Principles of Communications Lecture 7: Analog Modulation Techniques (5)

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Outlines

- Linear Modulation
- Angle Modulation
- Interference
- Feedback Demodulators
- Analog Pulse Modulation
- Delta Modulation and PCM
- Multiplexing

Analog Pulse Modulation

- Message waveform is represented by regularly spaced sample values (sample signals) – discrete in time.
- Historically, these methods are the early attempts to achieve modern communications. They are in the twilight zone between analog and digital modulations.
- Today, their basic forms can still be found in some electronic components such as ADC.

Analog/Digital Pulse-coded

- ***Analog pulse modulation:*** A pulse train is used as the carrier wave. Some characteristic feature of each pulse (e.g., amplitude, duration, or position) is used to represent message samples.

  PAM – pulse amplitude

  PDM – pulse duration

  PPM – pulse position

- ***Digital Pulse Modulation:*** Messages are discrete-amplitude (finite levels) samples.

  DM – delta modulation

  PCM – pulse-code modulation

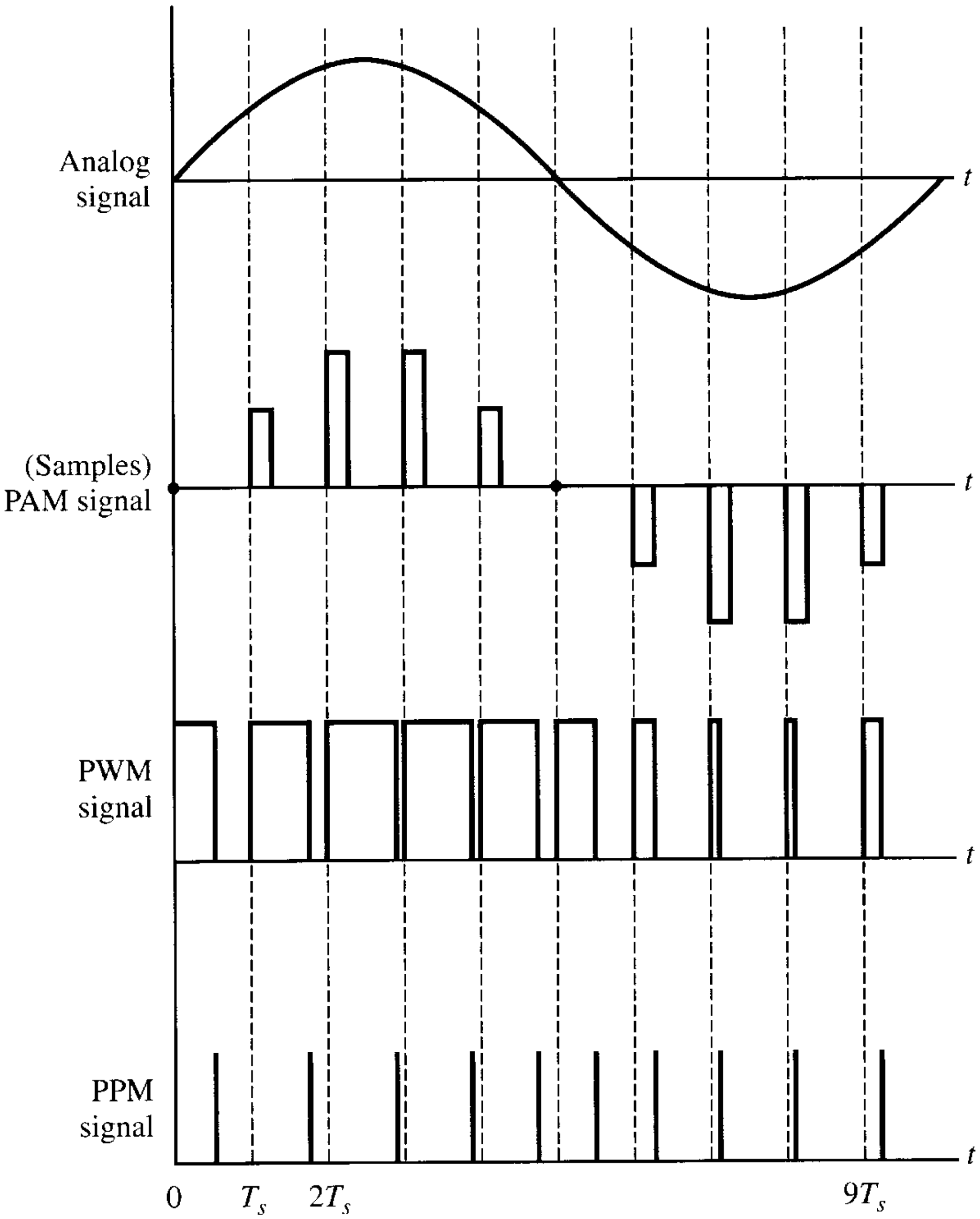


Figure 3.56
Illustration of PAM, PWM, and PPM.

Pulse-Amplitude Modulation (PAM)

- The amplitude of each pulse corresponds to the value of the message signal $m(t)$ (at the leading edge of the pulse).

$$m_c(t) = \sum_{n=-\infty}^{\infty} m(nT_S) \cdot \Pi\left[\frac{t-(nT_S+0.5\tau)}{\tau}\right]$$

$$\text{where } \Pi\left(\frac{t}{W}\right) = \begin{cases} 1, & |t| < W/2 \\ 0, & \text{otherwise} \end{cases}$$

- The *pulse generator* can be considered as a “filter”.

$$\begin{cases} m_c(t) = m_\delta(t) * h(t), & h(t) = \Pi\left[\frac{t-0.5\tau}{\tau}\right] \\ M_c(f) = M_\delta(f) \cdot H(f), & H(f) = \tau \cdot \text{sinc} f\tau \cdot e^{-j\pi f \tau} \end{cases}$$

$$m_\delta(t) = \sum_{n=-\infty}^{\infty} m(nT_s)\delta(t-nT_s) \quad \text{sampled message}$$

PAM Signals

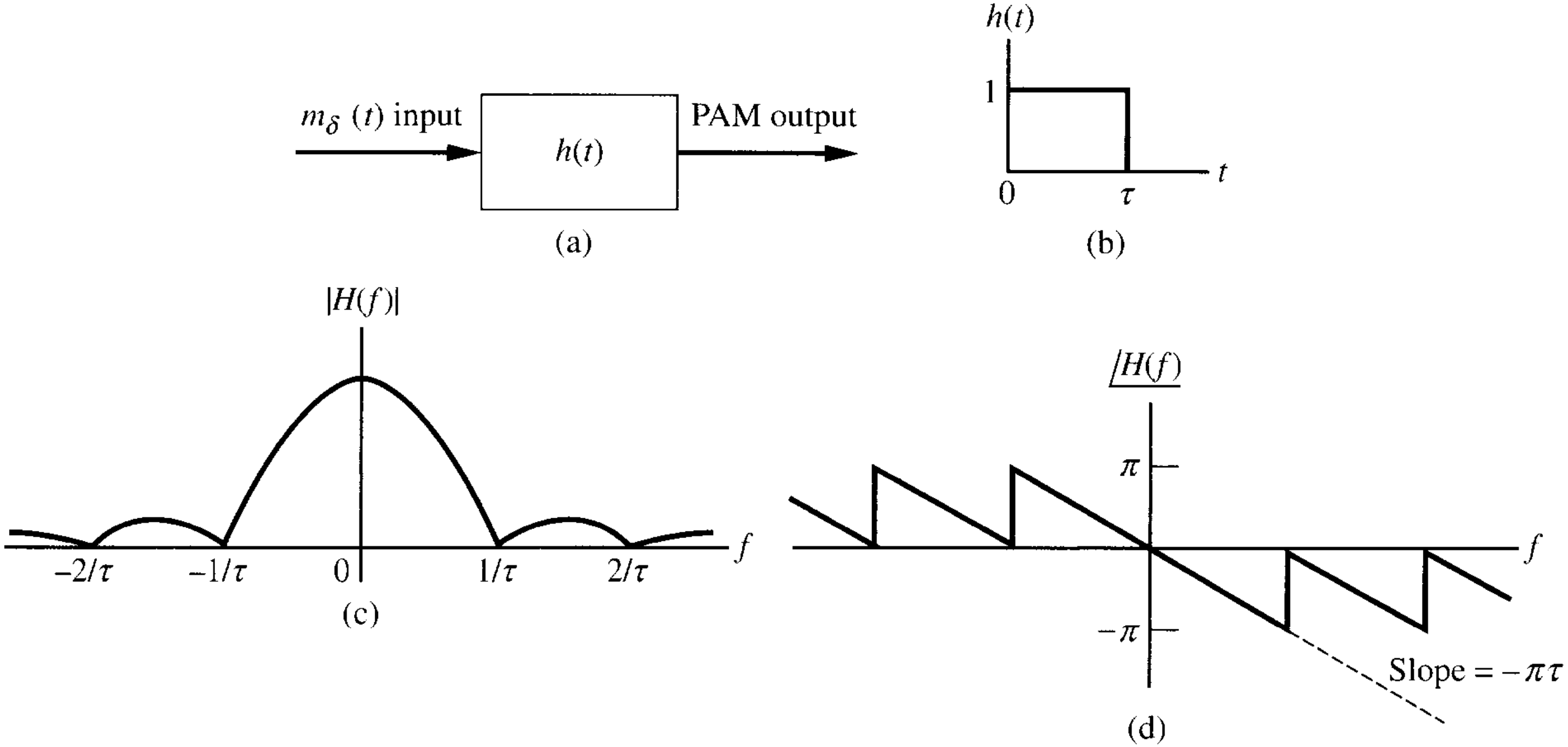
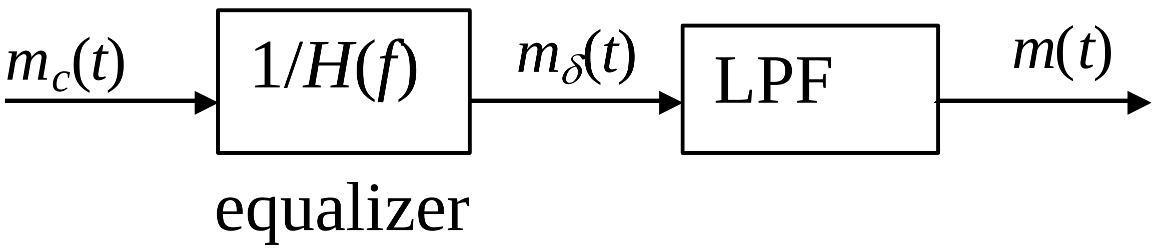


Figure 3.57
Generation of PAM. (a) Holding network. (b) Impulse response of holding network. (c) Amplitude response of holding network. (d) Phase response of holding network.

Demodulation

- Recover $M_\delta(f) \leftrightarrow m_\delta(t)$ samples
- Recover $M(f) \leftrightarrow m(t)$ message

$$M_\delta(f) = \frac{M_c(f)}{H(f)}$$



- ***Equalizer***: Recover distorted signals particularly when the distortion method is known or estimated.

Pulse-Width Modulation (PWM)

- Pulse width ∝ the values of message
- Spectrum: complicated (Fourier-Bessel spectra)

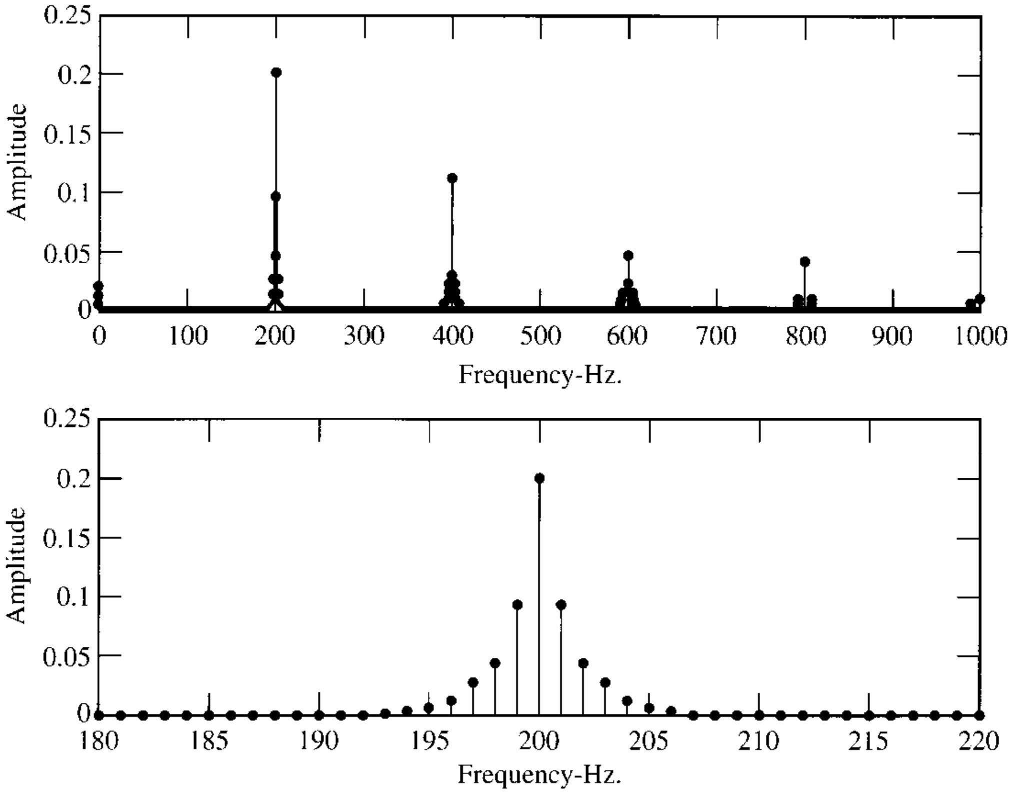


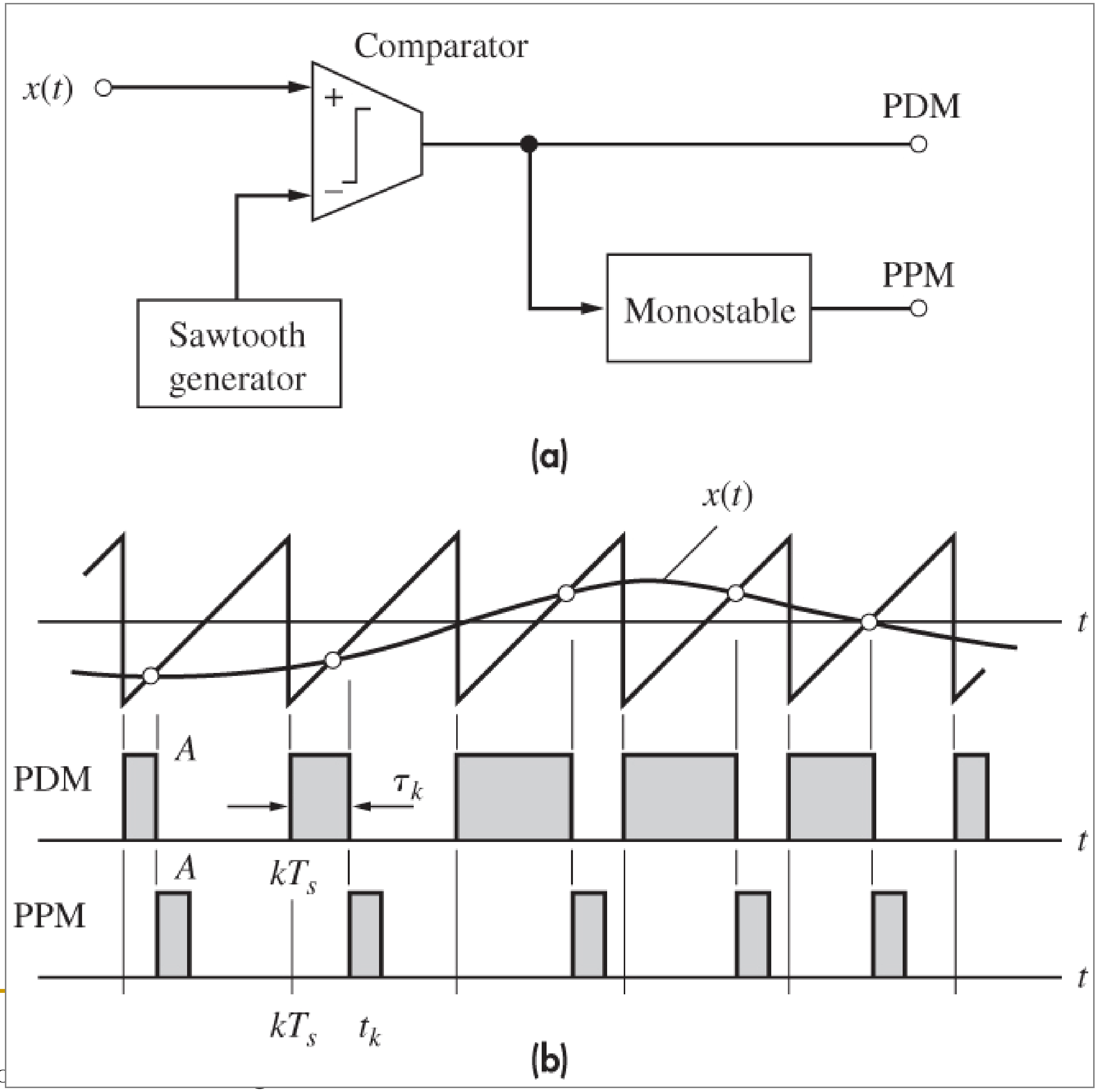
Figure 3.58
Spectrum of a PWM signal. (a) Spectrum for $0 \leq f \leq 1000$ Hz. (b) Spectrum in the neighborhood of $f = 200$ Hz.

PWM/PPM Generation

- Mod: <Carlson, Fig.6-3-2>

- Demod: area of "pulse".

Low-pass filtering (integration)



Pulse-Position Modulation (PPM)

- Pulse position $\propto$ the values of message

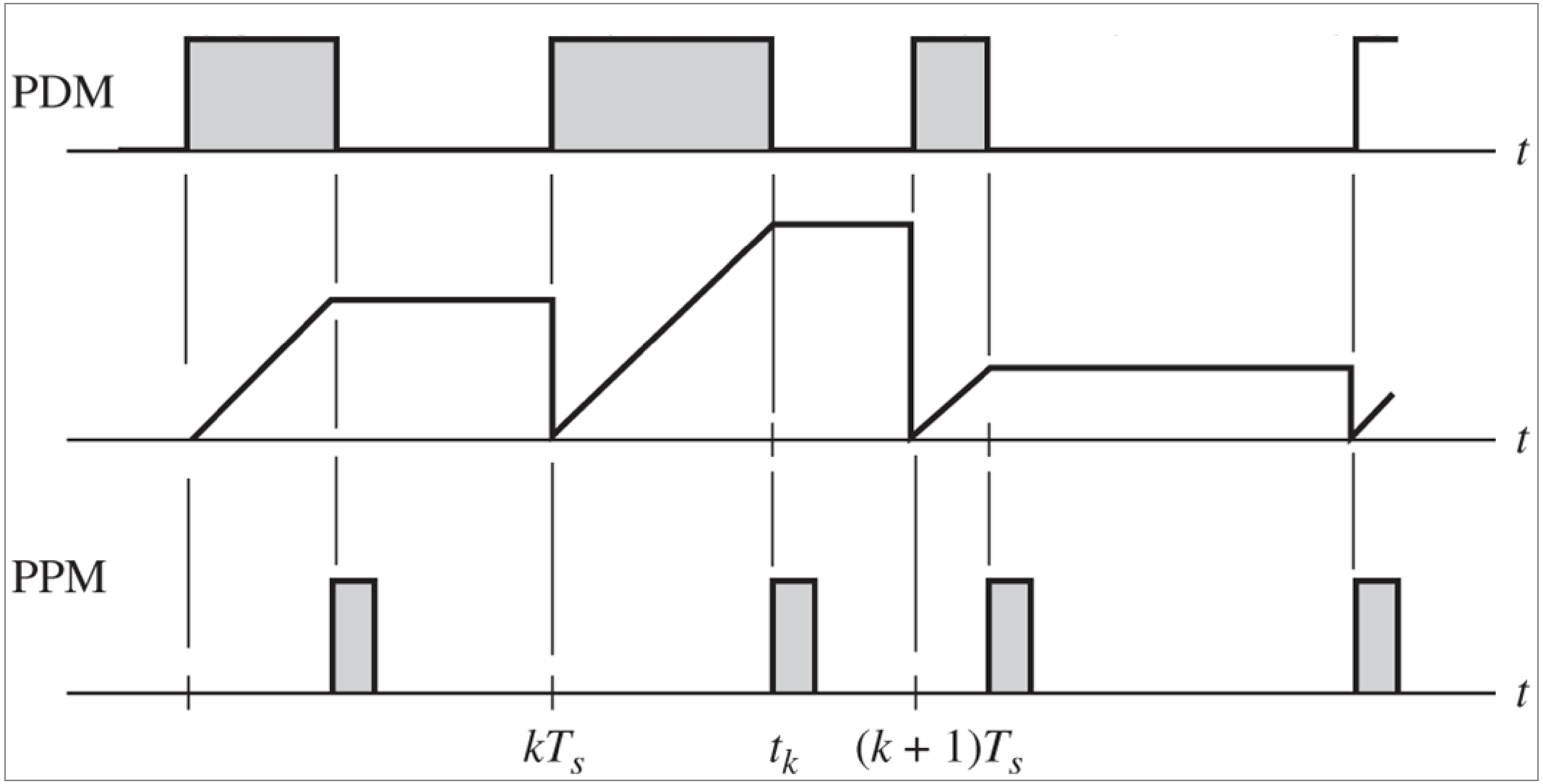
$$x(t) = \sum_{n=-\infty}^{\infty} g(t - t_n)$$

- Spectrum: complicated
- Demodulation: (1) LPF & integration

  (2) convert PPM to PWM $\rightarrow$ LPF
- Conversion of PPM or PWM to PAM: a ramp generator (re)starts at kT_s and stops at t_k. (next page)

Conversion Between PWM & PPM

<Carlson, Fig.6-3.3> (integration)



Delta Modulation

- $m(t) \to$ samples (analog amplitude) $\to$ difference $\to$ binary

  or $m(t) \to$ difference $\to$ binary $\to$ samples
- Operations:

(1) $d(t) = m(t) - m_s(t)$

(2) $\Delta(t) = threshold(d(t)) = \begin{cases} \delta_0, & d(t) \geq 0 \\ -\delta_0, & d(t) < 0 \end{cases}$

(3) $x_c(t) = \text{samples of } \Delta(t) = \Delta(t) \cdot \sum_{n=-\infty}^{\infty} \delta(t - nT_s) = \sum_{n=-\infty}^{\infty} \Delta(nT_s)\delta(t - nT_s)$

(4) $m_s(t) = \sum_{n=-\infty}^{\infty} \Delta(nT_S) \int^{t} \delta(\alpha - nT_S) d\alpha$

DM Signal Generation

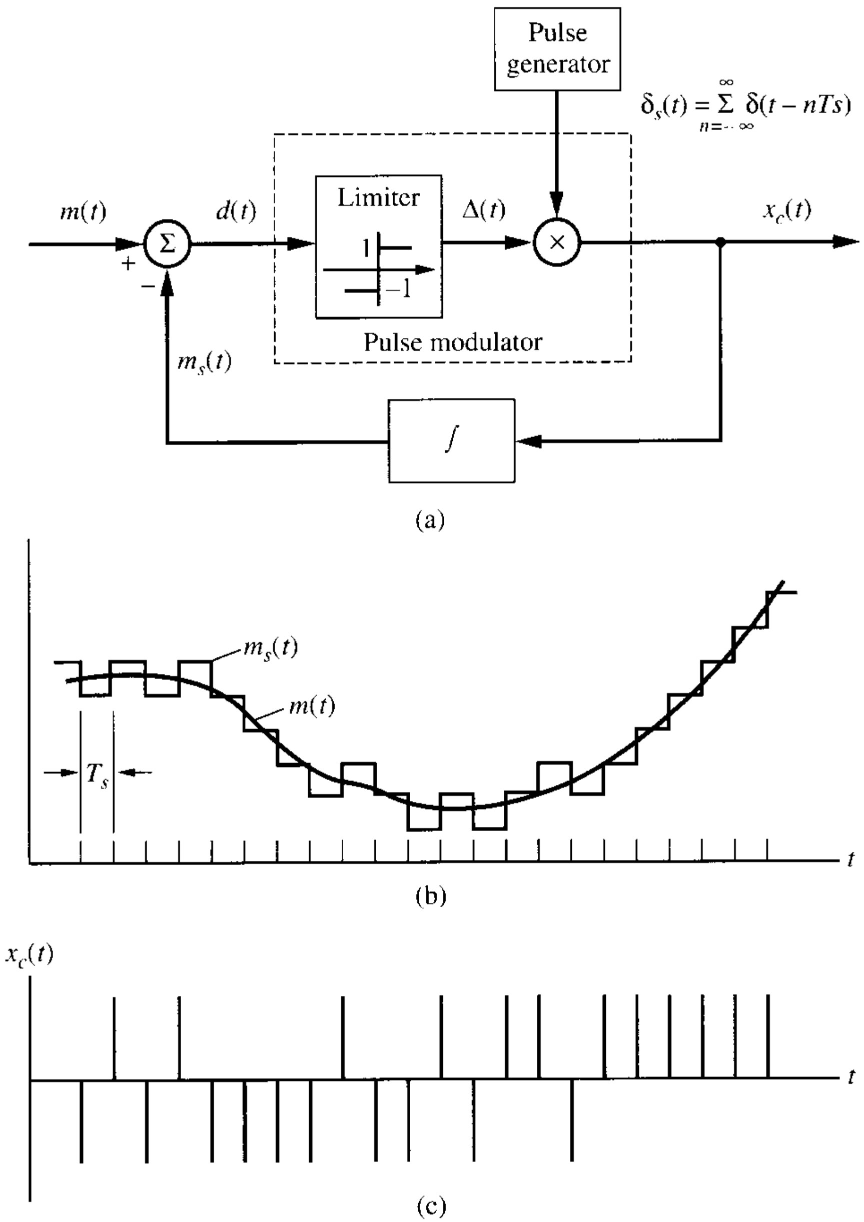


Figure 3.59
Delta modulation. (a) Delta modulator. (b) Modulation waveform and stairstep approximation. (c) Modulator output.

Slope Overload

- The message signal *m*(*t*) has a slope greater than can be followed by the stair-step approximation $m_s(t)$.
- Assume step-size = $\delta_0 \rightarrow$ slope (max) = δ_0/T_s

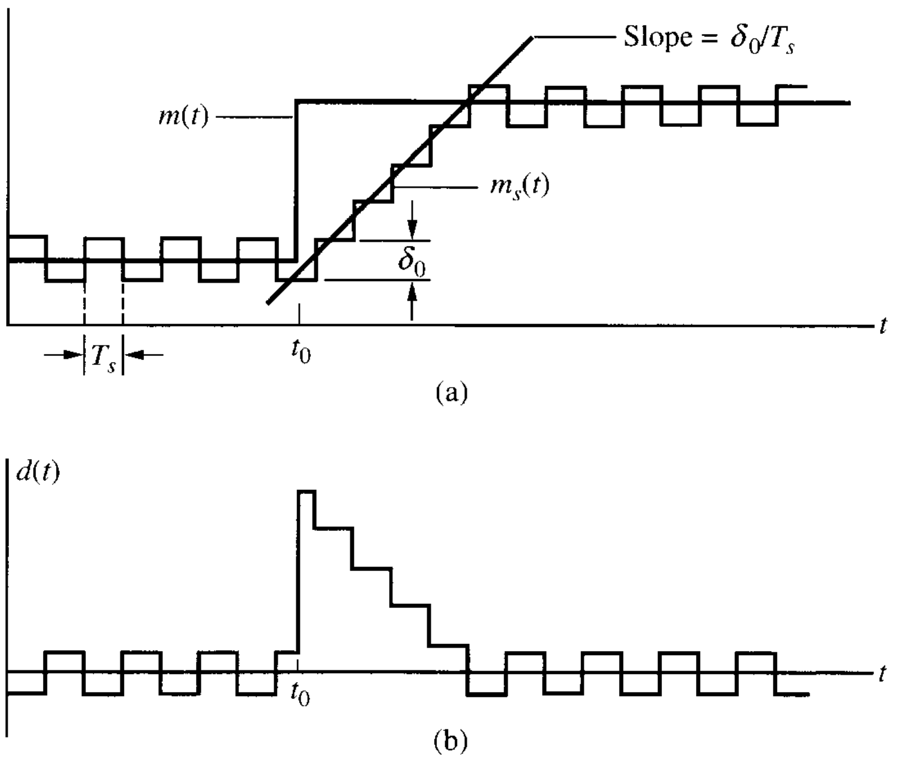


Figure 3.60
Illustration of slope overload.
(a) Illustration of $m(t)$ and $m_s(t)$ with step change in $m(t)$. (b) Error between $m(t)$ and $m_s(t)$.

Solution to Overload

- **Adaptive delta modulation** -- adjust the step-size δ_0 based on $x_c(t)$.
- *Idea*: If $m(t) \approx$ constant, $x_c(t)$ alternates in sign

  $\Rightarrow$ make $\delta_0 \downarrow$.

  If $m(t) \uparrow$ (or $\downarrow$) rapidly, $x_c(t)$ has the same polarity

  $\Rightarrow$ make $\delta_0 \uparrow$.
- *Method*: Detect the "trend" of signal

Adaptive DM

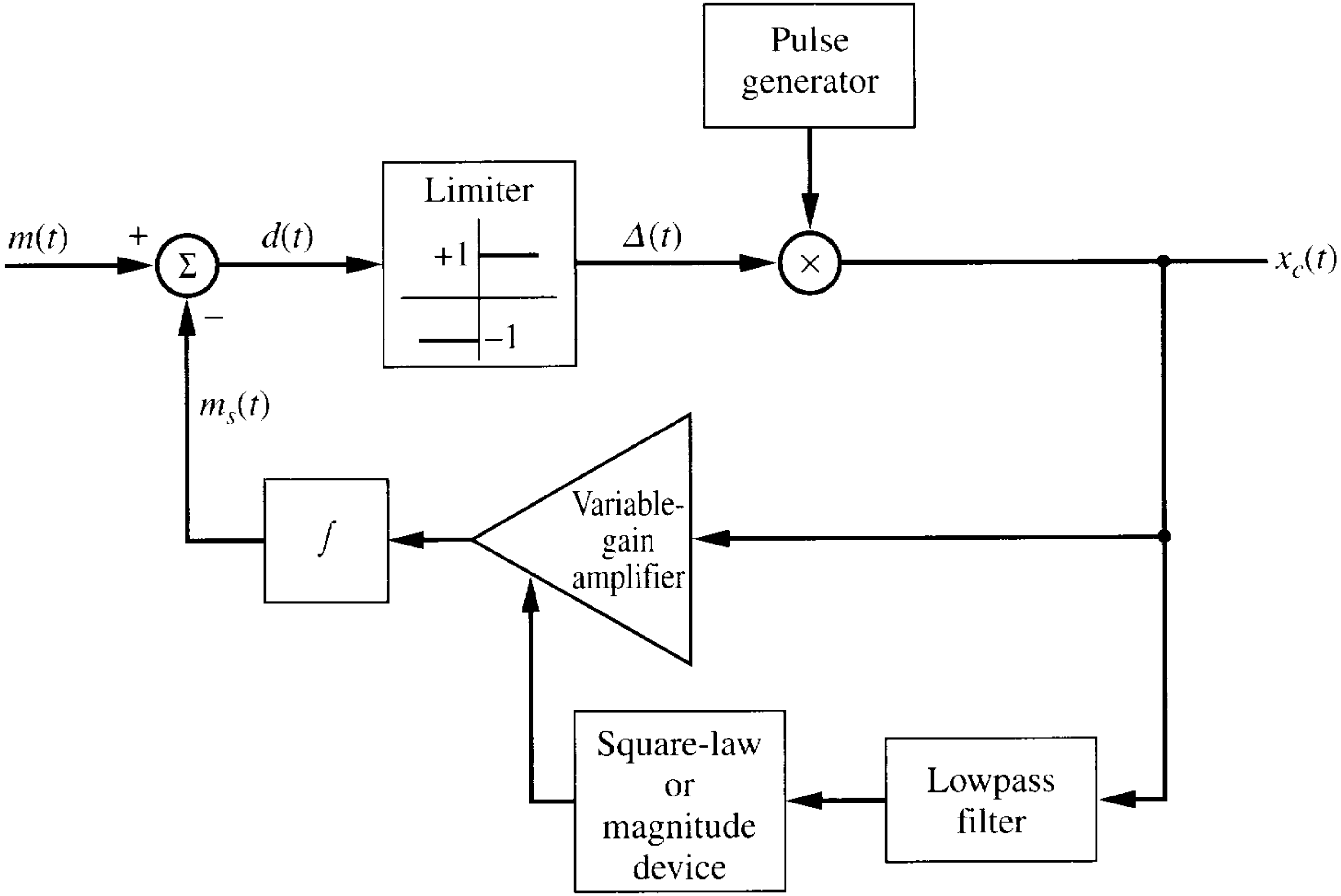


Figure 3.61
Adaptive delta modulator.

ADM Receiver

- Transmit step-size or regenerate the step-size at the receiver according to pre-decided “rules”.

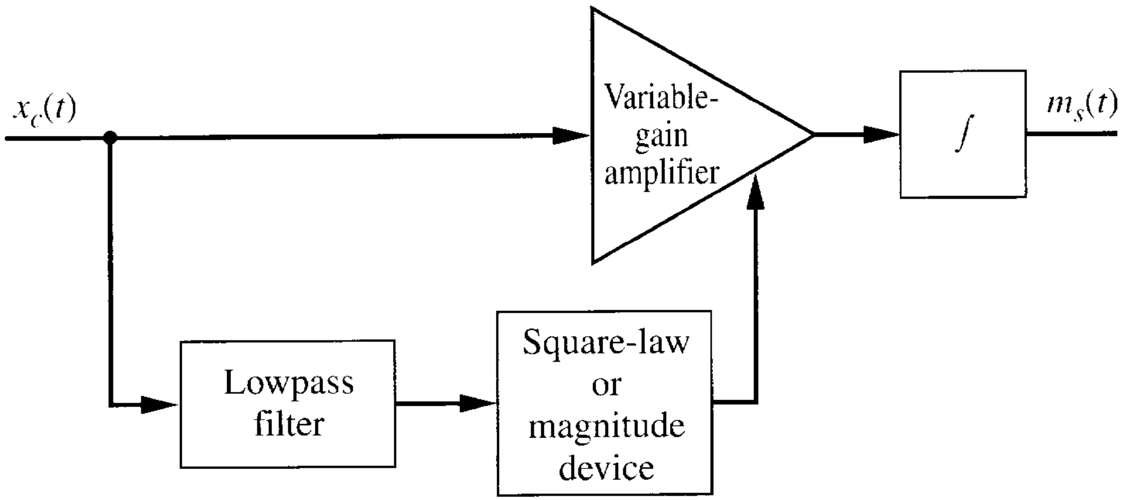


Figure 3.62
Adaptive DM receiver.

Pulse-Code Modulation (PCM)

- $m(t) \rightarrow$ samples (analog amplitude) $\rightarrow$ quantized samples $\rightarrow$ binary representation $\rightarrow$ binary modulated waveform (ASK (AM), PSK (PM), FSK (FM) **to be discussed in Commun.II**)
- Main advantages of digital communication

  – more reliable communication
- Main disadvantages of digital communication

  – wide BW (←reduced by "compression")

  – complicated circuits (← cost reduced by VLSI)

PCM Signal Generation

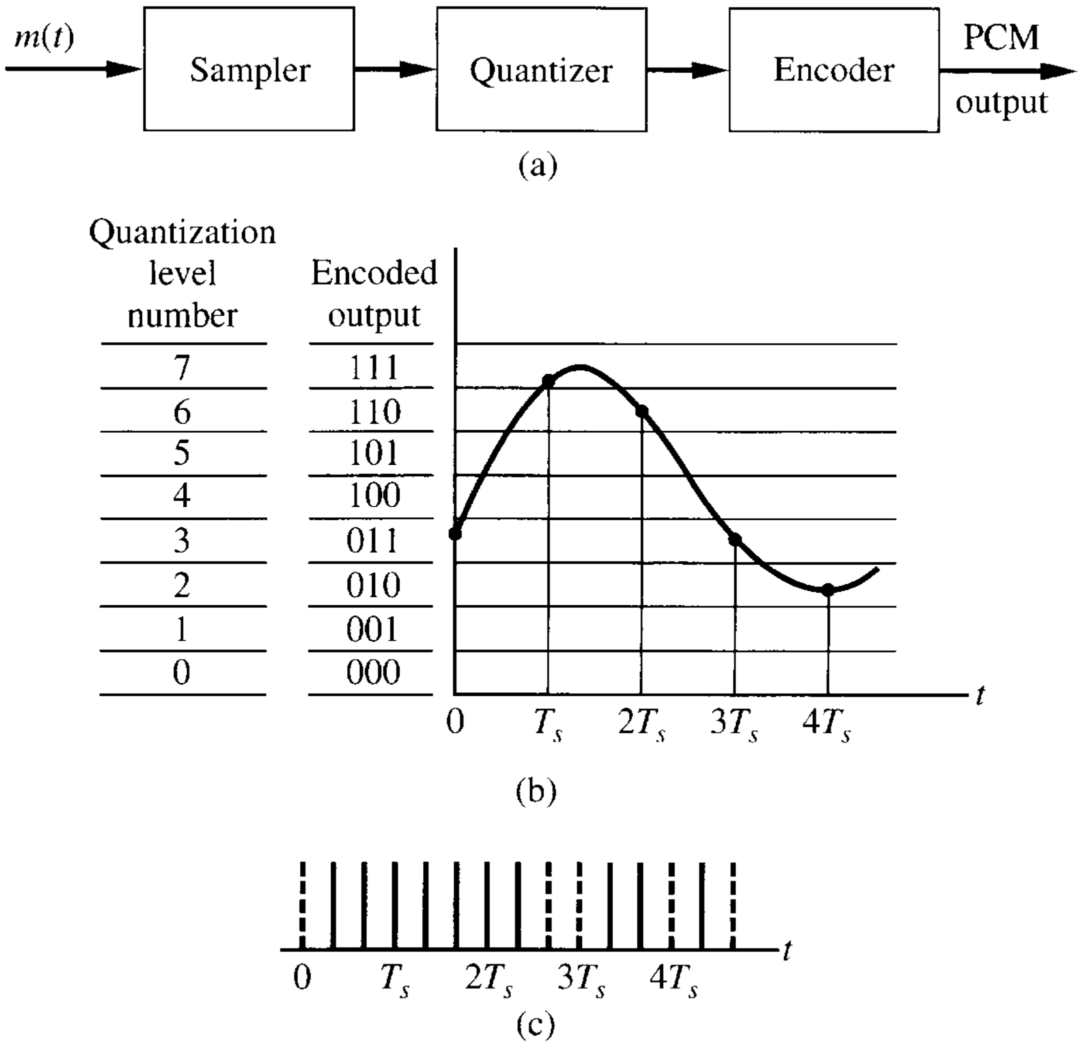


Figure 3.63
Generation of PCM. (a) PCM modulator. (b) Quantization and encoding. (c) Transmitted output.

BW of PCM

- Assume the number of quantization levels=$q=2^n$

  Message BW = W

  Sampling rate = $2W$

  $\Rightarrow$ $2nW$ binary pulses/second
- Assume maximum width of pulse, $\Delta\tau = \dfrac{1}{2nW}$

  $\Rightarrow$ transmission BW $\approx knW$, k=*constant*

  Hence, $B \approx k2W\log_2 q$
- Recovered message error is due to mainly quantization error. Thus, $q\uparrow$ ➔ error$\downarrow$ ➔ $B\uparrow$

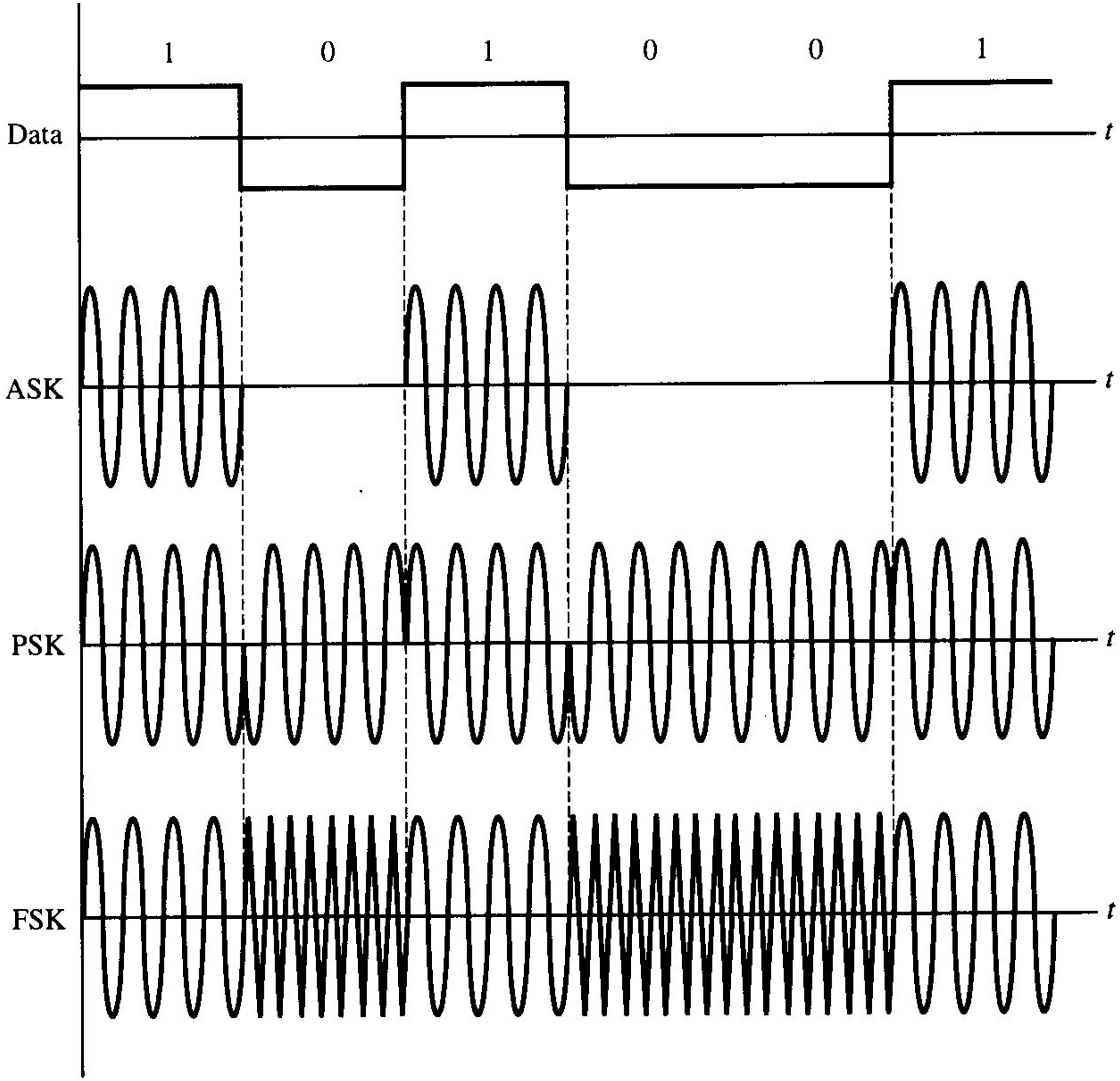


FIGURE 3.66 An example of digital modulation schemes.

Multiplexing

- A number of data sources share the same communication channel.
- Frequency-Division Multiplexing (FDM)
- Quadrature Multiplexing (QM)
- Time-Division Multiplexing (TDM)

FDM

Several message signals are translated, using modulation, to different spectral locations and added to form a baseband signal.

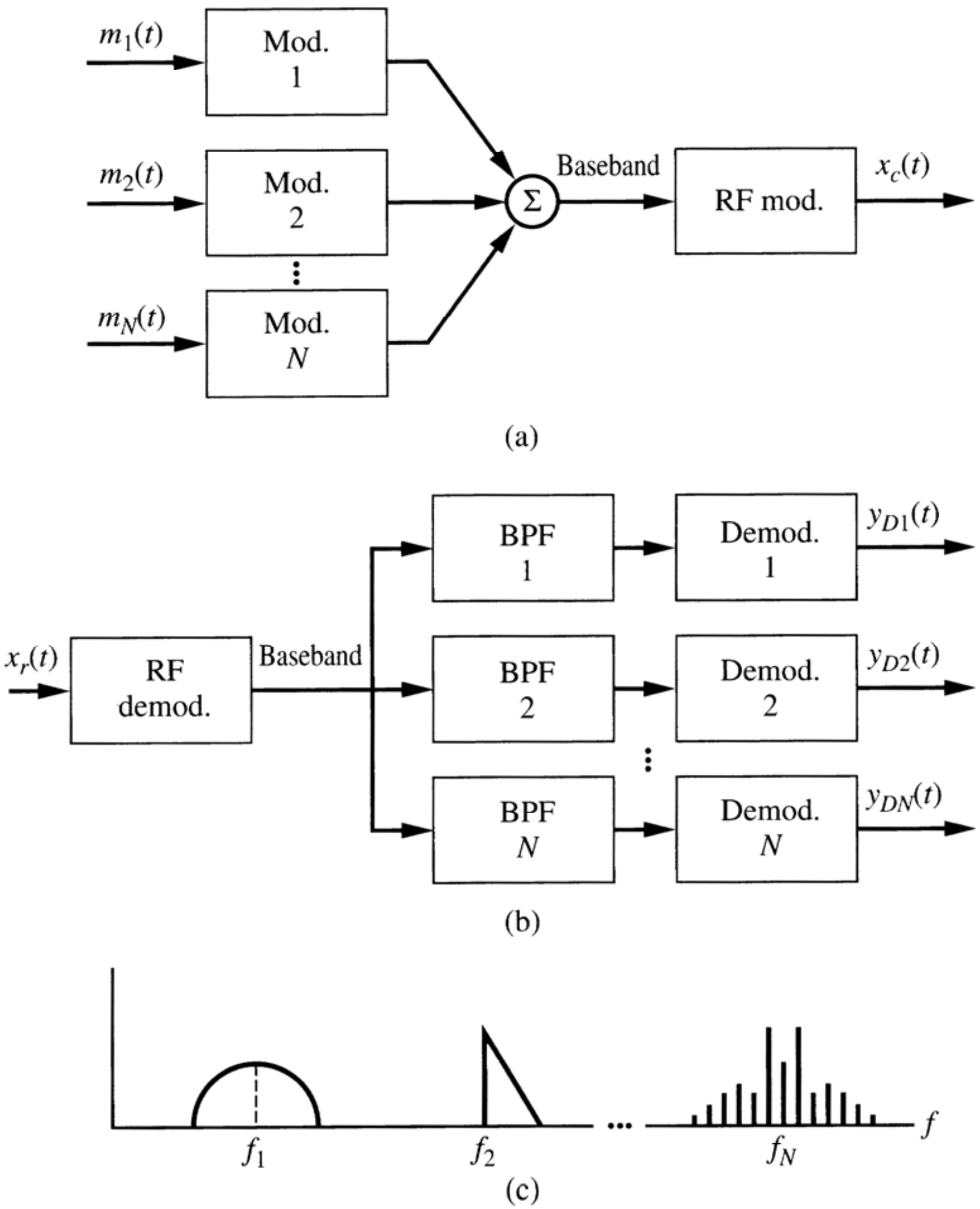


Figure 3.64
Frequency-division multiplexing. (a) FDM modulator. (b) FDM demodulator. (c) Baseband spectrum.

Example: Stereophonic FM

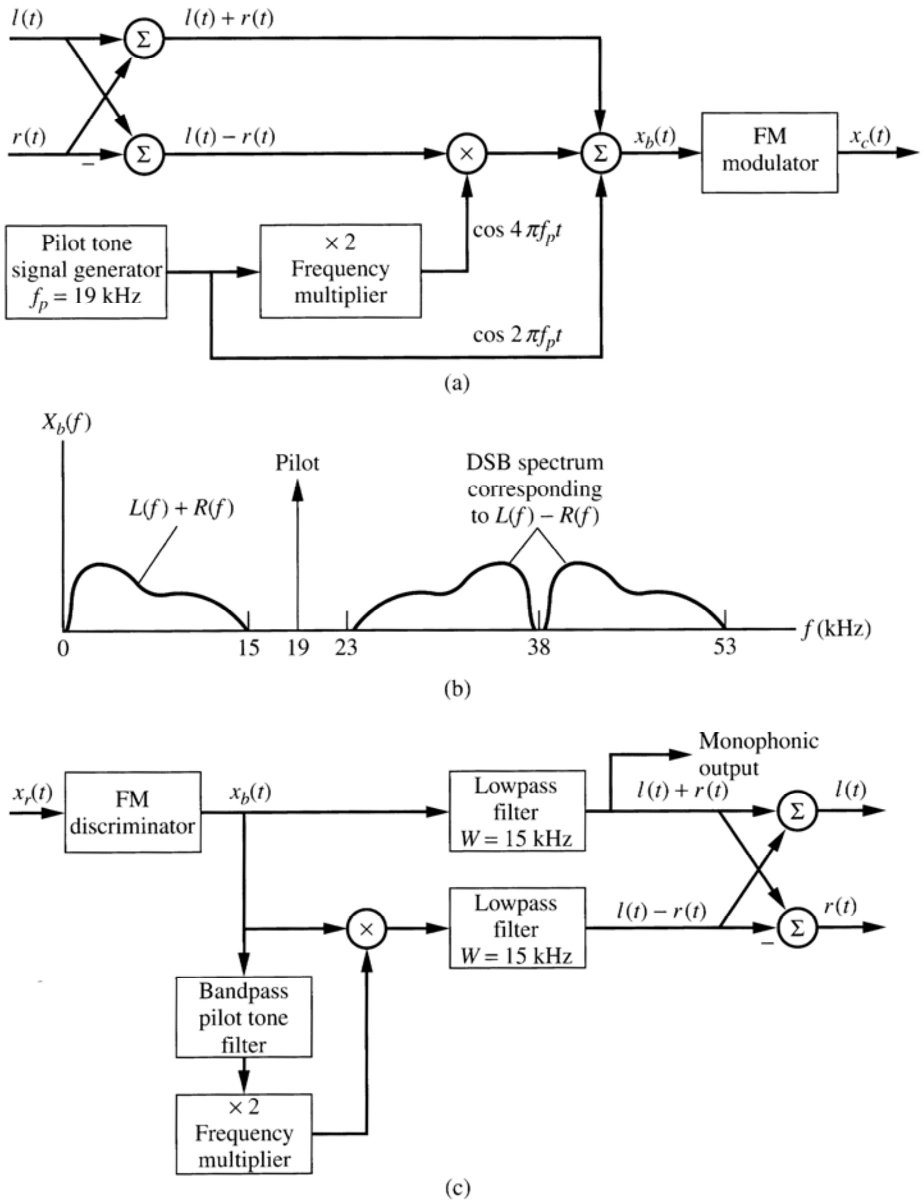


Figure 3.65
Stereophonic FM transmitter and receiver. (a) Stereophonic FM transmitter. (b) Single-sided spectrum of FM baseband signal. (c) Stereophonic FM receiver.

Quadrature Multiplexing (QM)

- Quadrature-carrier multiplexing: transmit two signals on the same carrier frequency. (not exactly FDM)
- Note that cos and sin are orthogonal.
- QM → Quadrature Amplitude Modulation (QAM)

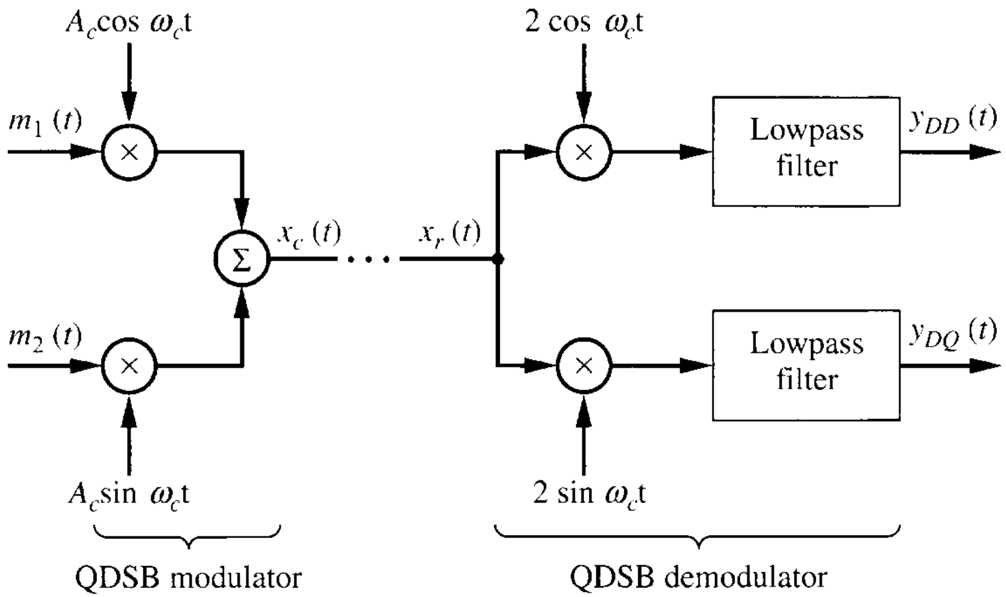


Figure 3.66
Quadrature multiplexing.

<Modulation>

$$x_c(t) = A_C[m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t].$$

<Coherent Demodulation>

If the receiver has a carrier phase error, i.e.,

$$LO(t) = 2\cos(\omega_c t + \theta).$$

$$x_r(t)\cdot 2\cos(\omega_c t + \theta)$$

$$= A_C[m_1(t)\cos\theta - m_2(t)\sin\theta]$$

$$+A_C[m_1(t)\cos(2\omega_c t + \theta) + m_2(t)\sin(2\omega_c t + \theta)].$$

$$\Rightarrow y_{DD}(t) = A_C[m_1(t)\cos\theta - m_2(t)\sin\theta]. \quad (\text{ideal}: \theta \to 0\ )$$

Time-Division Multiplexing (TDM)

- Each message signal occupies a small time slot in every T_s second.

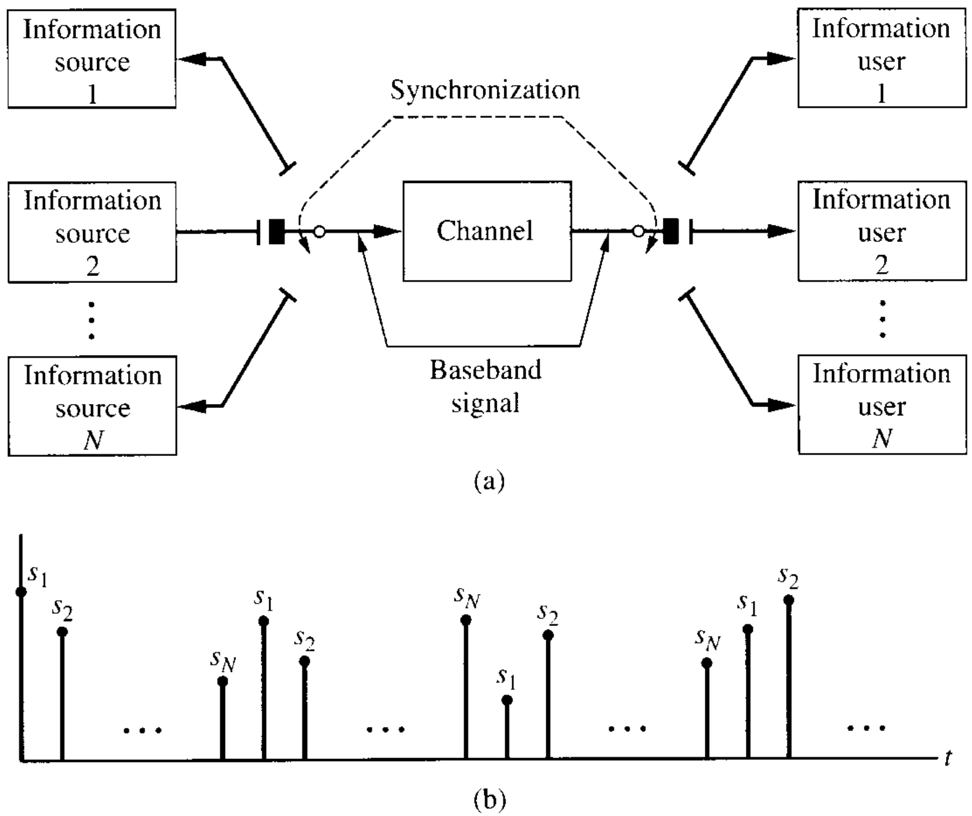


Figure 3.67
Time-division multiplexing. (a) TDM system. (b) Baseband signal.

BW of TDM

- A "rough" estimate of BW

Baseband message BW = W_i. There are N channels.

Samples per T second = $2W_iT$.

Total samples per T second: $n_s = \sum_{i=1}^{N} 2W_iT$. Or,

Total samples per second = $\sum_{i=1}^{N} 2W_i$.

Total baseband BW to accommodate all sources = $B \approx \sum_{i=1}^{N} W_i$.

Example: Digital telephony system

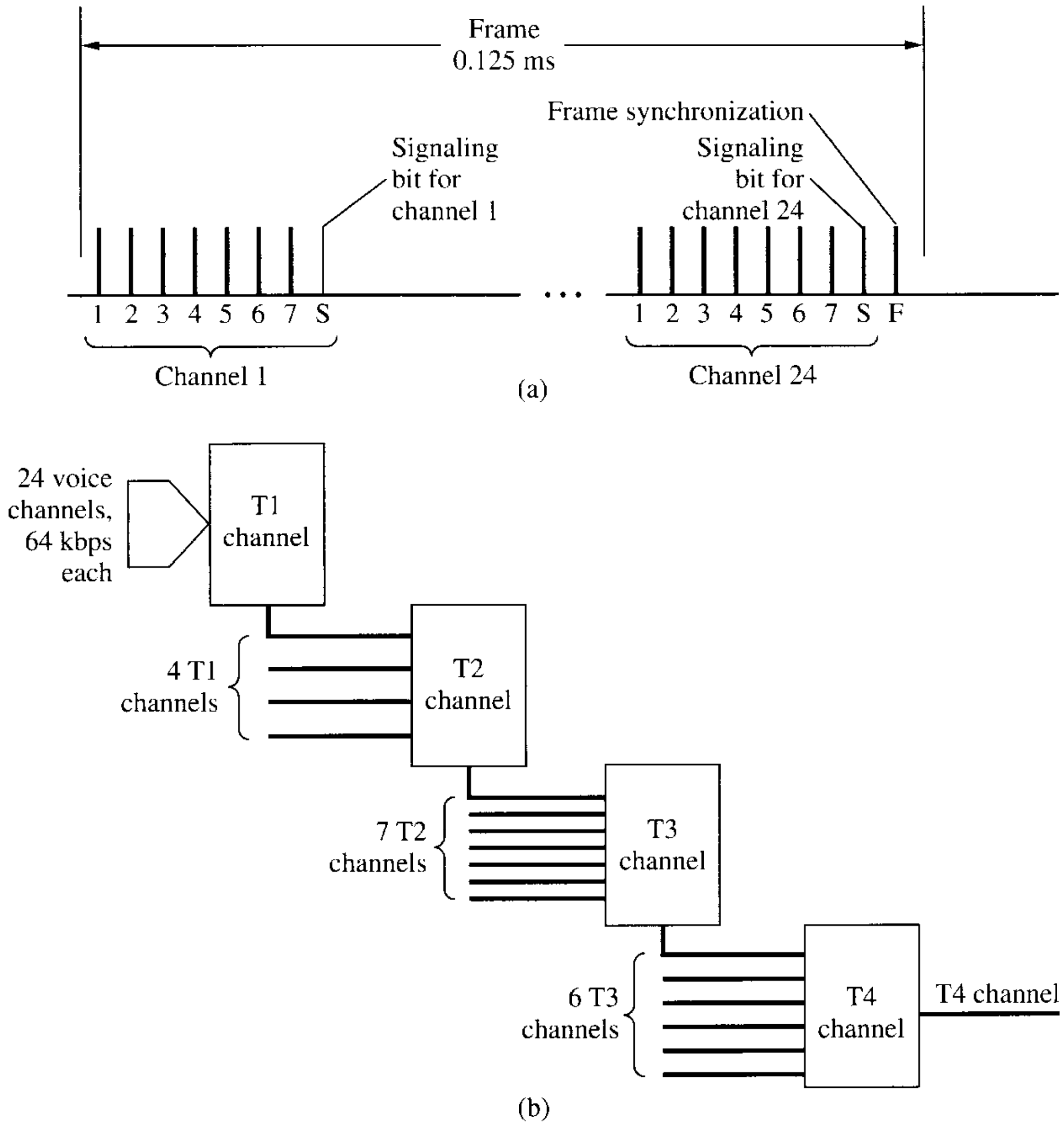


Figure 3.68
Digital multiplexing scheme for digital telephone. (a) T1 frame. (b) Digital multiplexing.

Comparison of MUX

- **FDM**: simple to implement,

  inter-modulation distortion (crosstalk) due to nonlinear channels
- **TDM**: less crosstalk (in memoryless channels),

  difficult to keep synchronization (frame structure, header), "digital" (sampled) signals
- **QM**: efficient use of channel, crosstalk between I & Q channels (needs coherent demodulation)