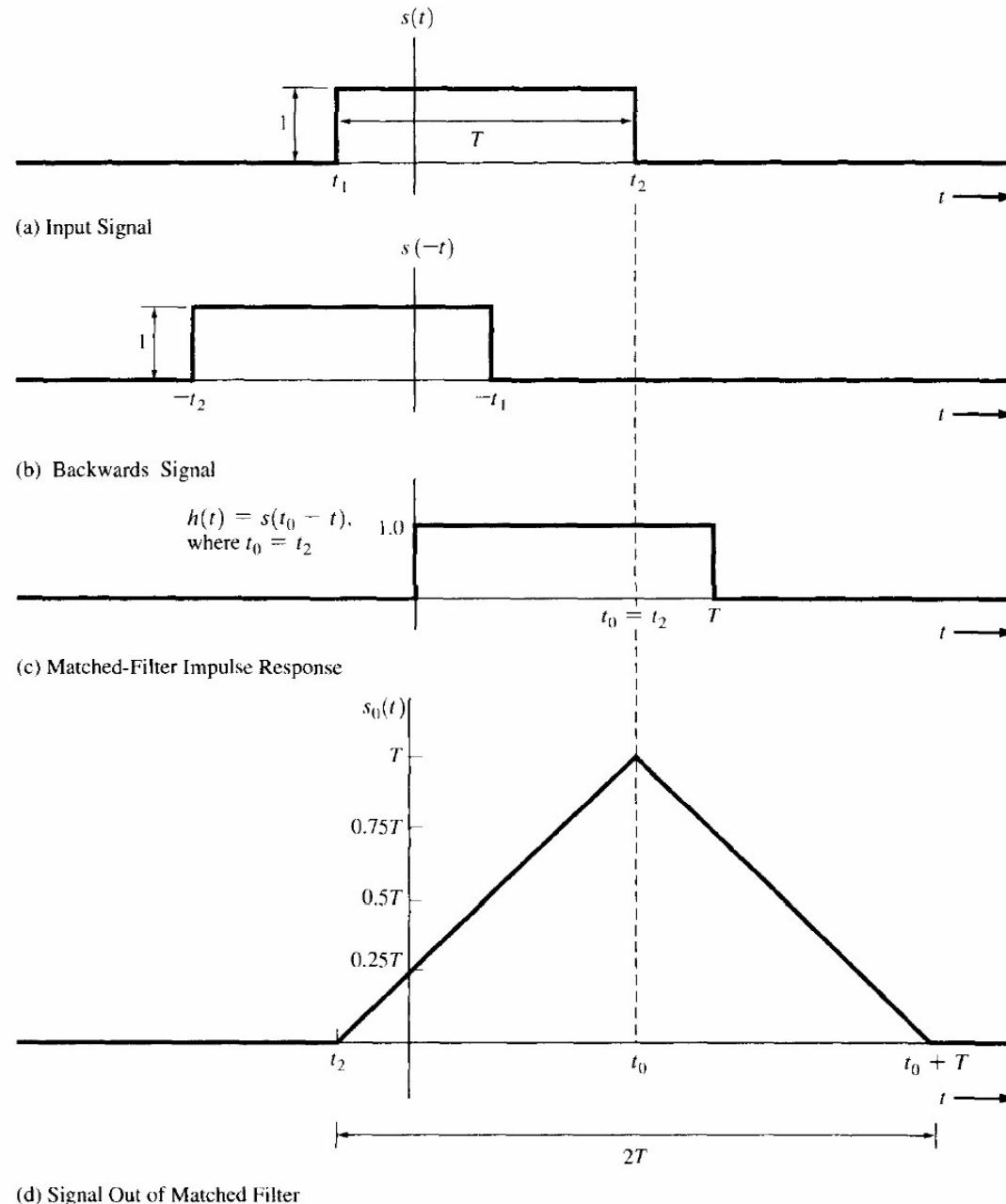
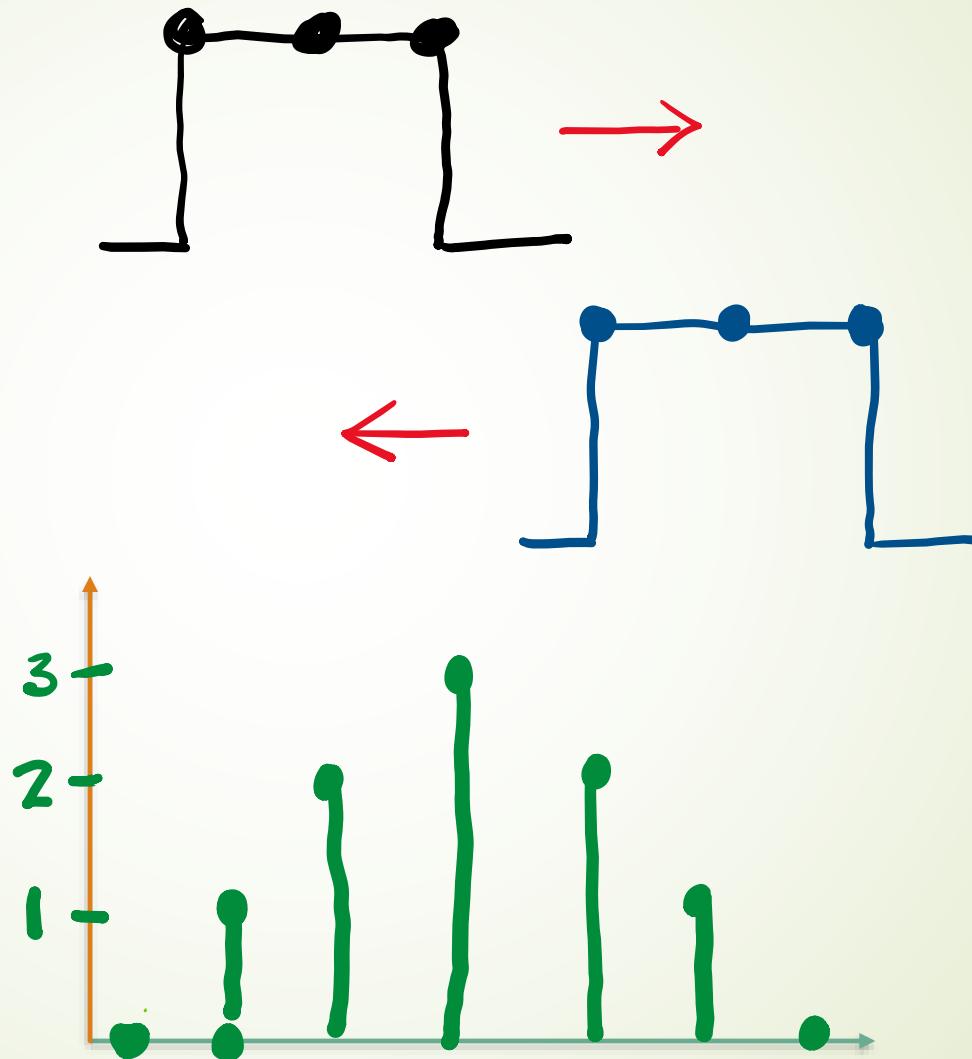
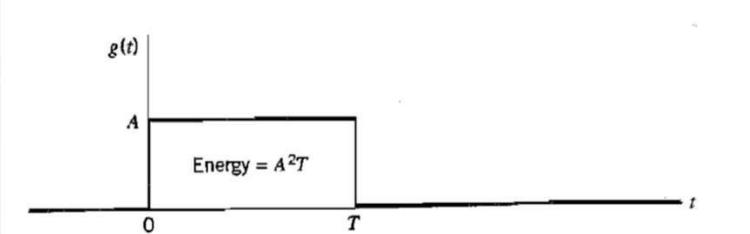


FIGURE 1-2 Waveforms associated with the match filter of Example 1-1

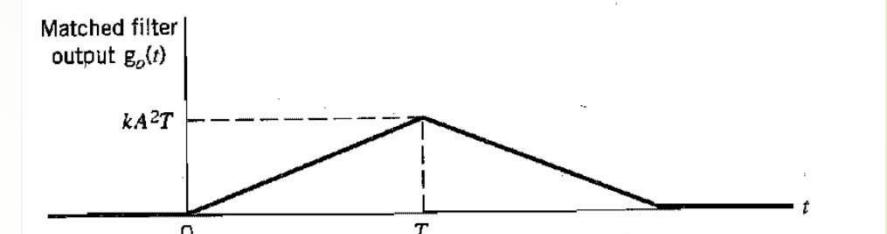
Convolution Process



Example 1.2: Match Filter for Rectangular Pulses



Rectangular pulse.



Matched filter output.

Example 1.3:

- A matched filter has the frequency response

$$H(f) = \frac{1 - e^{-j2\pi fT}}{j2\pi f}$$

- Identify the $h(t)$
- Identify the signal waveform $s(t)$ to which this filter is matched
- If $s(t)$ is applied to the input of the match filter, what is the peak value of the match filter output ?

Example 1.3: A matched filter has the frequency response

$$H(f) = \frac{1 - e^{-j2\pi fT}}{j2\pi f}$$

- Identify the $h(t)$
- Identify the signal waveform $s(t)$ to which this filter is matched
- If $s(t)$ is applied to the input of the match filter, what is the peak value of the match filter output ?

$$s(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S(\omega) e^{j\omega t} d\omega$$

WHERE

$$S(\omega) = \int_{-\infty}^{\infty} s(t) e^{-j\omega t} dt$$

$$\omega := 2\pi f$$

$$h_{\text{opt}}(t) = kg(T - t)$$

$$\eta_{\max} = \frac{(kE)^2}{(k^2 N_0 E / 2)} = \frac{2E}{N_0}$$



THANK YOU