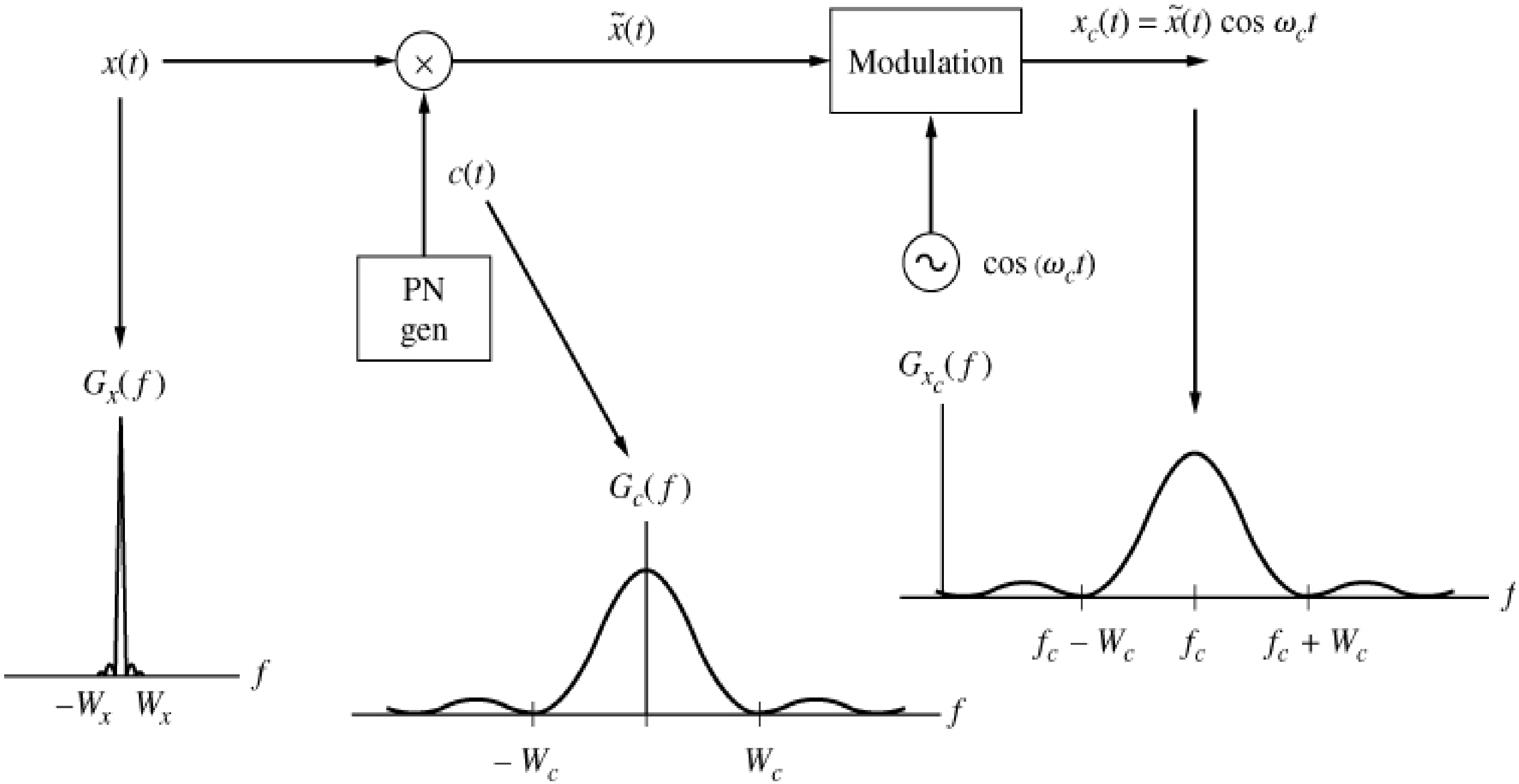
Chapter 15: Spread Spectrum Systems

- Direct-sequence spread spectrum
- Frequency hopping spread spectrum
- Coding
- Synchronization
- Wireless systems
- Ultra wideband systems

Direct-sequence spread spectrum

- Uses PN generator to spread the signal
- Output of PN generator can be a random sequence of $c(t) = \pm 1$ pulses
- To unauthorized listener, signal sounds like random noise $\Rightarrow$ low probability of intercept
- Greater immunity to interference and jamming
  - Multipath
  - Multiple users
  - Jamming
- Usually uses synchronous/correlation detection

DSSS Transmitter



DSSS signal generation

- Message: $x(t)$

$\Downarrow$

- Spreading:

$$\tilde{x}(t) = c(t)x(t)$$

$$\text{where } c(t) = \pm 1$$

$\Downarrow$

- BPSK or DSB modulation:

$$x_c(t) = \tilde{x}(t)\cos\omega_c t$$

Spreading

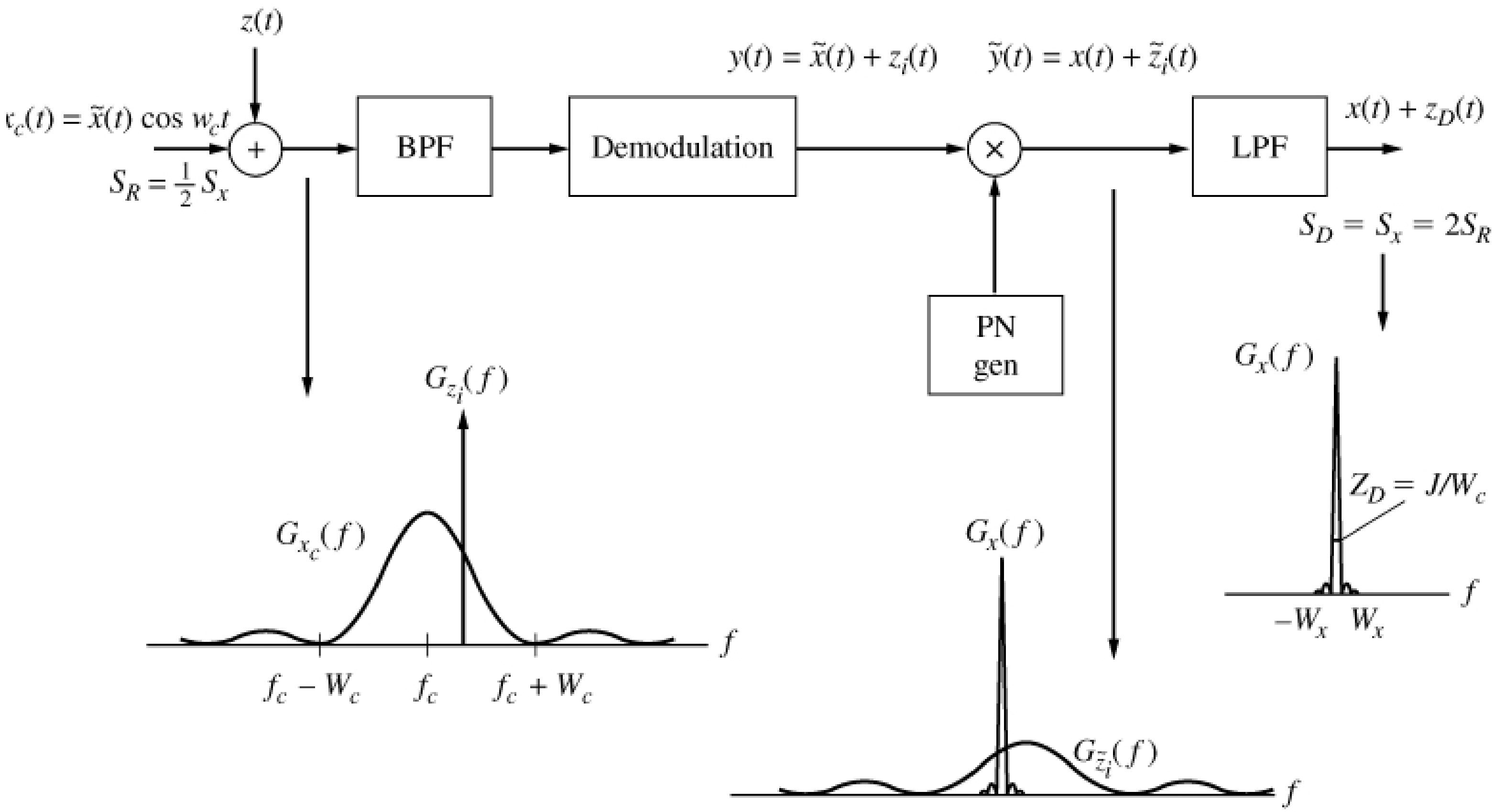
With spreading, message becomes:

$$x(t) \rightarrow x(t)c(t) = \tilde{x}(t)$$

Transmission bandwidth becomes

$$B_T = W_c + W_x$$

DSSS Receiver With Single Tone Jammer Interfering Input



DSSS message recovery

- Received signal: $\tilde{x}(t)\cos\omega_c t + z(t)$

$\Downarrow$

- Demodulation: $y(t) = \tilde{x}(t) + z_i(t)$

$\Downarrow$

$$= x(t)c(t) + z_i(t)$$

- Despreading:

$$\tilde{y}(t) = y(t)c(t) = x(t)c^2(t) + c(t)z_i(t)$$

$$= x(t) + \tilde{z}_i(t)$$

Despreading

Prior to the receiver's detector, we have

$$\tilde{x}(t) = c(t)x(t)$$

At the receiver $\tilde{x}(t) \rightarrow c(t)\tilde{x}(t) \Rightarrow c^2(t)x(t) = x(t)$

since $c^2(t) = 1$

Note: To recover message we require $c^2(t) = 1$

How is the effects of the Jammer Minimized

- The receiver’s PN generator despreads the message
- The receiver’s PN generator spreads the single tone jammer over a wide bandwidth $\Rightarrow$ jammer power is diluted
- Because the jammer signal is spread out, the LPF will remove most of its power but retain the message

Noise and Jamming

- DSSS has the same SNR and *P(error)* as DSB/BPSK systems

Thus, $(S/N)_D = \dfrac{S_R}{N_0 W_x}$ and $P_e = Q\left(\sqrt{\dfrac{2E_b}{N_0}}\right)$

- Jammer power is reduced so $J \to J/W_c \;\Rightarrow \left(S/J\right)_D = \dfrac{W_c S_R}{W_x J}$

- Jammer becomes another noise source $\Rightarrow \; N_J = J/W_c$

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_J}}\right)$$

with white noise $P_e = Q\left(\sqrt{\dfrac{2E_b}{(N_0 + N_J}}\right)$

Multiple Access

- Multiple users and multipath are just another noise source

Thus, with M users

$$P_e = Q\left(\frac{1}{\sqrt{(M-1)/3Pg + N_0/2E_b}}\right)$$

where $Pg = \frac{W_c}{W_x}$

- Unauthorized listener hears just noise
- Unlike TDMA, FDMA, there is no cross talk

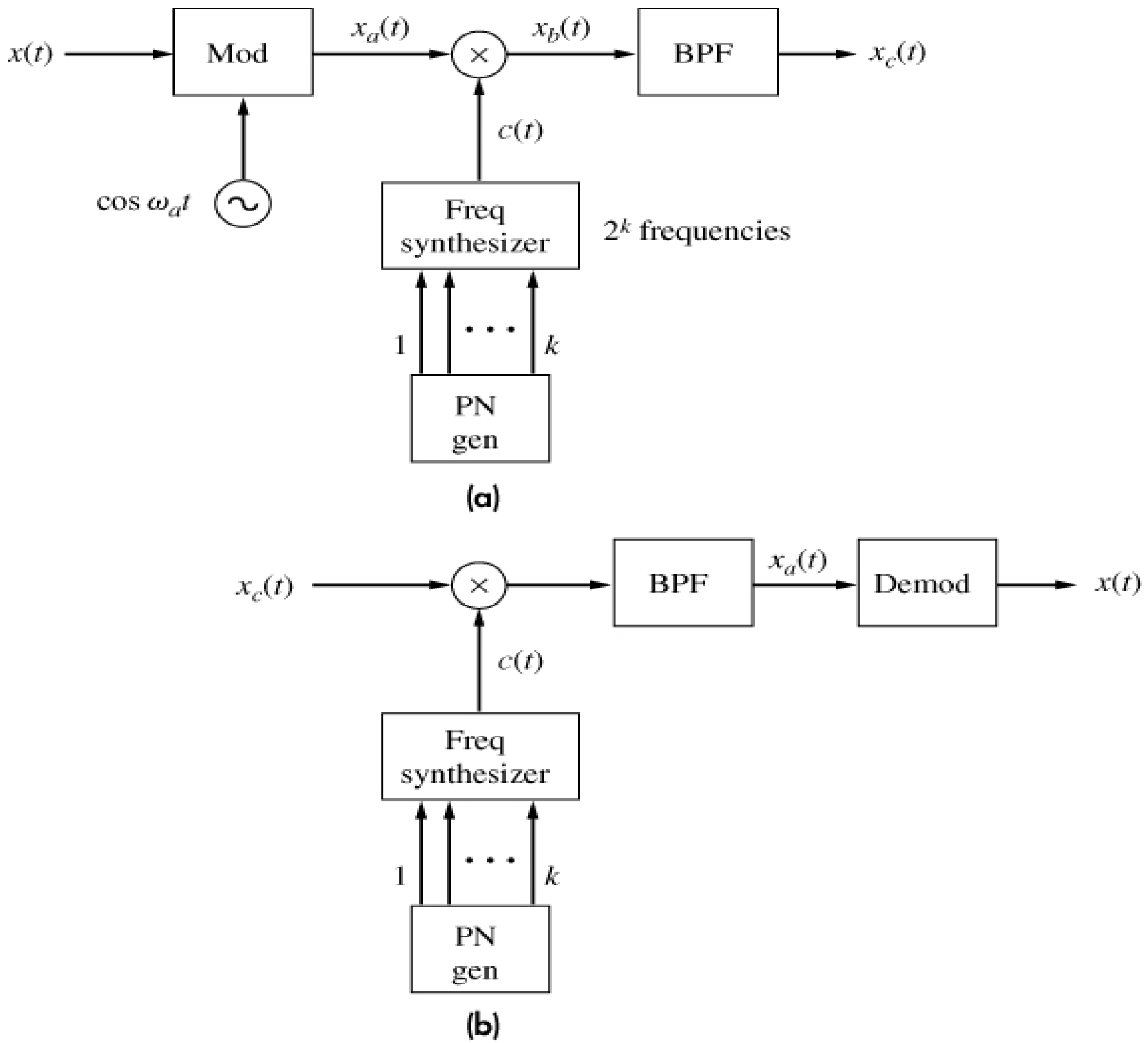
Frequency Hopping Spread Spectrum (FHSS)

- Hops at different frequencies
- Larger frequency spread than DSSS ⇒larger Pg
- Slop hop: multiple symbols/hop
- Fast hop > multiple hops/symbol ⇒ can achieve frequency diversity for greater reliability

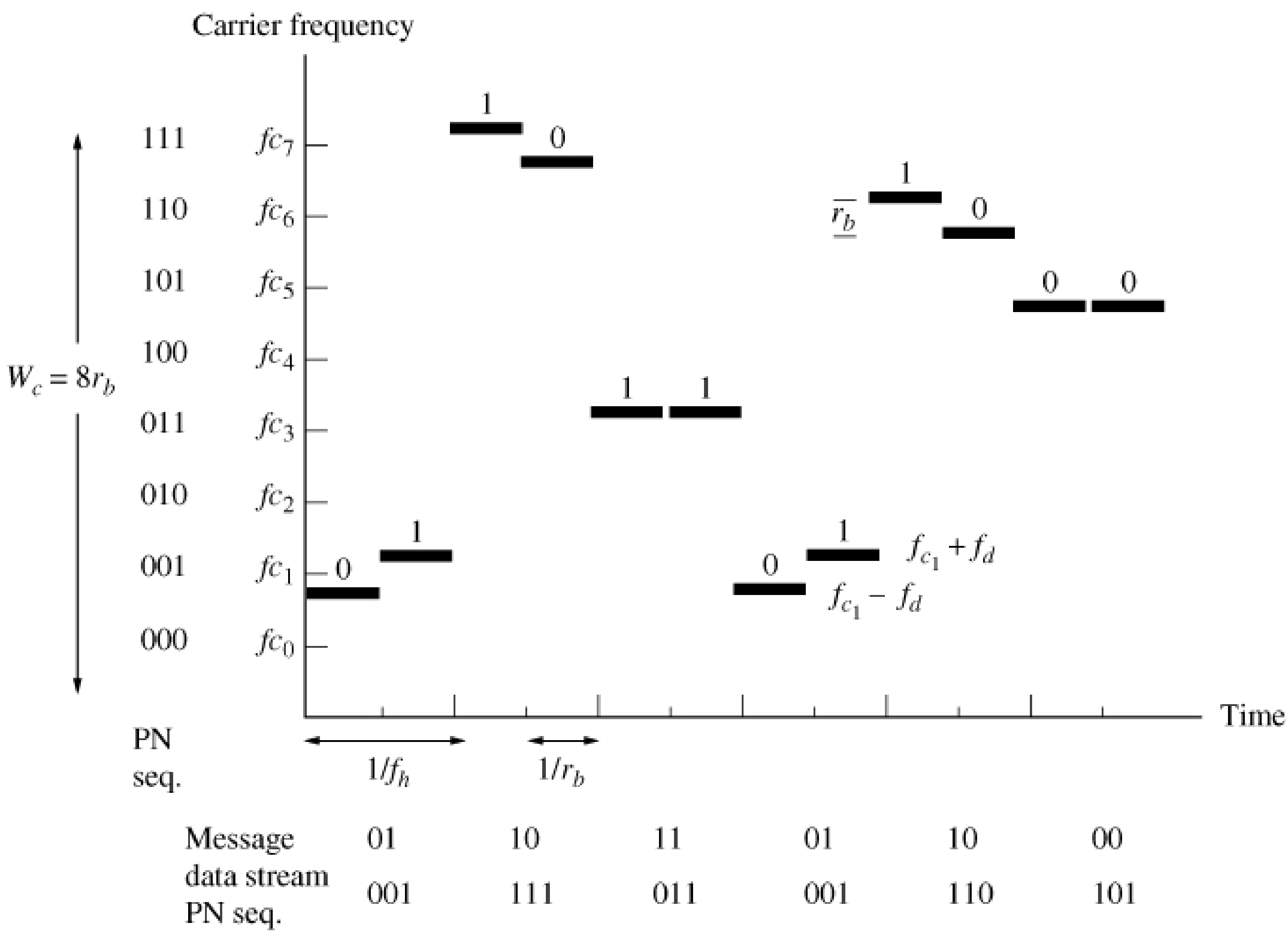
Frequency hopping spread spectrum

- PN generator causes carrier frequency to vary in a pseudo random fashion
- Slow-hop: 1 or more symbols per hop
- Fast-hop: 1 or more hops per symbol
- Usually uses noncoherent (e.g. envelope) detection

FH-SS Transmitter and Receiver



FHSS Spectrum for Slow Hop FH-SS: Output frequency vs input



Noise and Jamming

- FH-SS *P(error)* as FSK systems

  Thus, $P_e = \frac{1}{2} e^{-E_b / 2N_0}$

- Jammer power is reduced so $J \rightarrow \quad N_J = J / W_c$

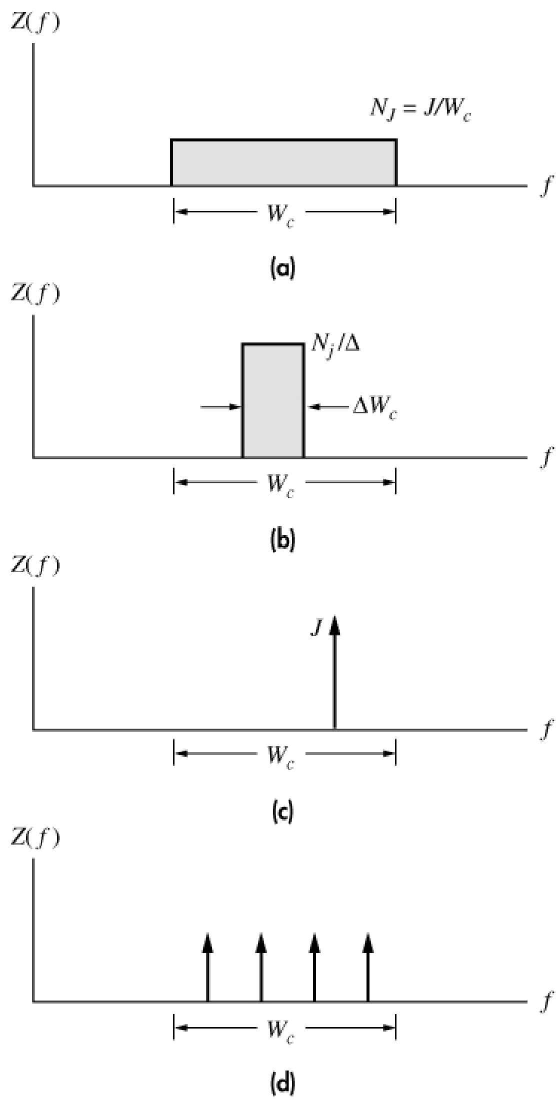
- Partial band jamming = ΔW_c

$$P_e = \frac{1-\Delta}{2} e^{-E_b / 2N_0} + \frac{\Delta}{2} e^{-E_b / [2N_0 + N_J / \Delta)]}$$

- M - Users @ $Y = 2^k$ frequencies

$$P_e = \frac{1}{2}\left(\frac{M-1}{Y}\right) + \frac{1}{2} e^{-E_b / 2N_0}\left(1 - \frac{M-1}{Y}\right)$$

Types of jamming for FH-SS systems. (a) barrage (b) partial-band (c) single tone (d) multiple tone



Coding

Objective: Generate the PN Code

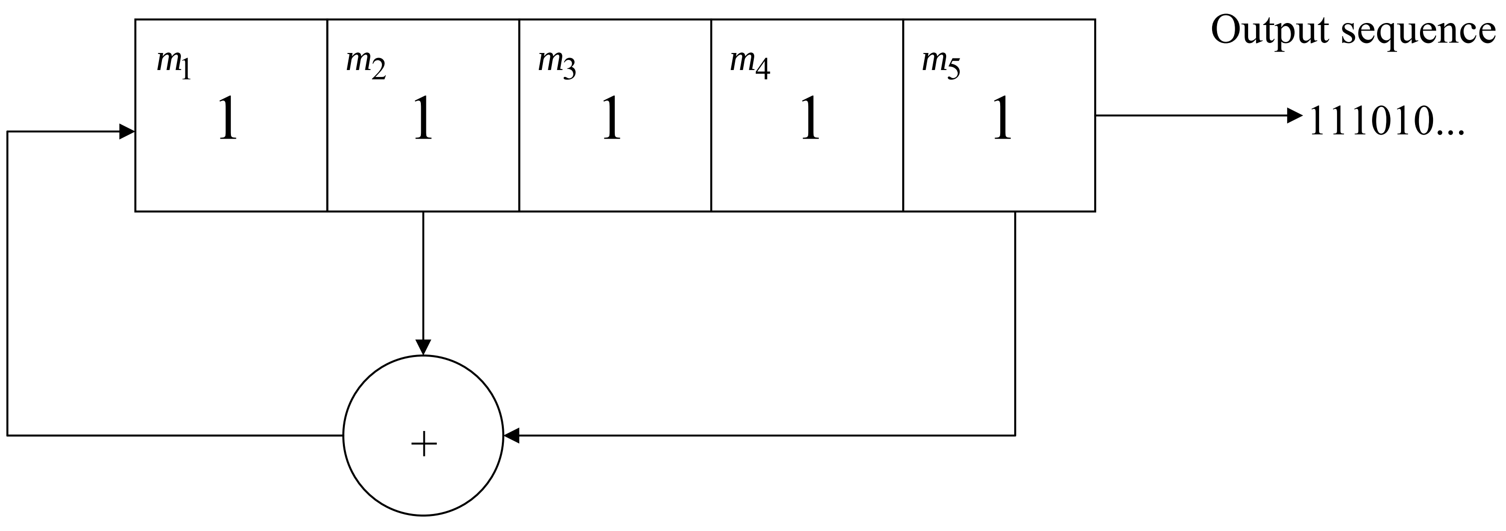
Coding Requirements

- High autocorrelation ⇒ receiver can identify intended source
- Low cross-correlation ⇒ receiver can reject other signals
- Multiplicity of unique codes for given shift register length

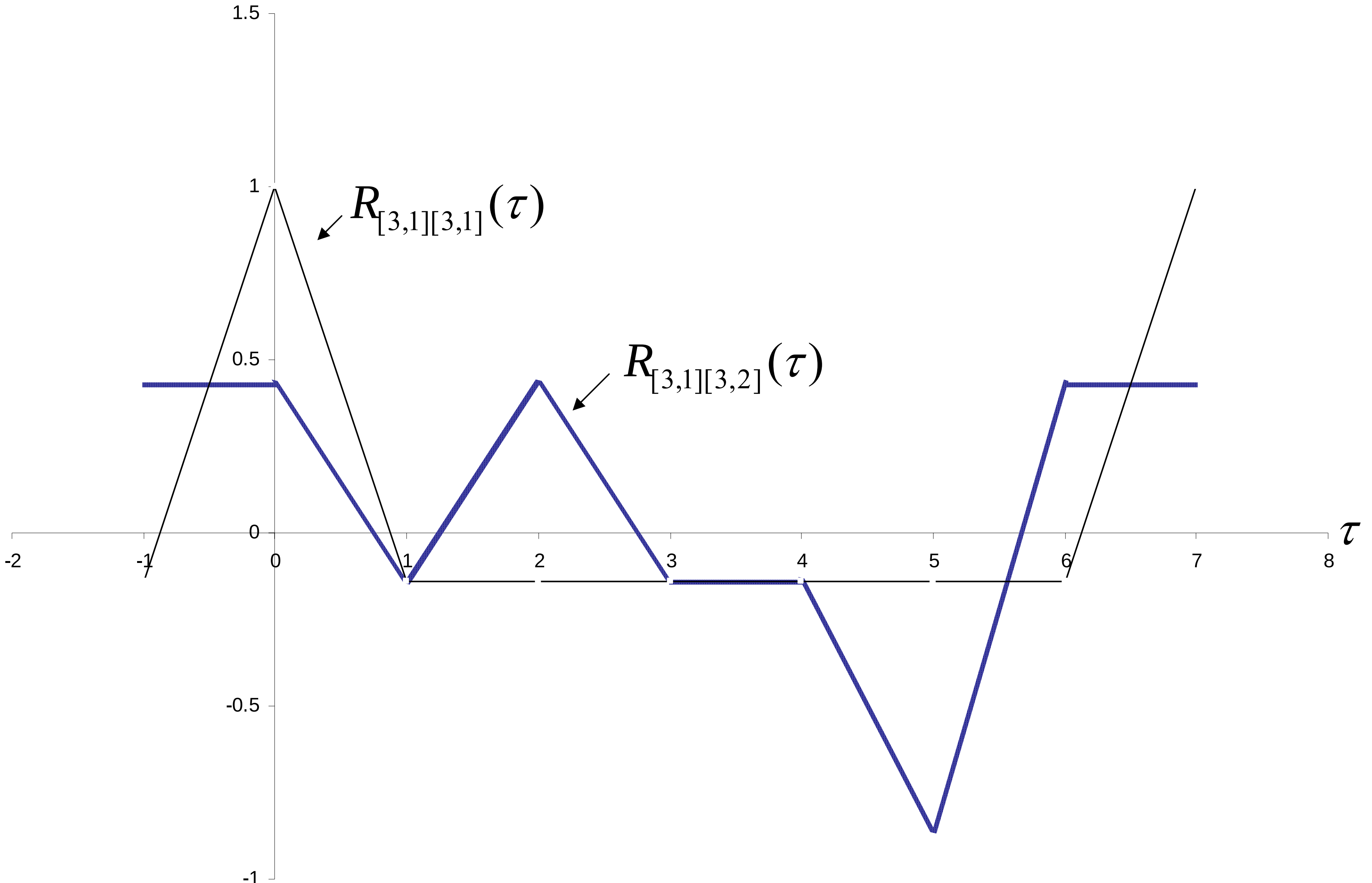
Single Shift Register with Feedback

- Good autocorrelation
- Poor cross-correlation
- Few codes for given register size

Shift register sequence generator with [5,2] configuration



Auto and cross-correlation of [3,1] and [3,2] PN Sequences.



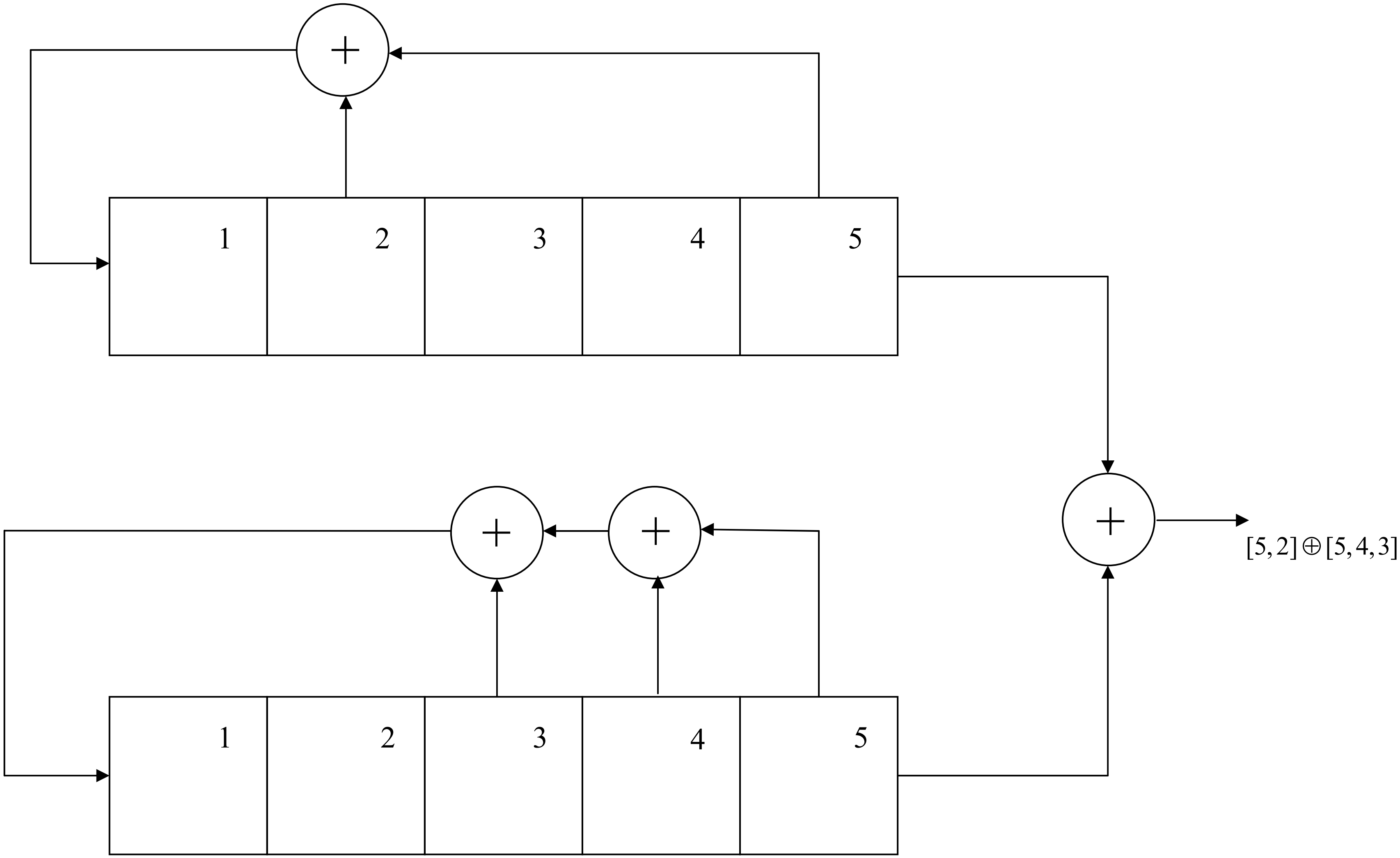
Gold Codes

- Numerous codes from a given shift register configuration

$$\#\ \text{codes} = 2^n$$

- Desirable cross/auto-correlation properties

Gold Code generator



Synchronization

Synchronization goal

Received signal: $\mathrm{y}(t) = \tilde{x}(t) = x(t)c(t)$

At demodulation: $\tilde{y}(t) = \tilde{x}(t)c(t-\tau)$

where $c(t-\tau)$ = receiver PN output

Goal: make $c(t-\tau) = c(t)$ so $c(t)c(t) = c^2(t) = 1$

Thus: $\tilde{y}(t) = \tilde{x}(t)c(t-\tau) = x(t)c^2(t) = x(t)$

$\Rightarrow$ Message recovered!

Of course this assumes periodicity of $c(t) = c(t+nT)$

Synchronization process

- Acquisition: course alignment of the two PN codes to within a 1/2 chip

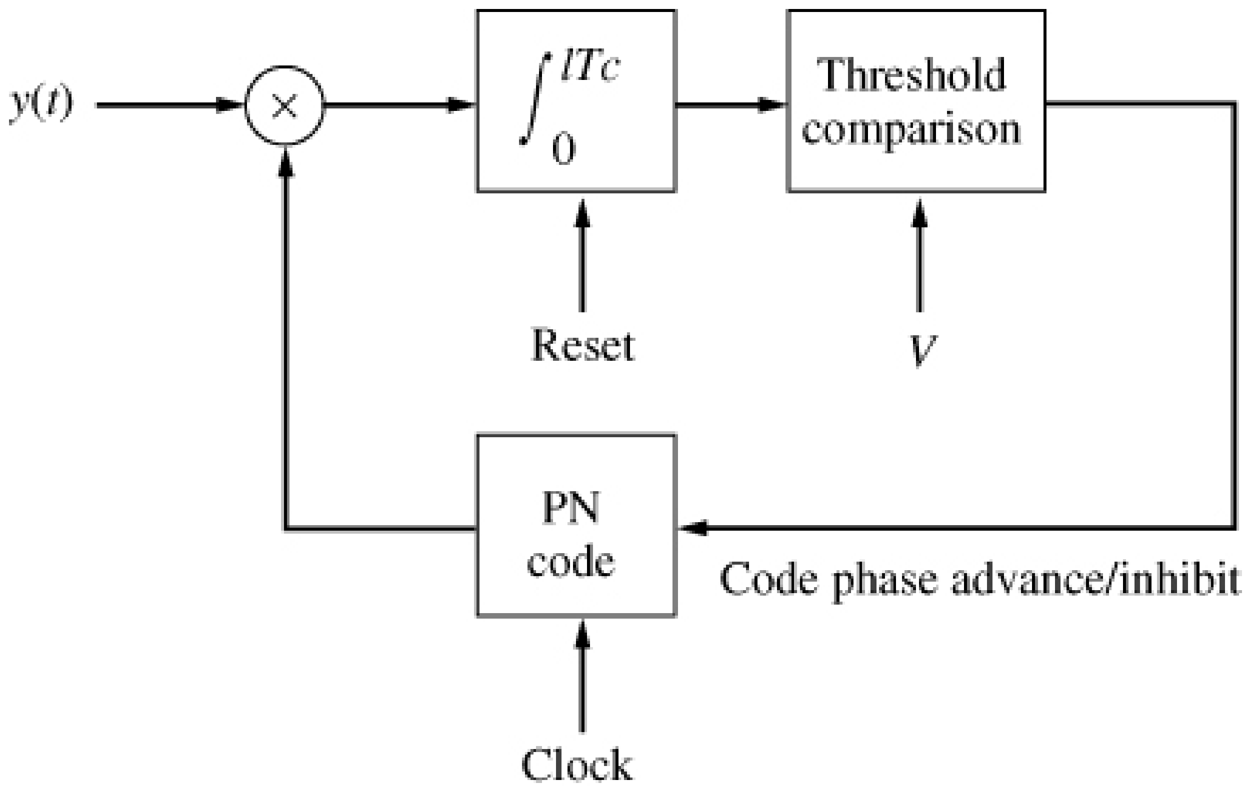
- Tracking: fine alignment

Misalignment

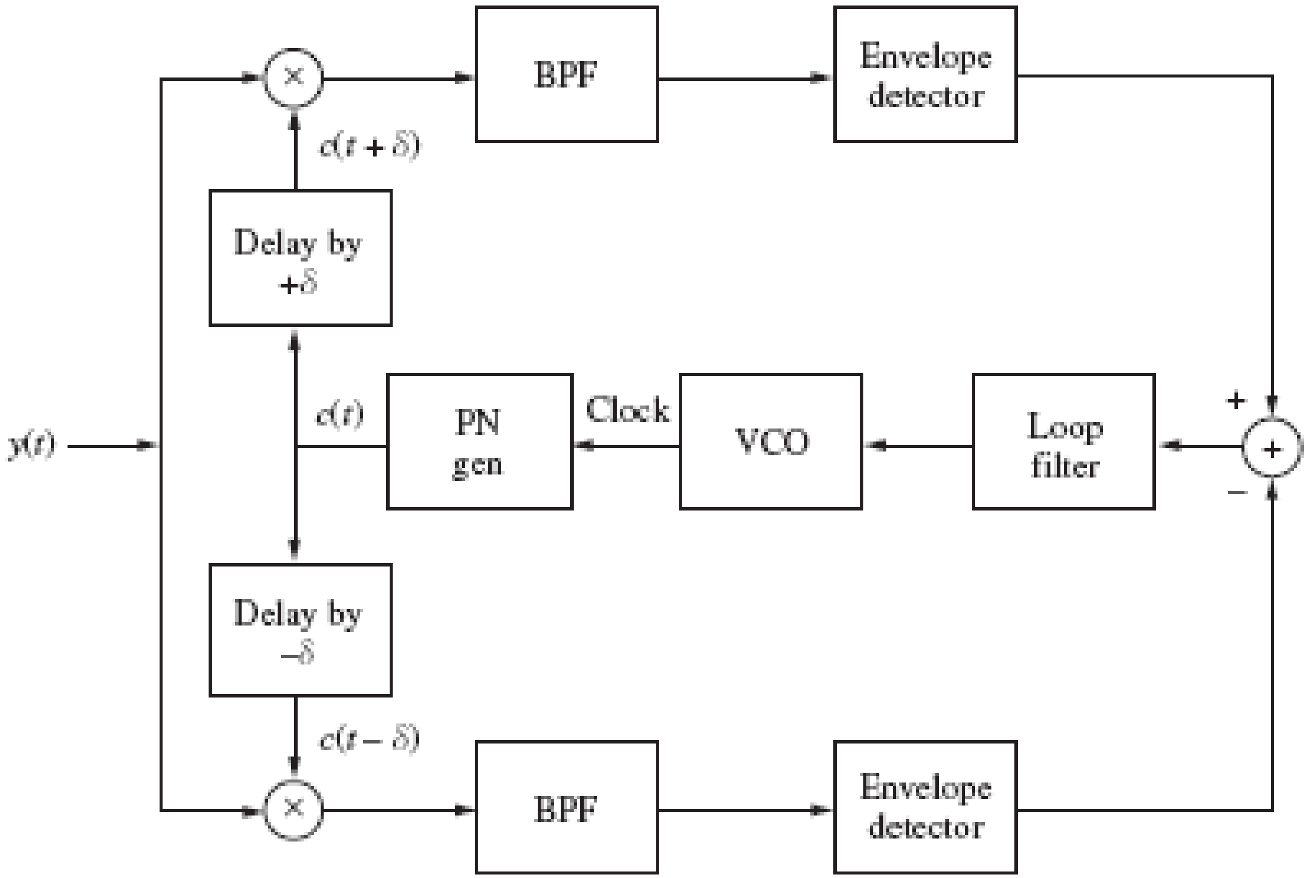
- Problem: $c_{transmitter}(t) \neq c_{receiver}(t)$ or

  $c_{transmitter}(t) = c_{receiver}(t - \tau)$
- Causes
  - distance
  - Doppler
  - movement of the transmitter and/or receiver

DS serial search acquisition ⇒ course alignment

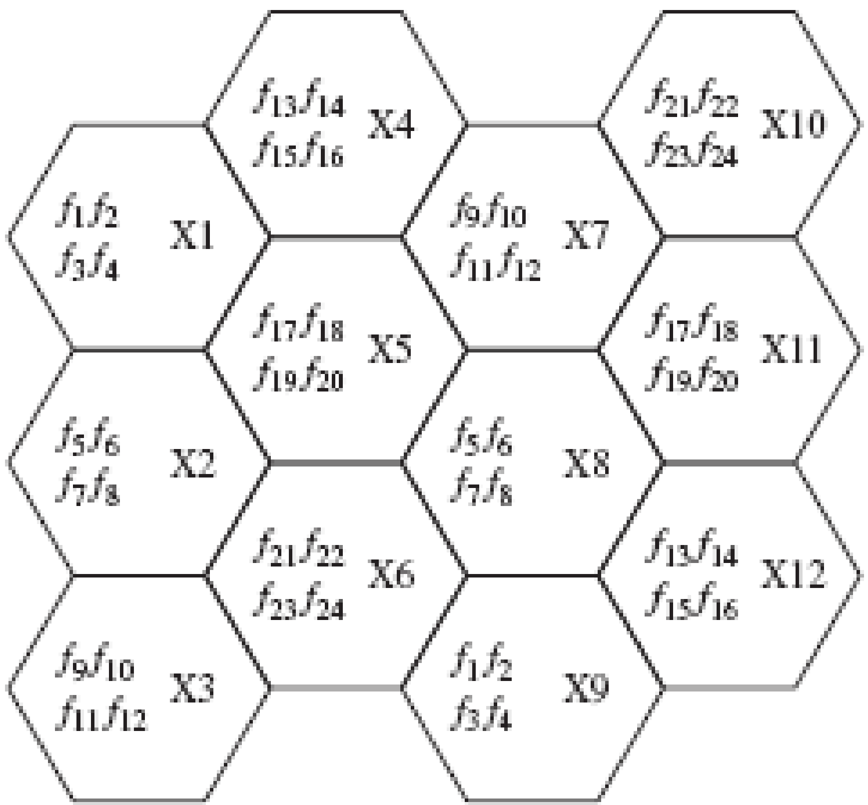


Tracking ⇒ fine alignment



Wireless systems

- Cellular concept: divide geographical area into small cells



Original FDMA Cellular Concept

- In a given cell, the caller communicates to the tower via two frequencies- listen/talk (full duplex)
- When the call is made the tower assigns two unused frequencies.
- If the caller moves to a new cell, there is a handoff whereby, the user is reassigned 2 new frequencies, if these are available, otherwise the call is dropped.
- Each cell has a hard limit on number of frequencies available. However, there is re-use of frequencies at some distant cell.
- Re-use and number of available frequencies/cell are dictated by interference considerations.

2G and 2.5G concept

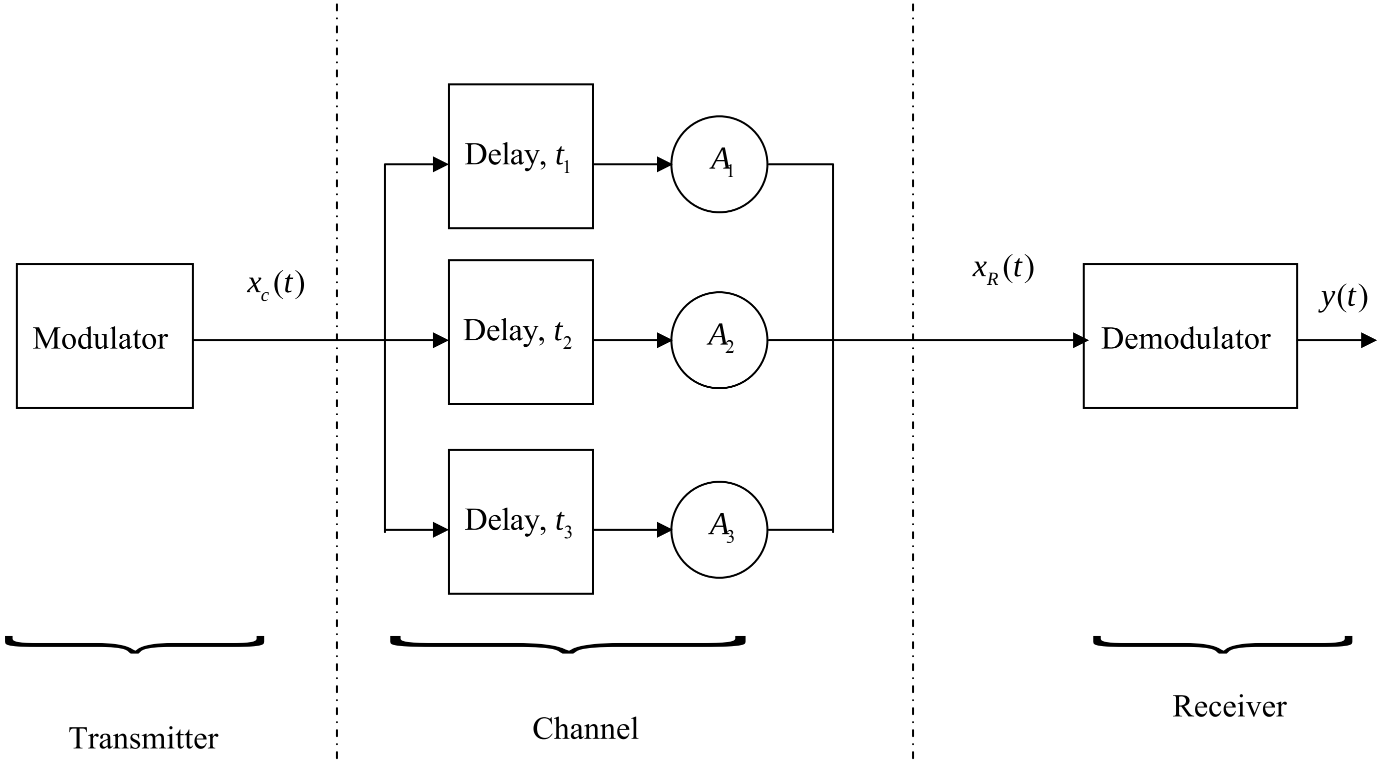
- There is still assignment of frequencies, but a given frequency channel, can have time or code slots
- Concept expanded to include TDMA or CDMA
- Data services include internet, text messaging included
- GSM, IS-54→IS-136 are TDMA
- IS-95 is CDMA
- 850 and 1900 MHz bands used
- More re-use as compared to original 1G standard
- Voice circuit switching, text packet switching

3G Concept

- Expanded data services
- Some voice is packet switched

Reducing multipath interference for DSSS using the Rake receiver

Channel model for Multipath

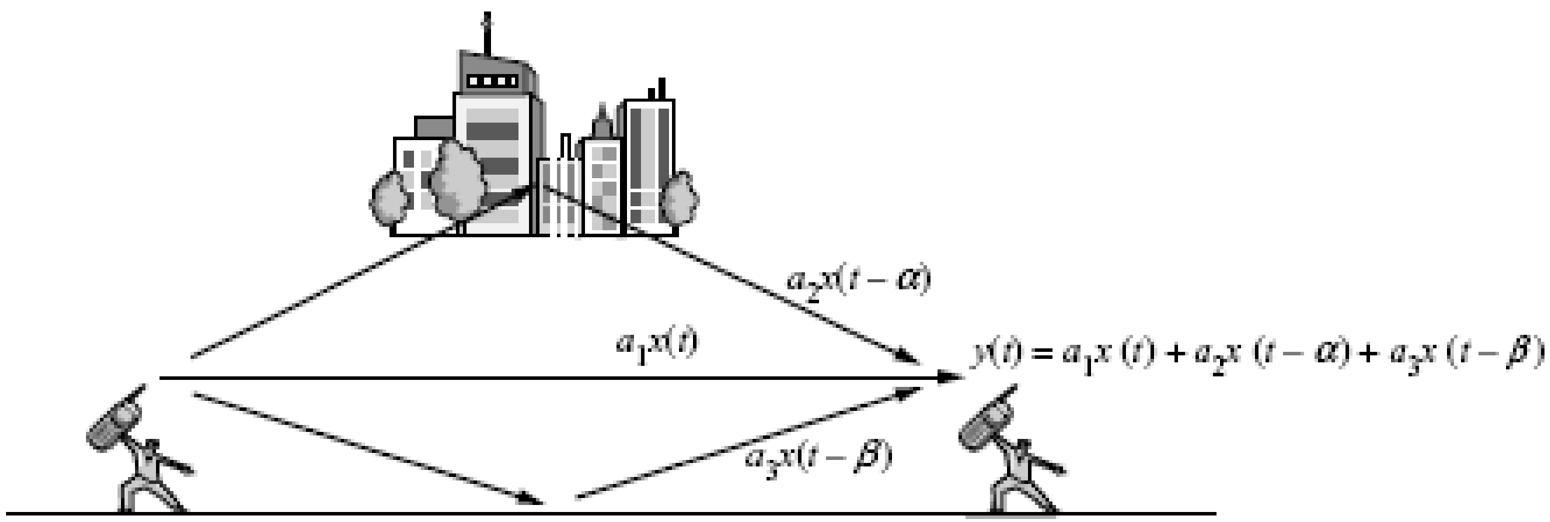


Multipath

- Problem:

  because of obstacles, the transmitted signal may travel over several paths to the receiver

  ⇒ destructive interference or **fading**



Multipath model

$$y(t) = \underbrace{\sum_{i=1}^{l} A_i x(t - t_i) c(t - t_i)}_{\text{The desired signal plus its } l \text{ multipath versions}} + \underbrace{\sum_{m=1}^{M-1} A_m x_m (t - t_m) c_m (t - t_m) + n(t)}_{\text{other } M-1 \text{ users and noise}}$$

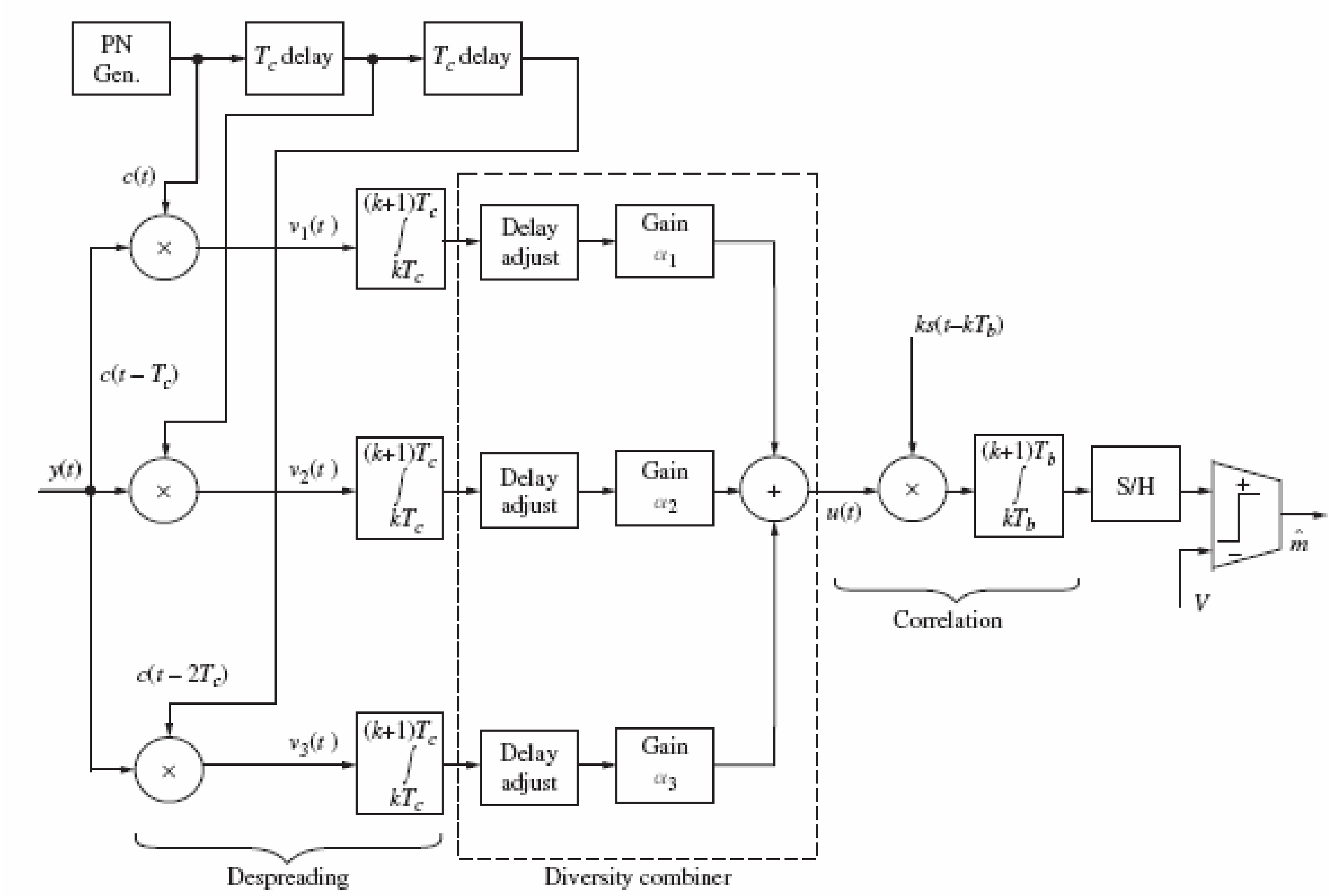
If noise and other interferences, are neglected, we get

$$y(t) = \sum_{i=1}^{l} A_i x(t - t_i) c(t - t_i)$$

Rake receiver: a solution to multipath

- Incorporate multiple detectors that will
  - alter the phase/time delay and amplitude of each component
  - when added $\Rightarrow$ achieve **constructive** interference
- Rake: structure of receiver looks like the tines on a garden rake
- Rake is **adaptive –** adjustments will occur as conditions change

DSSS Rake Receiver to Overcome Multipath



Phase/gain adjustments

- Phases are adjusted so signals from various paths are added constructively.
- Amplitudes are adjusted to favor those signals with the maximum SNR

Rake receiver signals

The output of each of the 3-PN multipliers yields

$$v_i(t) = \underbrace{A_i c^2(t - t_i)x(t - t_i)}_{\text{output of } i\text{th multiplier}} + \underbrace{\sum_{j \neq i} A_j x(t - t_j)c(t - t_{j \neq i})c(t - t_i)}_{\text{output of other multipliers}} \quad i = 0,\ 1,\ 2$$

$$\downarrow \qquad\qquad\qquad\qquad \downarrow$$

$$\Rightarrow v_i(t) = \text{ in-phase } \qquad + \quad \text{out-of-phase summation}$$

$$\Rightarrow v_i(t) = A_i x(t - t_i) + \tilde{z}_i \qquad i = 0,1,2$$

After despreading, the output of the diversity combiner becomes

$$u(t) = \sum_{i=0}^{2} \alpha_i [A_i x(t-\Delta) + \tilde{z}_i^{'}] \qquad i = 0,1,2$$

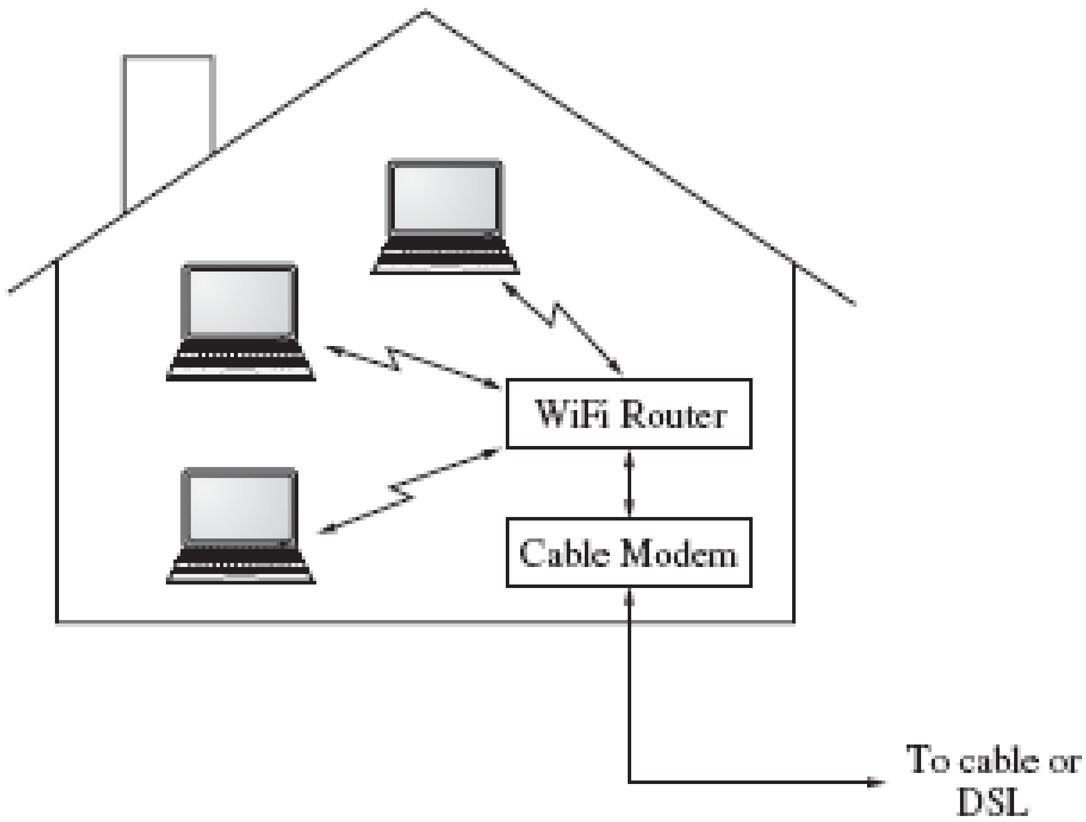
$\Rightarrow$ each in-phase component adds constructively, but the sum of the out of phase terms is minimal

$\Rightarrow u(t) \to$ correlation detector $\to$ message

Wireless Networks

- Wi-Fi (IEEE-802.11)
- WiMax (IEEE-802.16)

Wi-Fi system for home or business



WiMAX and Wi-Fi

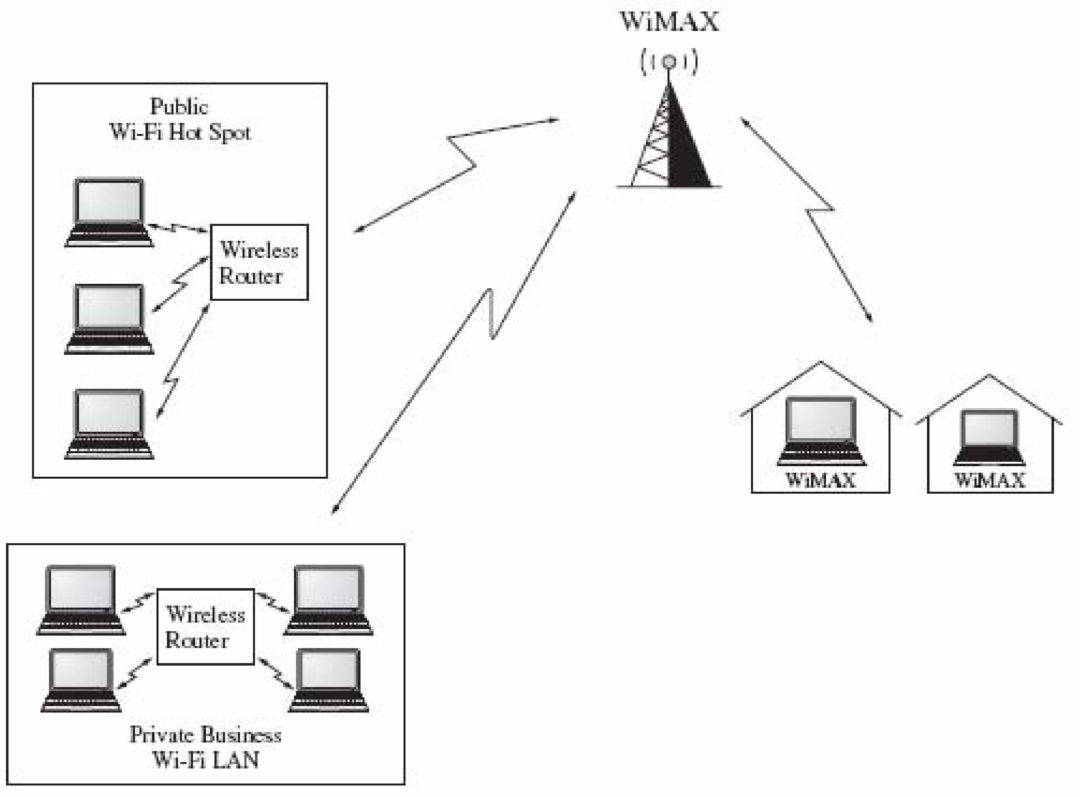


Figure 15.5–3 WiMAX cell concept.

Wi-Fi

- Local area wireless network: 100-500 feet
- OFDMA and CSMA
- CSMA$\Rightarrow$ coverage limited in crowded areas
- “Hot spots”

WiMAX

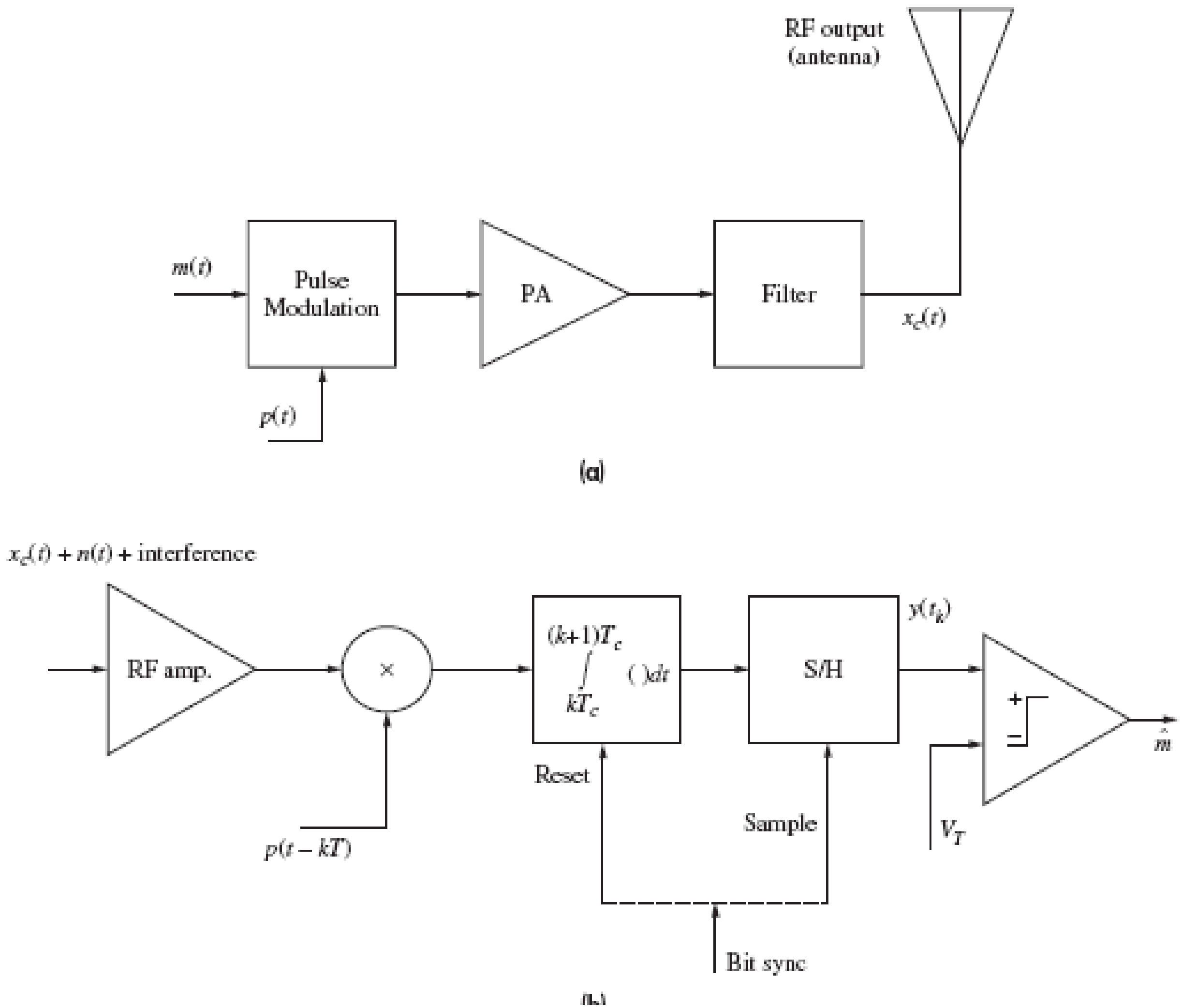
- Similar to wireless cell phones
- Can use the same cell/tower infrastructure
- Coverage and distance can be similar to wireless phones (i.e. ≈ miles)
- OFDMA

Ultra wideband systems

A system where a binary message alters a wideband pulse in some way.

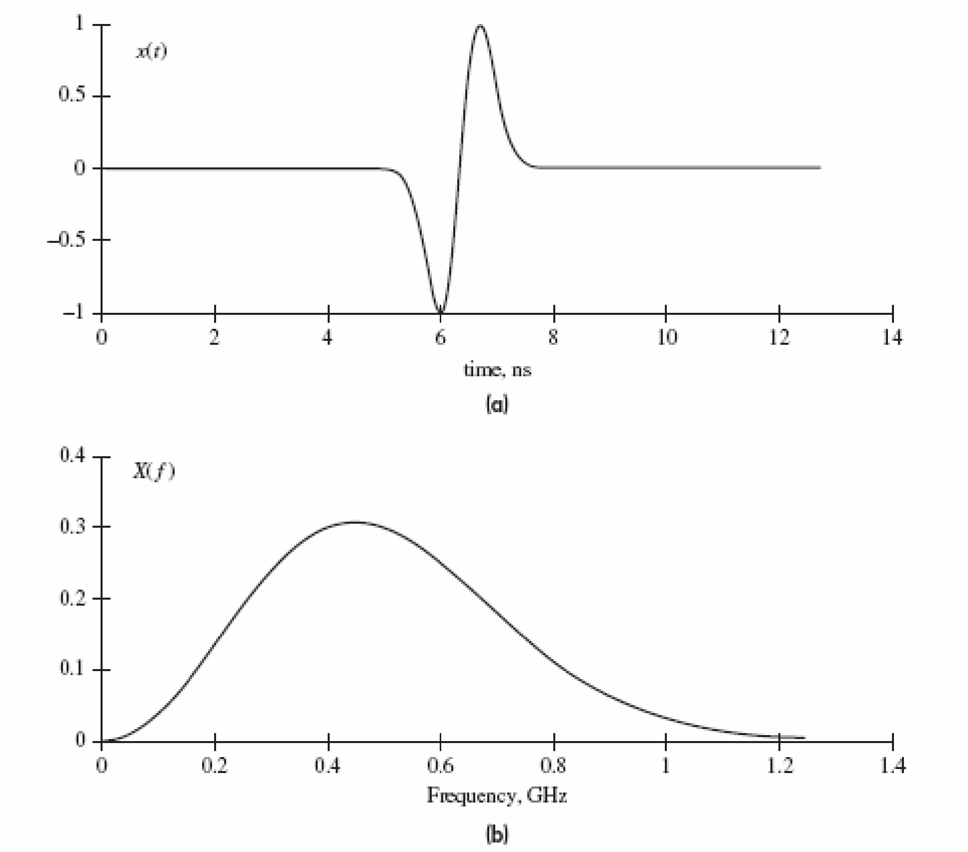
1. Antipodal (PAM)
2. OOK and amplitude (PAM) $a_k = \pm 1$
3. Position (PPM)
4. With suitable synchronization, can operate below the ambient RF levels

UWB transmitter/Receiver



(a) transmitter, (b) receiver

UWB signal example



UWB gaussian monocycle. (a) time, (b) spectra

UWB signal example

We can use a gaussian monocycle pulse shape or

$$p^1(t-t_d)=\frac{-2\pi(t-t_d)}{\tau^2}e^{-\pi(t-t_d)^2/\tau^2}$$

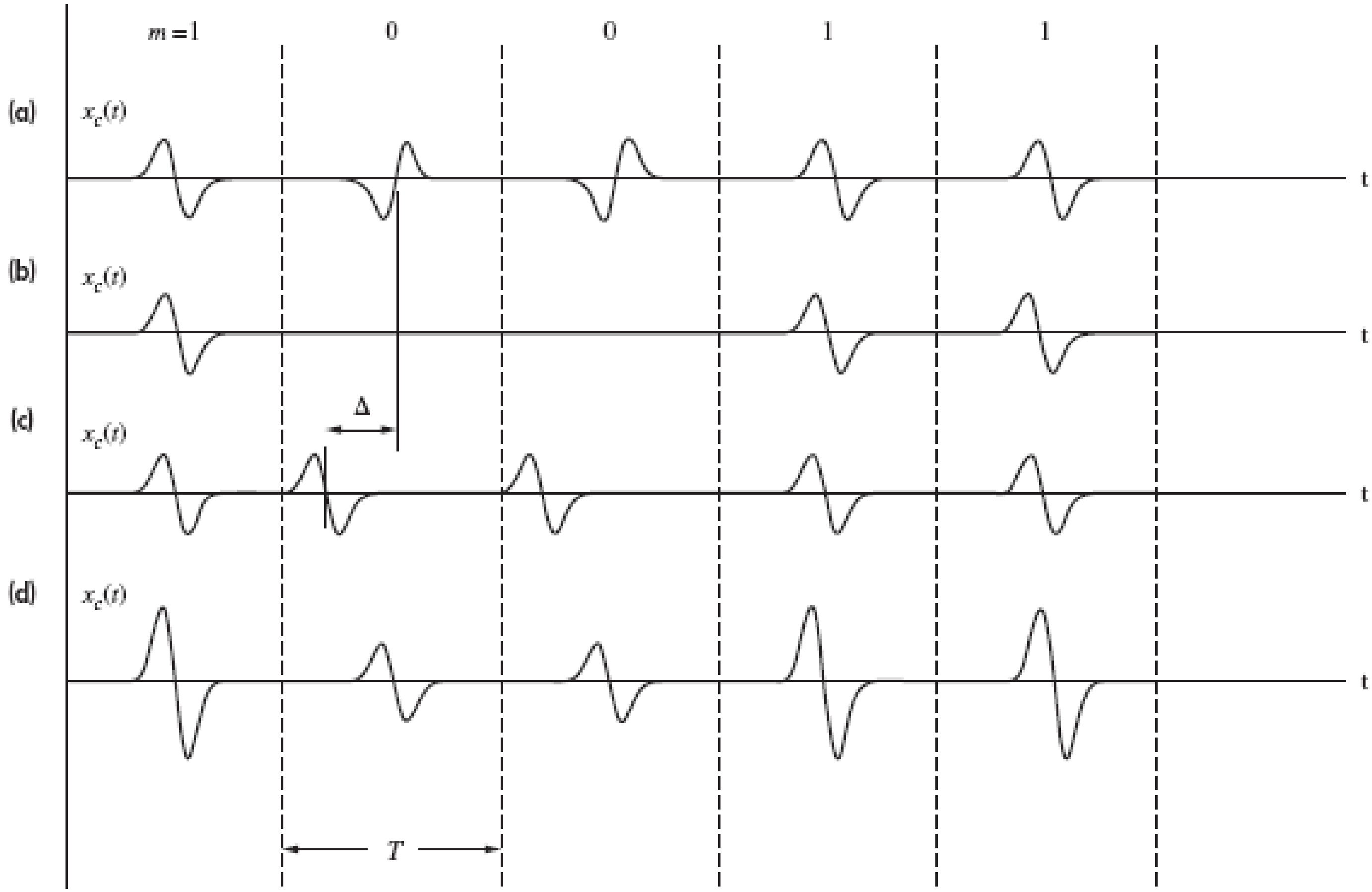
Then one of the following encoding schemes:

$$x_{c_{ppm}}(t)=A_c\sum_{k=0}^{N}p(t-kT-d_k\Delta)$$

$$x_{c_{OOK\ or\ PAM}}(t)=A_c\sum_{k=0}^{N}a_k\,p(t\text{ - }kT)$$

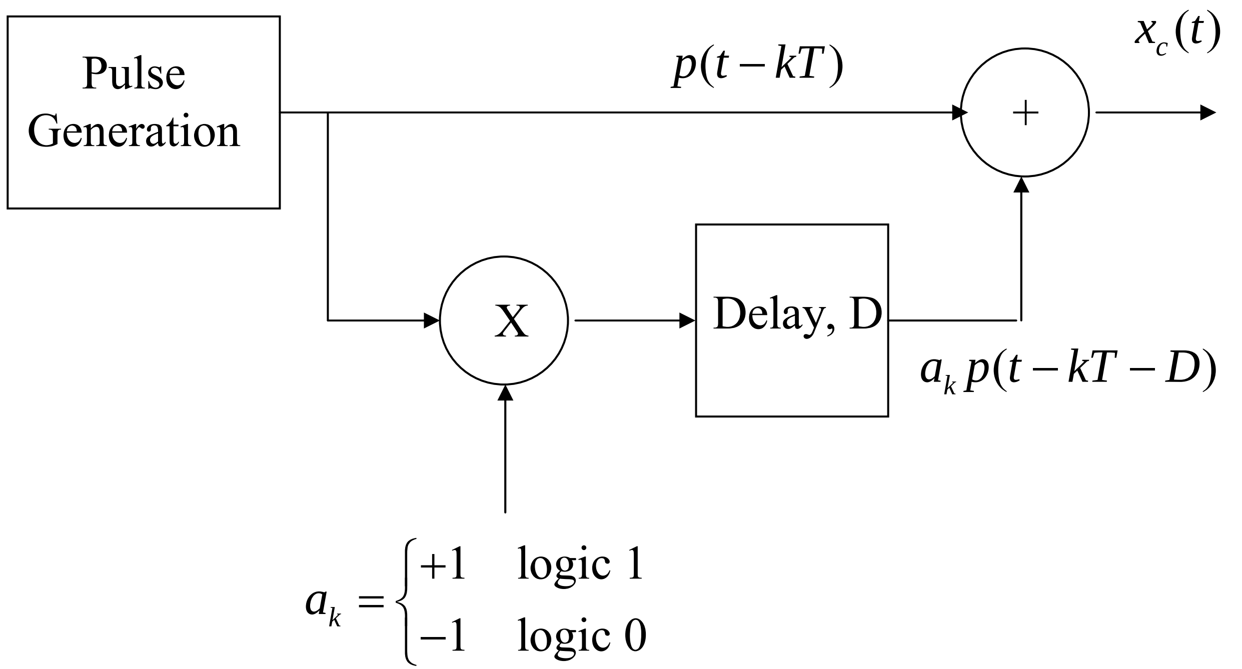
Where a_k and d_k are the message digits

Types of UWB

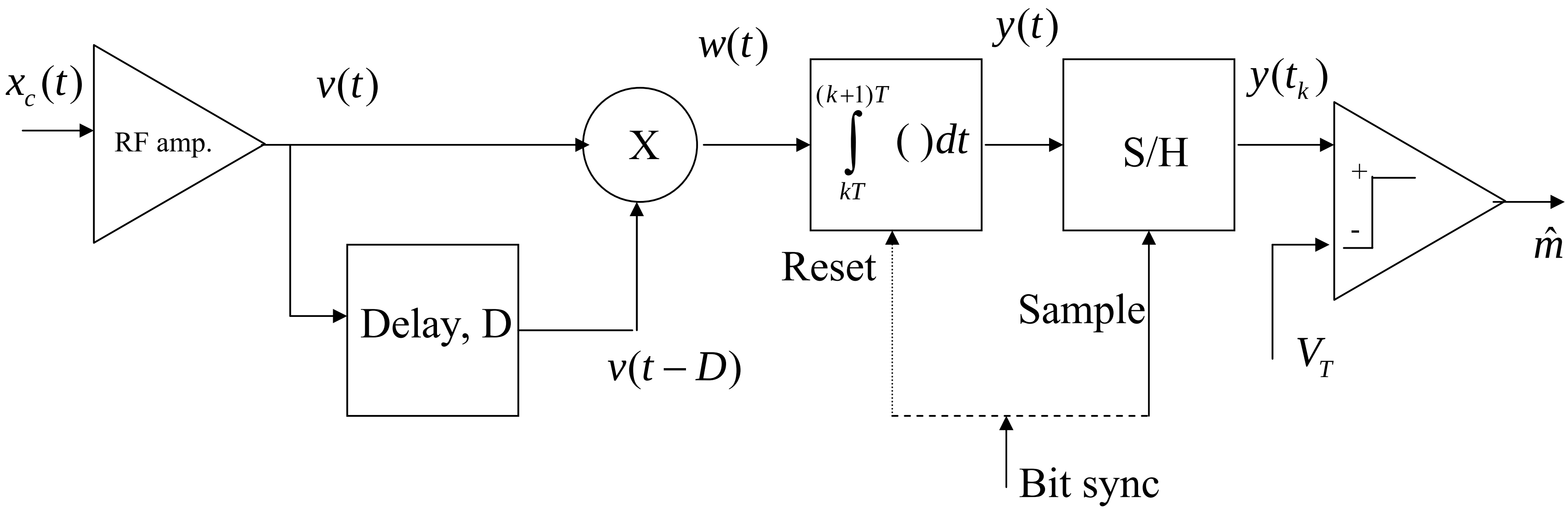


Signal types for 10011 message. (a) antipodal, (b) amplitude OOK, (c) position, (d) amplitude

Transmitt Reference (TR) UWB system: Transmitter

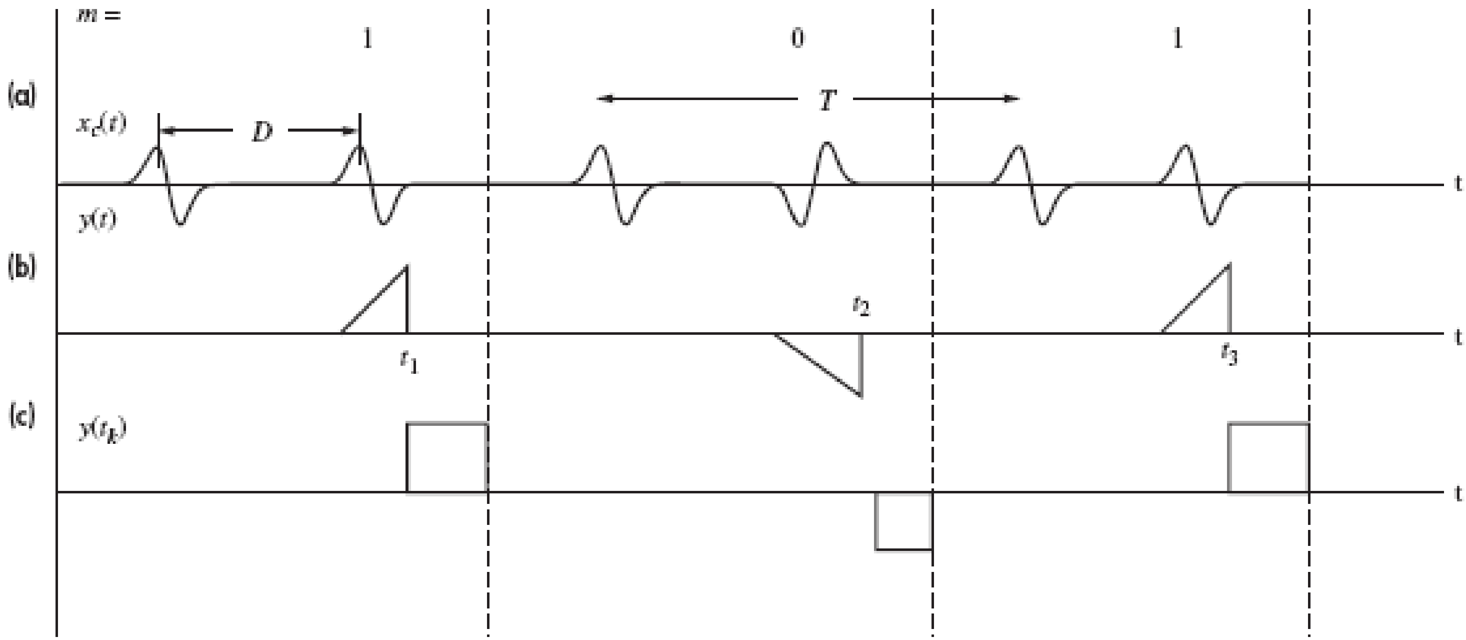


TR Receiver



$x_c(t)$
RF amp.
$v(t)$
X
$w(t)$
$\int_{kT}^{(k+1)T} (\ )dt$
$y(t)$
S/H
$y(t_k)$
+
-
$\hat{m}$
Delay, D
$v(t-D)$
Reset
Sample
V_T
Bit sync

TR Waveforms



TR-UWB signal to correlation receiver. (a) input, (b) integrator output, (c) sample and hold output

UWB vs. DSSS

- Fundamentally different
  - DSSS has a carrier frequency
  - UWB has a pulse
- Fractional bandwidth

  $B_{T_{DSSS}} \approx \text{MHz vs } B_{T_{UWB}} \approx \text{GHz}$
- Duty cycle
  - DSSS≈ 100%
  - UWB ≈ 0.5%