Modulation Techniques for Mobile Radio

- Modulation is the process of encoding information from message source in a manner suitable for transmission.

- It generally involves translating a base band message signal (source) to a bandpass signal at frequencies >> baseband frequency.

- Demodulation is the process of extracting the baseband message from the carrier.

Modulation

Analog Modulation | Digital Modulation techniques

- First Generation mobile radio | Present & future systems

Review of Analog modulation Schemes

Amplitude Modulation

- m(t) – message signal
- $A_c \cos(2\pi f_c t)$ - Carrier signal
- AM Signal $S_{AM}(t) = A_c [1+m(t)] \cos(2\pi f_c t)$
- AM Spectrum

$$S_{AM}(f) = 0.5 A_c [\delta(f - f_c) + m(f - f_c) + \delta(f + f_c) + m(f + f_c)]$$

<u>AM parameters</u>

- Modulation Index $k = A_m / A_c \leq 1$
- Bandwidth $B_{AM} = 2 f_m$
- Total Power in AM signal

$P_{AM} = 0.5 A_c^2 [1 + 2<m(t)> + <m^2 (t)>]$

- Power in the carrier $P_c = A_c^2 / 2$

Single Sideband AM

lower sideband

Signal $S_{SSB} = A_c [m(t)\cos(2\pi f_c t) \pm \hat{m}(t) \sin(2\pi f_c t)]$

upper sideband

- $\hat{m}(t) = m(t) \otimes h(t)$

  $h(t) = 1/\pi t$

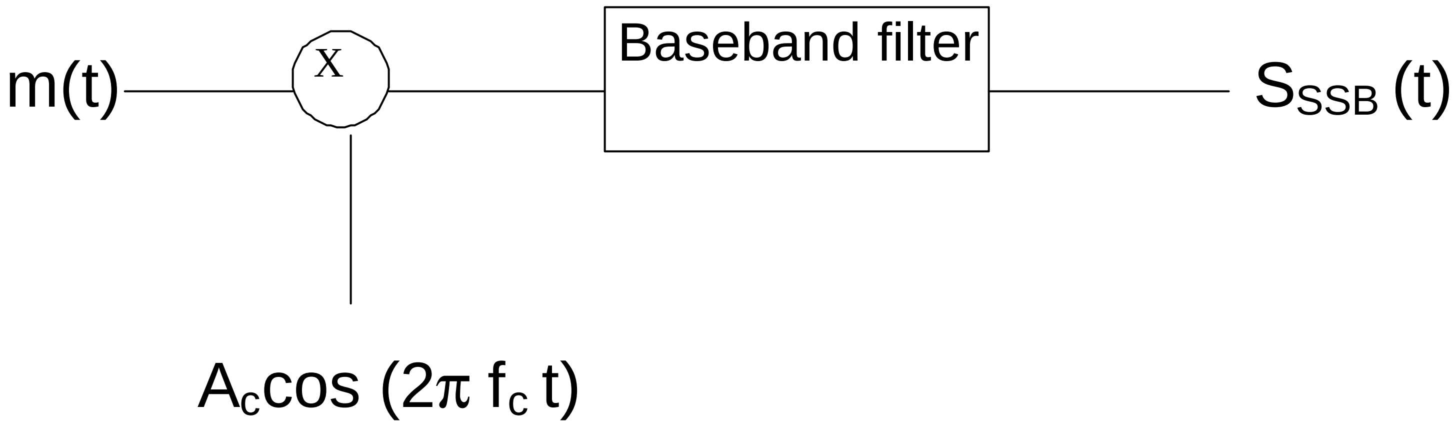
- Hilbert transform of m(t)

  $H(f) = -j , f > 0$

  $H(f) = +j, f < 0$

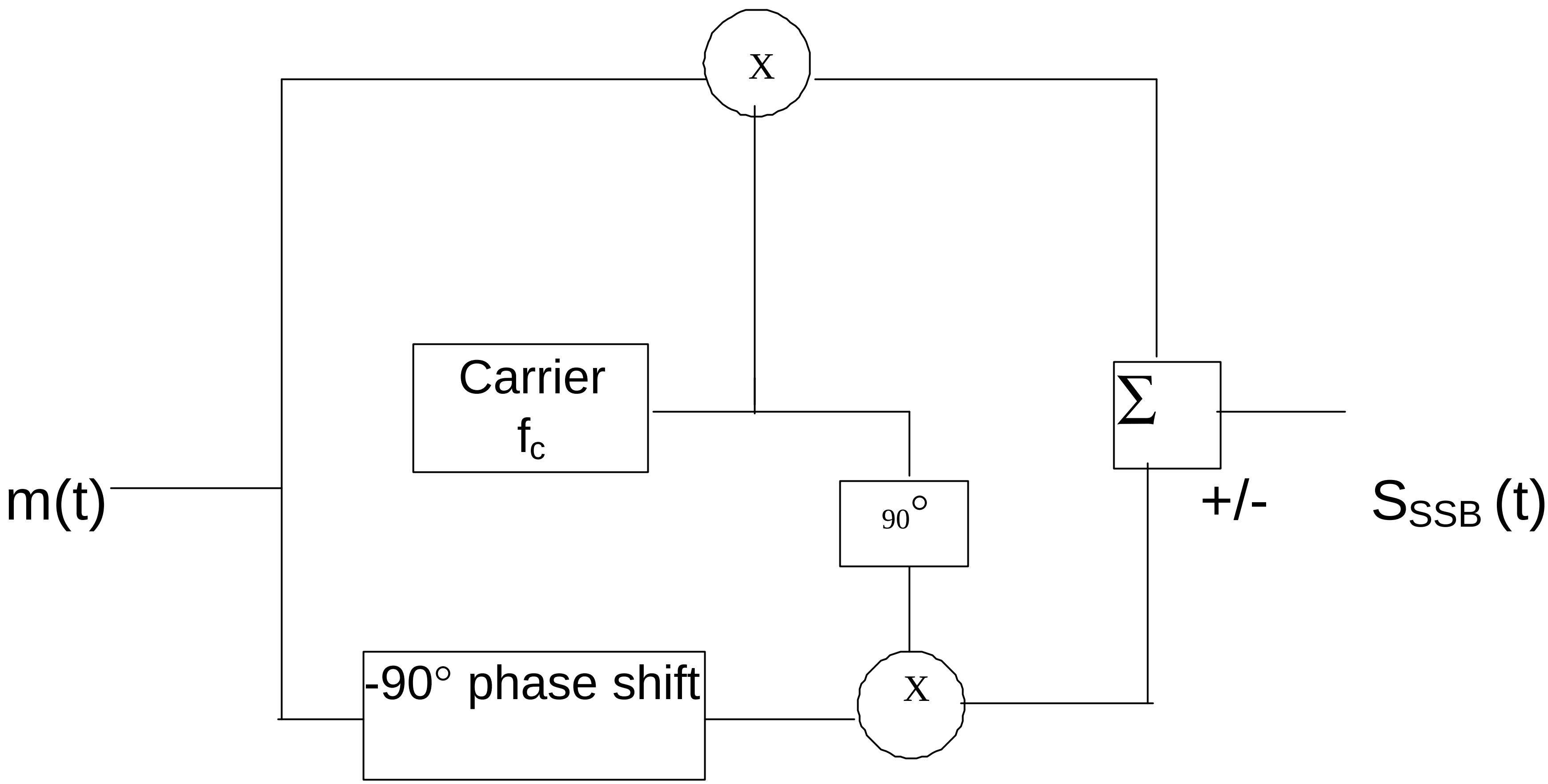
SSB Generation

Filter Method



- Baseband filter passes only one of the sidebands- upper or lower

Balanced Modulator



Properties of SSB

- Bandwidth = f_m
- Bandwidth of SSB is very efficient
- However, Doppler spreading and Rayleigh fading can shift the signal spectrum, causing distortion.
- Frequency of the receiver oscillator must be exactly the same as that of the transmitted carrier f_c. If not, this results in a frequency shift $f_c \pm \Delta f$, causes distortion.

Solution - Pilot Tone SSB

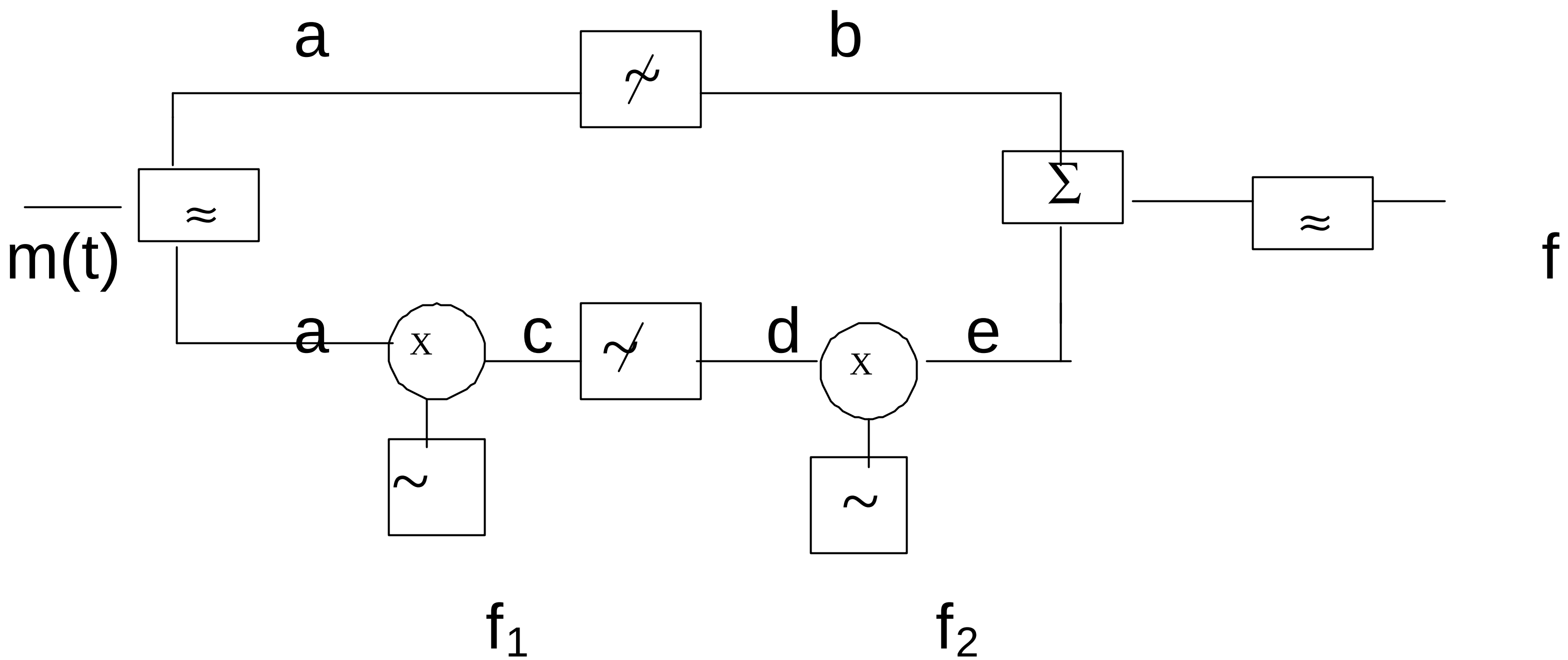
- Transmit a low level pilot tone along with the SSB signal

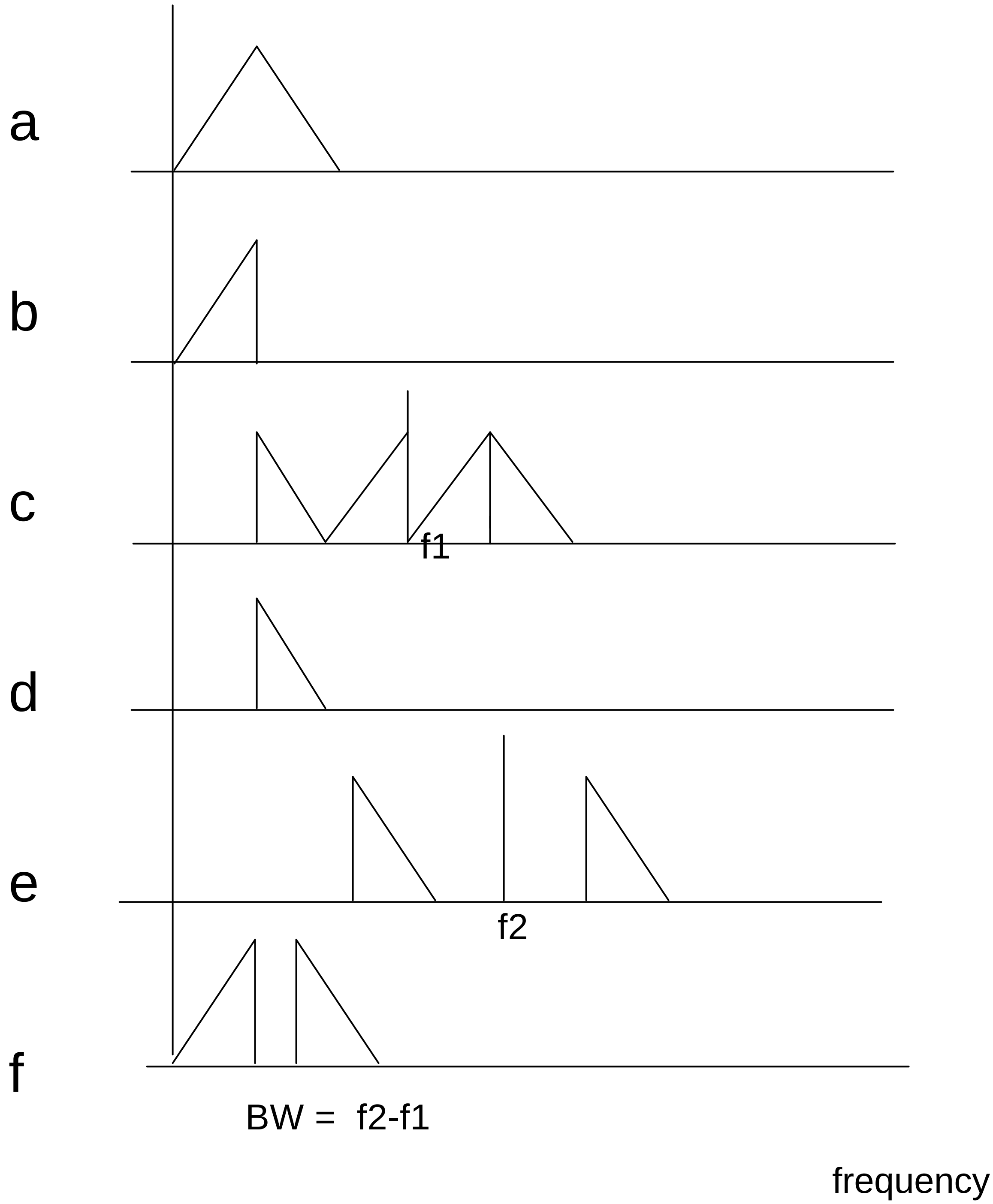
- The pilot tone has information on the frequency and amplitude of the carrier.

- The pilot tone can be tracked using signal processing FFSR - Feed Forward Signal Regeneration.

- Keeping the phase and amplitude of the pilot as reference, the phase and amplitude distortion in the received sidebands can be corrected.

TTIB (Transparent Tone In-Band) System




a
b
c
f1
d
e
f2
f
BW = f2-f1
frequency

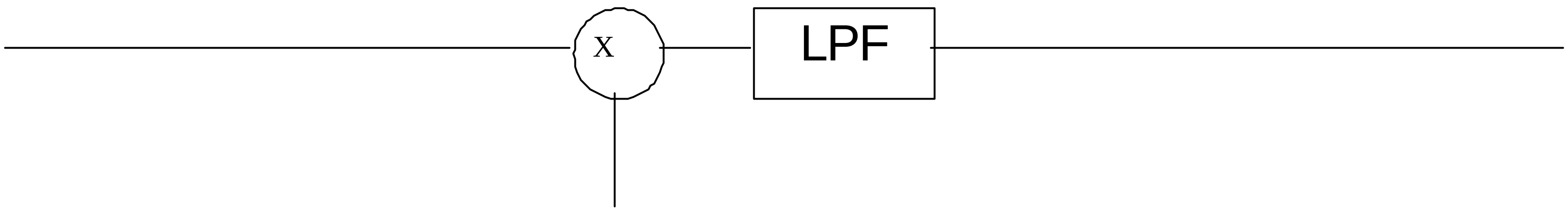
Properties of TTIB system

- Tone frequency is transparent to data => avoids overlap with audio frequency
- Baseband signal is split into two equal width segments
- Small portion of audio spectrum is removed and a low-level pilot tone is inserted in its place.
- This procedure maintains the low bandwidth of the SSB signal
- Provides good adjacent channel protection

Demodulation of AM signals

Coherent Demodulation

$S_{AM} = R(t) \cos(2\pi f_c t + \theta_r)$ $V_{OUT}(t) = 0.5 A_0 R(t) \cos(\theta_r - \theta_0)$



$A_0 \cos(2\pi f_c t + \theta_0)$

- Coherent demodulation requires knowledge of the transmitted carrier frequency and phase at the receiver.

Non-coherent Demodulation

Envelope Detectors

Frequency Modulation

- Message signal m(t)

- FM signal

$$S_{FM}(t) = A_c \cos[2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(t)\, dt]$$

- Power in FM signal $P_{FM} = A_c^2/2$

- Frequency modulation index $\beta_f = k_f A_M / W = \Delta f / W$

  W = Highest frequency component in message signal m(t)
  A_M = Peak value of modulating signal m(t)

Phase Modulation

- PM signal $S_{PM}(t) = A_c \cos[2\pi f_c t + k_\theta m(t)]$
- Phase modulation index $\beta_\theta = k_\theta A_M$
- Power in PM signal: $P_{PM} = A_c^2 / 2$

Bandwidth $B_T = 2\Delta f$

FM modulation/demodulation methods

FM Modulation

- Direct Method – VCO
- Indirect Method – Armstrong

FM Detection

- Slope Detection
- Zero Crossing Detection
- PLL for FM Detection
- Quadrature Detection

Comparison between AM and FM

FM	AM
• FM signals are less susceptible to atmospheric noise, because information is stored as frequency variations rather than amplitude variations.	• AM signals are more susceptible to noise, because information is stored as amplitude variations rather than frequency variations.
• The modulation index can be varied to obtain greater SNR (6dB for each doubling in bandwidth)	• Modulation index cannot be changed automatically.
• FM signals occupy more bandwidth	• AM signals occupy lesser bandwidth.
• Efficient Class C amplifiers	• Class A or AB amplifiers

Trade off between SNR and Bandwidth in an FM signal

- SNR at output of a properly designed FM receiver is

$$(SNR)_{out} = 6(\beta_f + 1)\, \beta_f^2\, (\overline{m(t)^2} / A_M)\, (SNR)_{in}$$

- $(SNR)_{in} = \quad [A_c^2/2] / [2N_0(\beta_f + 1)B]$

N_0 = White noise RF power spectral density
B = Equivalent RF bandwidth of BP filter at front end of receiver

Example: For $m(t) = A_m \sin(\omega_m t)$
$(SNR)_{out} / (SNR)_{in} = 3\beta_f^2(\beta_f + 1)$

Digital Modulation

- Advancements in VLSI and DSP have made digital modulation more cost efficient than analog transmission systems.

- **Advantages**
  - Greater noise immunity
  - Easier multiplexing of information (voice, data, video)
  - Can accommodate digital transmission errors, source coding, encryption and equalization.
  - DSP can implement digital modulators, demodulators completely in software.

Basics of digital communications

- In digital wireless communication systems, the message (modulating signal) is represented as a time sequence of symbols or pulses.

- Each symbol has m finite states

  Example m=8

  Each symbol represents n bits of information

  $n = \log_2 m$ bits/symbol = 3

Bandwidth efficiency and Shannon's capacity theorem

- **Bandwidth efficiency** $\eta_B = R / B$ bps/Hz

  R=Data rate in bits/second
  B=Bandwidth occupied by modulated RF signal

- **Shannon's formula**

$$\eta_{Bmax} = C/B = \frac{\text{channel capacity (bits/s)}}{\text{RF bandwidth}}$$

$$= \log_2(1 + S/N)$$

S/N = Signal to noise ratio

<u>Example</u> : For US digital cellular standard, R = 48.6 kbps

RF bandwidth = 30 khz

For SNR = 20 dB = 100

$C = 30000 * \log_2(1 + S/N)$

$= 30000 * \log_2(1 + 100) = 199.75$ kbps

For GSM standard R = 270.833 kbps

C = 1.99 Mbps for S/N = 30 dB

Bandwidth and Power Spectral density(PSD) of Digital signals

Power Spectral density (PSD) of a random signal $w(t)$ is defined as:

$$P_w(t) = \lim_{T \to \infty} \frac{\overline{|W_T(f)|^2}}{T}$$

$$w_T(t) \longleftrightarrow W_T(f)$$

$$w_T(t) = w(t) \quad , -T/2 < t < T/2$$

$$= 0 \quad , \text{elsewhere}$$

PSD of modulated signal

$s(t) = \text{Re}\{ g(t)\, e^{j2\pi f_c t} \}$

$P_s(f) = .25\, [P_g(f - f_c) + P_g(f + f_c)]$

Bandwidth

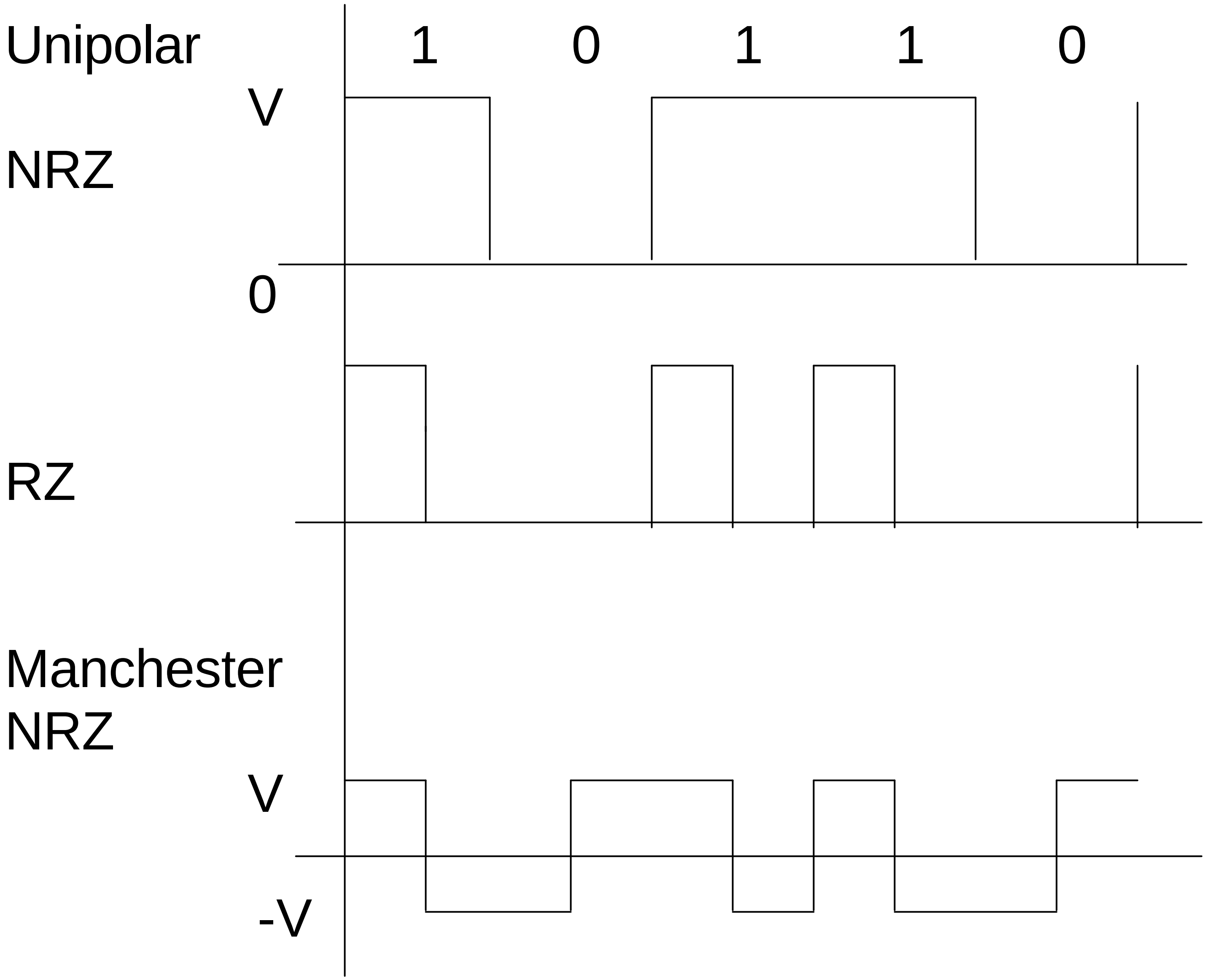
- Absolute Bandwidth
- Null-to-null bandwidth
- Half Power bandwidth (3 dB bandwidth)

Line Coding

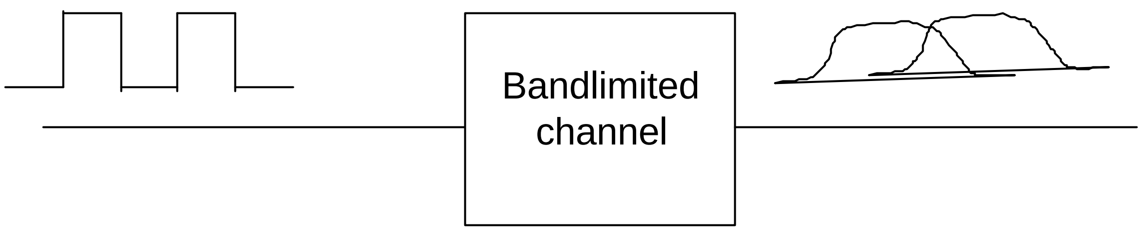
- Line codes are used to provide particular spectral characteristics of a pulse train.

- Most commonly used
  - ◊ Return-to-zero (RZ)
  - ◊ Nonreturn-to-zero (NRZ)
  - ◊ Manchester Code

- Unipolar (0,V) or Bipolar (-V, V)


Unipolar
1
0
1
1
0
V
NRZ
0
RZ
Manchester
NRZ
V
-V

Pulse Shaping Techniques

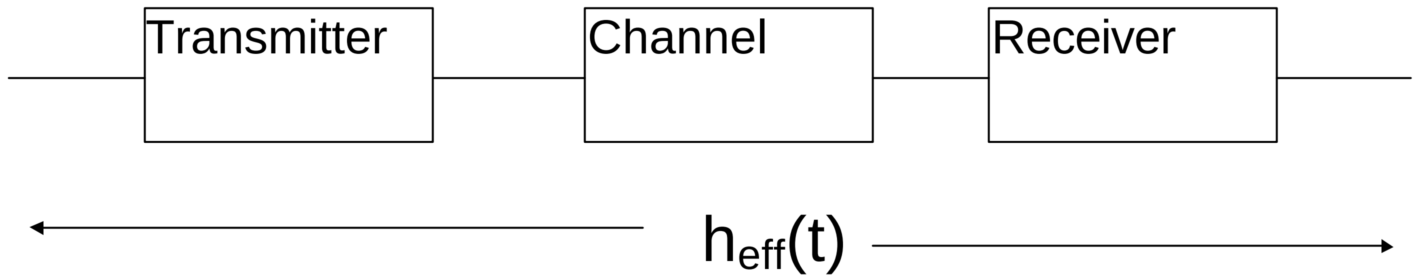


- ISI – Inter symbol interference
  $\Rightarrow$ errors in transmission of symbols

- Pulse shaping techniques $\rightarrow$ reduces the intersymbol effects

Nyquist criteria for ISI cancellation

Condition for impulse response for overall communication system



$$h_{eff}(nT_s) = \begin{cases} k \text{ (constant)}, & n = 0 \\ 0, & n \neq 0 \end{cases}$$

T_s = symbol period

k = non zero constant