CDMA SYSTEMS

UNIT 1

Introduction

• **Multiple Access:**

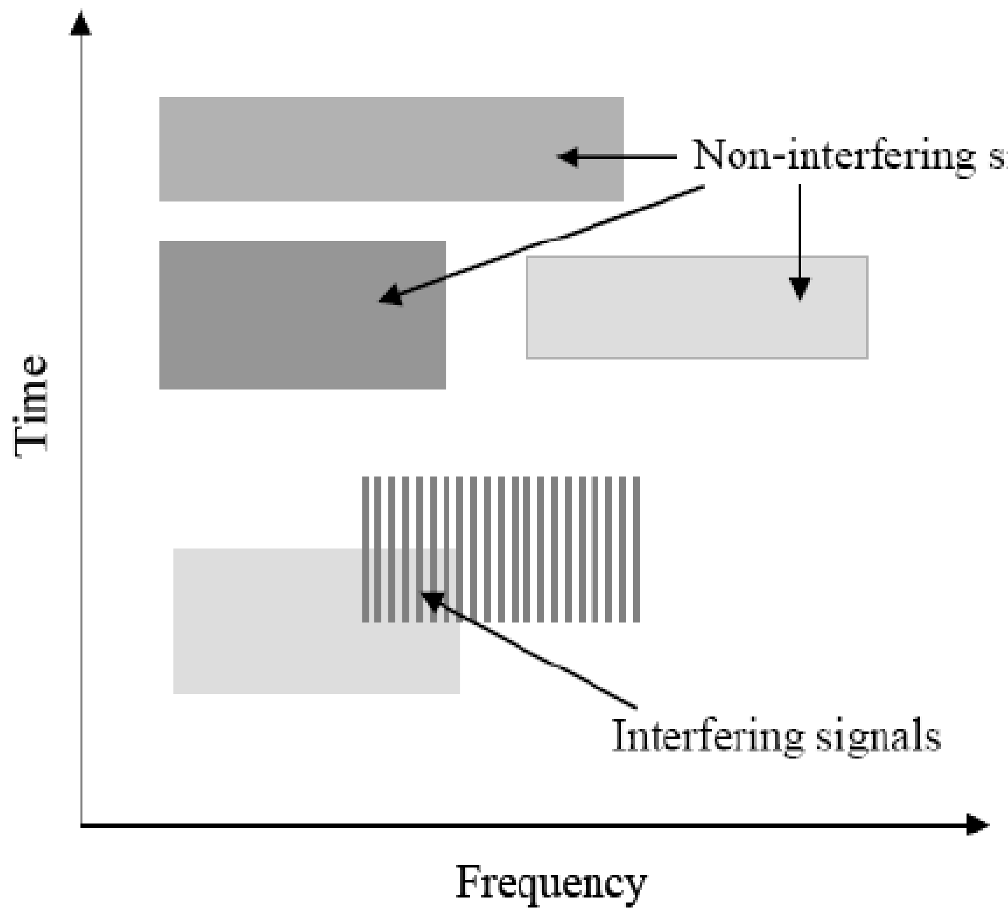
The transmission from the BS in the downlink can be heard by each and every mobile user in the cell, and is referred as *broadcasting.*

Transmission from the mobile users in the uplink to the BS is many-to-one, and is referred to as multiple access.

Introduction

- Multiple Access:
  - Enable many mobile users to share simultaneously radio spectrum.
  - Provide for the sharing of channel capacity between a number of transmitters at different locations.
  - Aim to share a channel between two or more signals in such way that each signal can be received without interference from another.

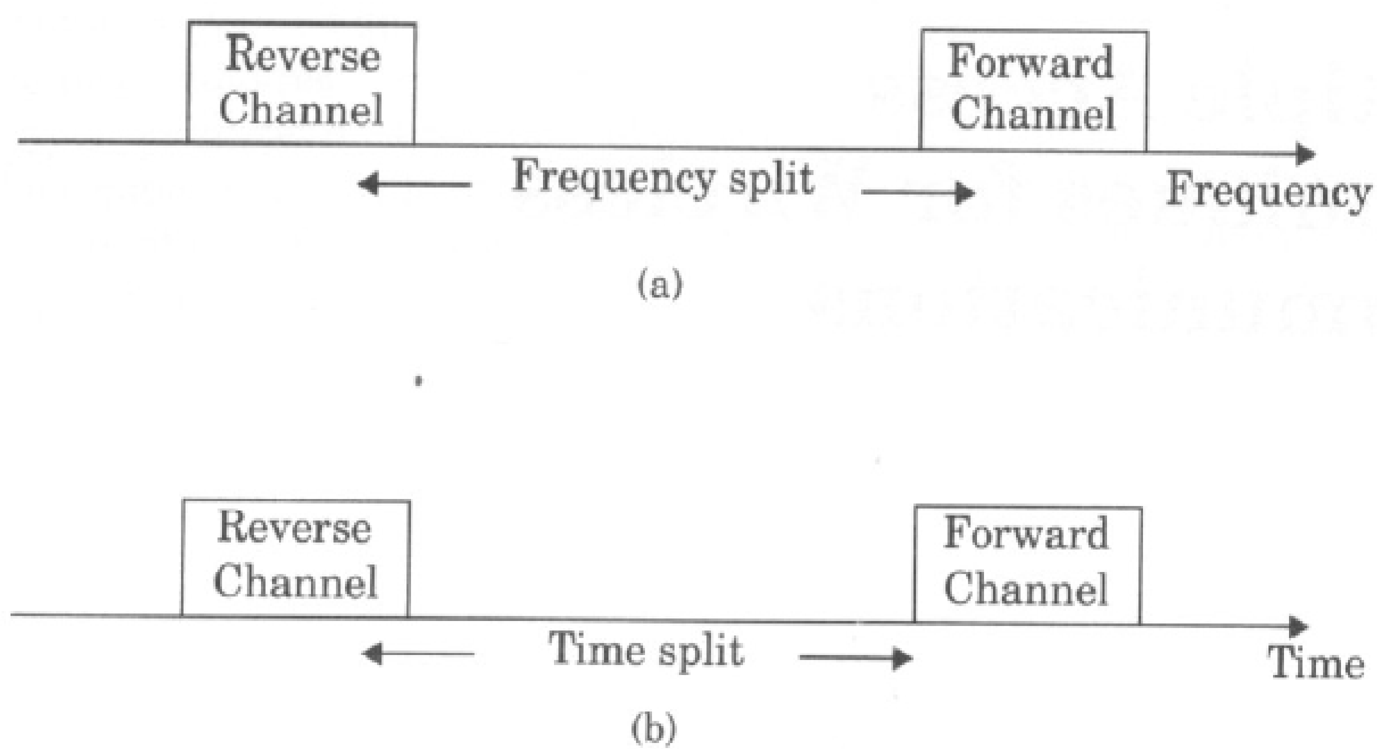
Introduction



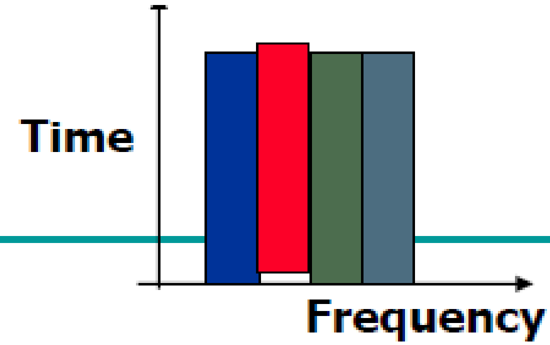
Introduction

- In conventional telephone systems, it is possible to talk and listen simultaneously, called duplexing.
- Duplexing
  - Allow the possibility of talking and listening simultaneously.
  - Frequency Division Duplex (FDD)
    - Provides two distinct bands of frequencies for every user
  - Time Division Duplex (TDD)
    - Multiple users share a signal channel by taking turns in time domain
    - Each duplexing channel has both a forward time slot and a reverse time slot to facilitate bidirectional communication.

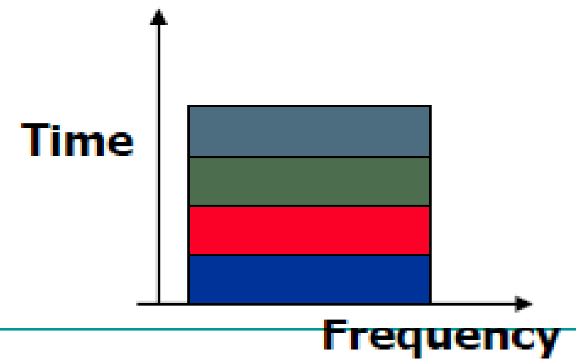
Introduction (4)



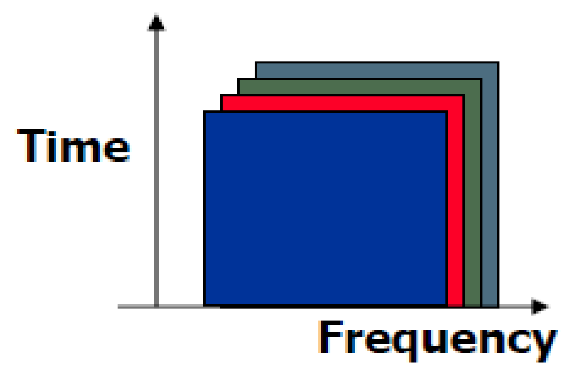
Multiple Access Techniques



FDMA



TDMA



- CDMA

Multiple Access techniques

- Goal — allow many users to simultaneously share a communications resource

- Time Division Multiple Access (TDMA)
- Space Division Multiple Access (SDMA)
- Frequency Division Multiple Access (FDMA)
- Polarization Division Multiple Access (PDMA)
- Code Division Multiple Access (CDMA)
  - A Spread Spectrum form

Key Issue

- separate the signals at the receiver to extract *your* information

Two methods

- Do not mix the signals in the first place
  - can use space or time (SDMA or TDMA)
- Use distinctive properties of each signal as a means to identify
  - Frequency spectrum (FDMA)
  - Polarization of waves (PDMA)
  - code sequence attached to each message (CDMA)

▪SPREADING SPECTRUM

▪Shannon's Equation

C= W Log (1+S/N)

Where C=Capacity (bps)

W=Bandwidth

S=Signal Power

N=Noise Power

• Shannon's Capacity Equation is basis for spread spectrum. System with large band width can operate at very low SNR level & can provide acceptable data rate per user.

• Therefore in CDMA

- All users uses same 1.25 MHz spectrum.
- Each user has unique Digital code identifier.
- Digital codes separate users to avoid interference.

SPREAD SPECTRUM TECHNIQUES

1. **Frequency Hopped Spread Spectrum:**

- **Spreading can also be achieved by hopping the narrowband information signal over a set of frequencies. The type of spreading can be classified as fast or slow depending upon the rate of hopping to the rate of information.**

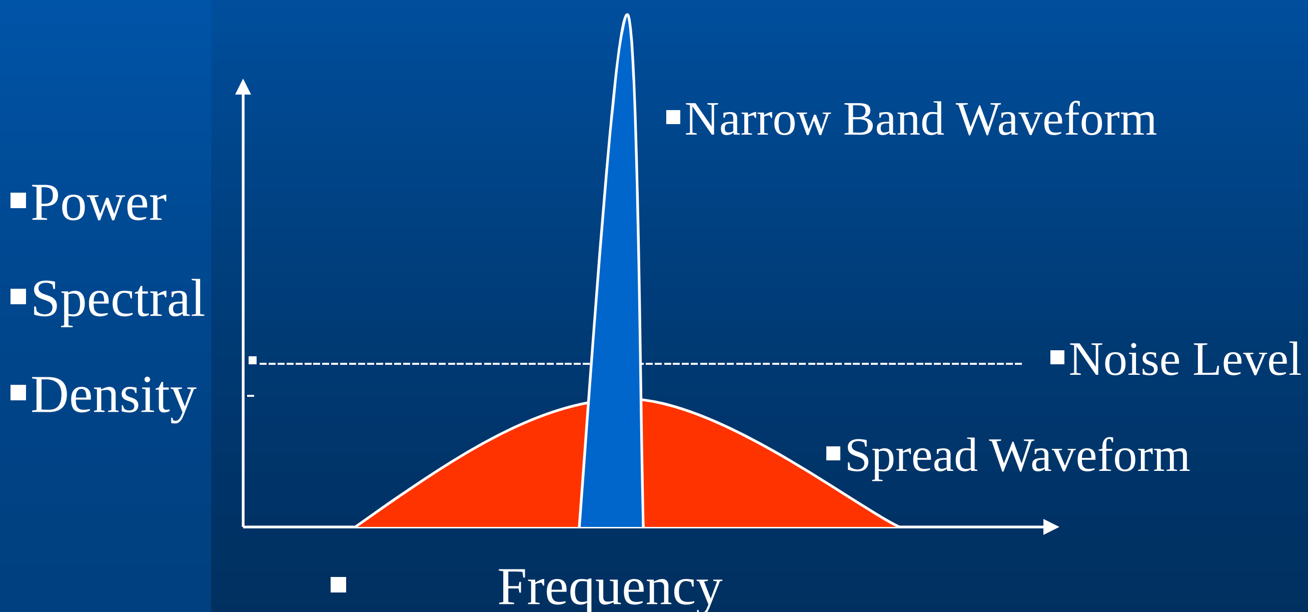
2. Direct Sequence Spread Spectrum:

- **The information signal is inherently narrowband, on the order of less than 10KHz. The energy from this narrowband signal is spread over a much larger bandwidth by multiplying the information signal by a wideband spreading code. DSS technique is used in the IS-95 CDMA cellular system.**

- Direct Sequence Spread using Walsh code
  - ✓ Consist of 64 orthogonal codes each 64 bits long
  - ✓ Spreads spectrum to 1.2288 M bps from 9.6 Kbps

Channel Capacity

- ✓ C=W log (1+S/N)
- ✓ Increasing BW improves Signal Transmission with lower S/N



PROCESSING GAIN

- **One of the major advantages with an SS system is its robustness to interference. The system processing gain Gp quantifies the degree of interference rejection. The system processing gain is the ratio of RF bandwidth to the information rate:**
- Gp =W/R
- $=1.2288 \times 10^{6} / 9.6 \times 10^{3}$
- =128
- dBgain $=10\log_{10} 128$
- =21

▪**Spread spectrum principle**:

▪Originally spread spectrum radio technology was developed for military use to counter the interference by hostile jamming. The broad spectrum of the transmitted signal gives rise to”spread spectrum”. A spectrum signal is generated by modulating the radio frequency (RF) signal with a code consisting of different pseudo random binary sequences, which is inherently resistant to noisy signal environment.

- A number of spread spectrum RF signals thus generated share the same frequency spectrum and thus the entire bandwidth available in the band will be used by each of the users using same frequency at the same time.
- On the receive side only the signal energy with the selected binary sequence code is accepted and information content is recovered. The other user signals, whose codes do not match contribute only the noise and are not “de-spread” back in bandwidth. This transmission and reception of signals differentiated by “codes” using the same frequency simultaneously by a number of users is known as code Division Multiple Access (CDMA).

Spread Spectrum Multiple Access

Spread spectrum systems

The desired signal is transmitted over a bandwidth which is much larger than the Nyquist bandwidth.

It is first developed for military applications for

1. Security
2. Undetectability: minimum probability of being detected
3. Robust against intentional jammers

Spread Spectrum Multiple Access

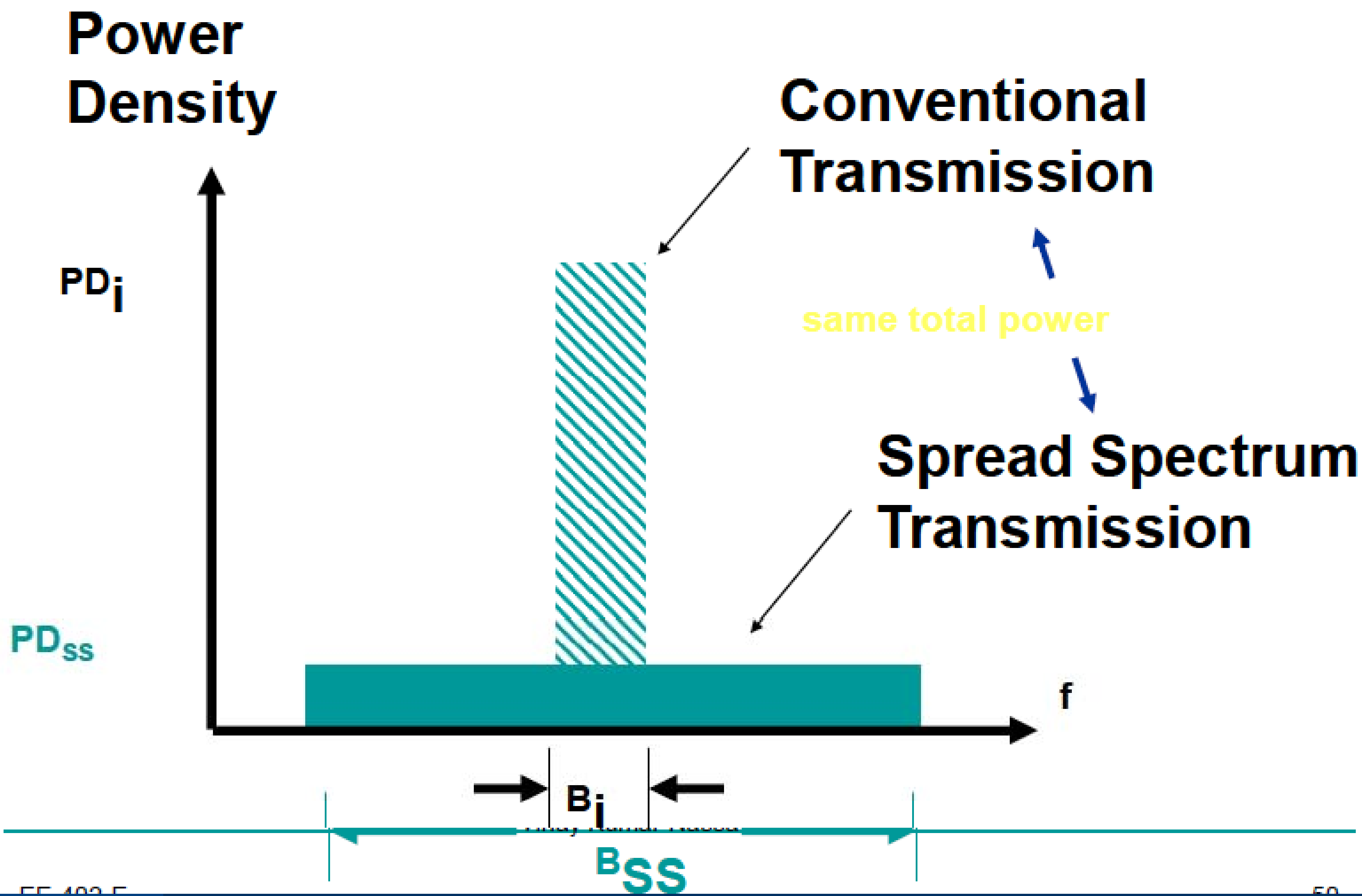
Applications

- Security
- Robust against unintentional interference
- It is not bandwidth efficient when used by a single user but has the capability to overcome narrowband jamming signals (cannot overcome AWGN or wideband jamming signal) and multipath.
- Providing multiple access
- If many users can share the same spread spectrum bandwidth without interfering with one another, bandwidth efficient improved but will affect the capability to overcome jamming.

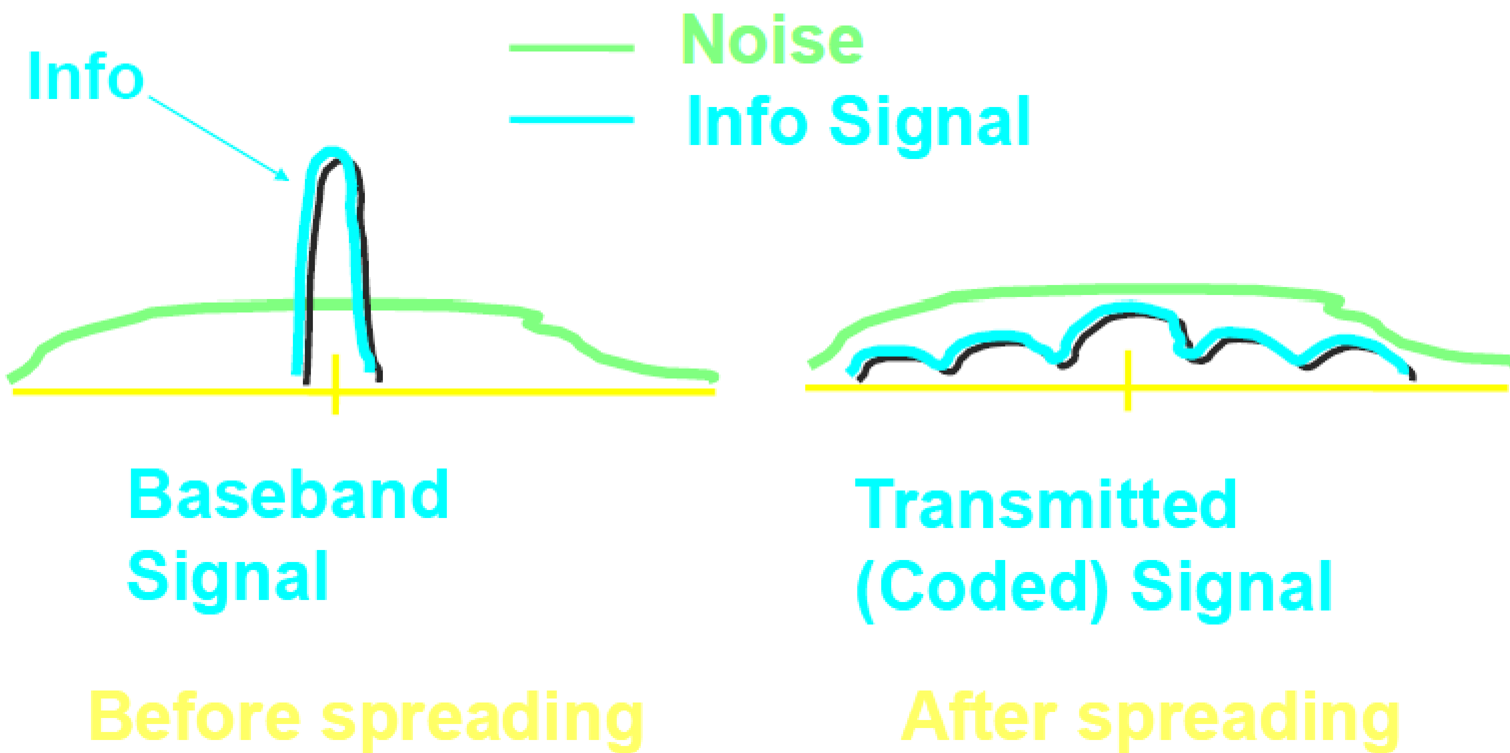
Spread Spectrum Multiple Access

- A transmission technique in which a PN(Pseudo Noise) code, independent of information data, is employed as a modulation waveform to "spread" the signal energy over a bandwidth much greater than the signal information bandwidth.
- At the receiver the signal is "despread"(Correlate) using a synchronized replica of the PN code.
- Direct Sequence Spread Spectrum (DSSS)
- Frequency Hopping Spread Spectrum (FHSS)

Spread Spectrum - illustrated



Spreading Process

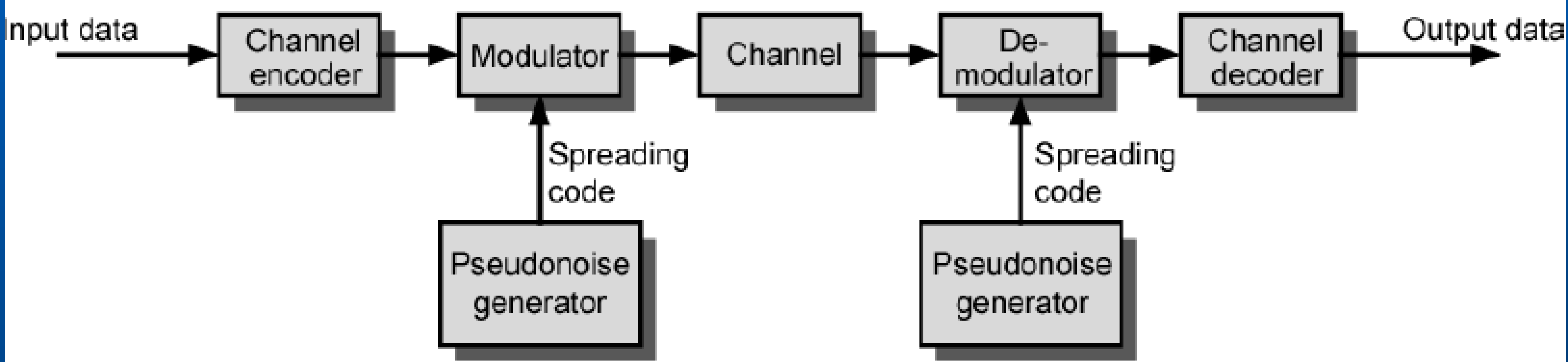


How can you recover signal < noise

Spread Spectrum Concept

- Input fed into channel encoder
  - Produces narrow bandwidth analog signal around central frequency
- Signal modulated using sequence of digits
  - Spreading code/sequence
  - Typically generated by pseudonoise/pseudorandom number generator
- Increases bandwidth significantly
  - Spreads spectrum
- Receiver uses same sequence to demodulate signal
- Demodulated signal fed into channel decoder

General Model of Spread Spectrum System



Gains

- Immunity from various noise and multipath distortion
  - Including jamming
- Can hide/encrypt signals
  - Only receiver who knows spreading code can retrieve signal
- Several users can share same higher bandwidth with little interference
  - Cellular telephones
  - Code division multiplexing (CDM)
  - Code division multiple access (CDMA)

Pseudorandom Numbers

- Generated by algorithm using initial seed
- Deterministic algorithm
  - Not actually random
  - If algorithm good, results pass reasonable tests of randomness
- Need to know algorithm and seed to predict sequence

PN Sequence Generator

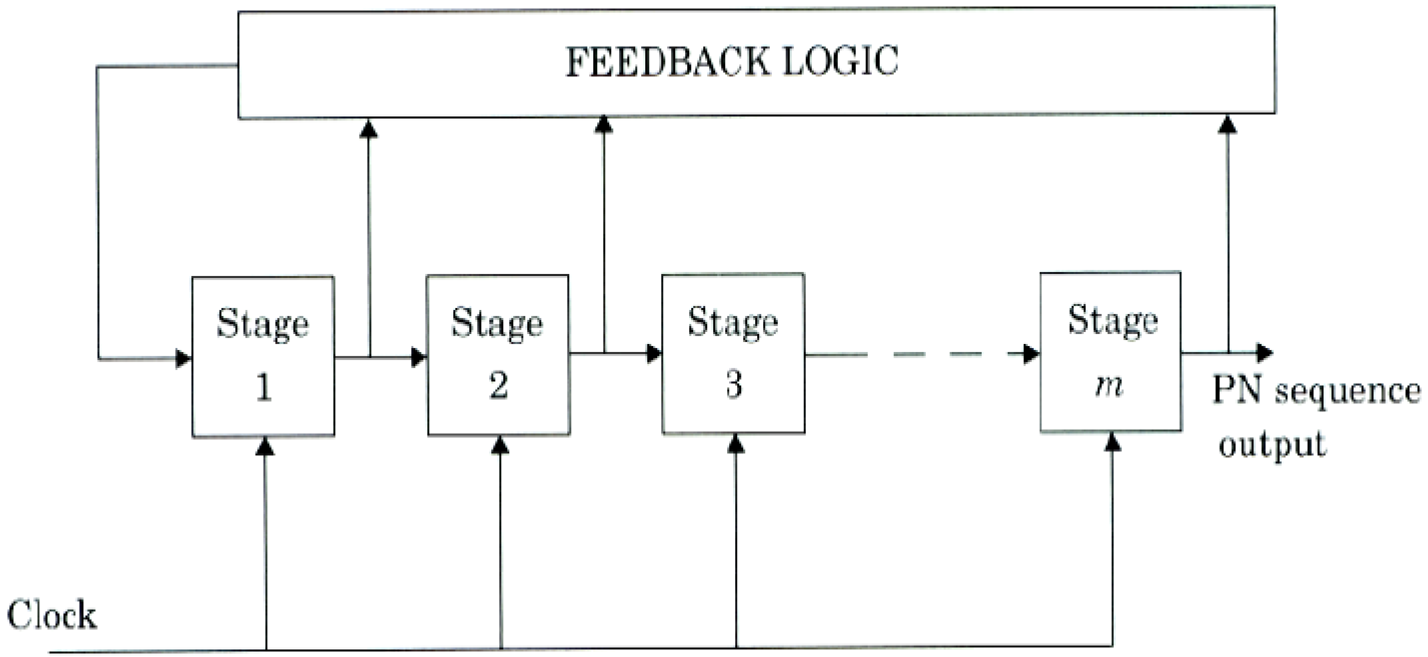


Figure 6.48 Block diagram of a generalized feedback shift register with *m* stages.

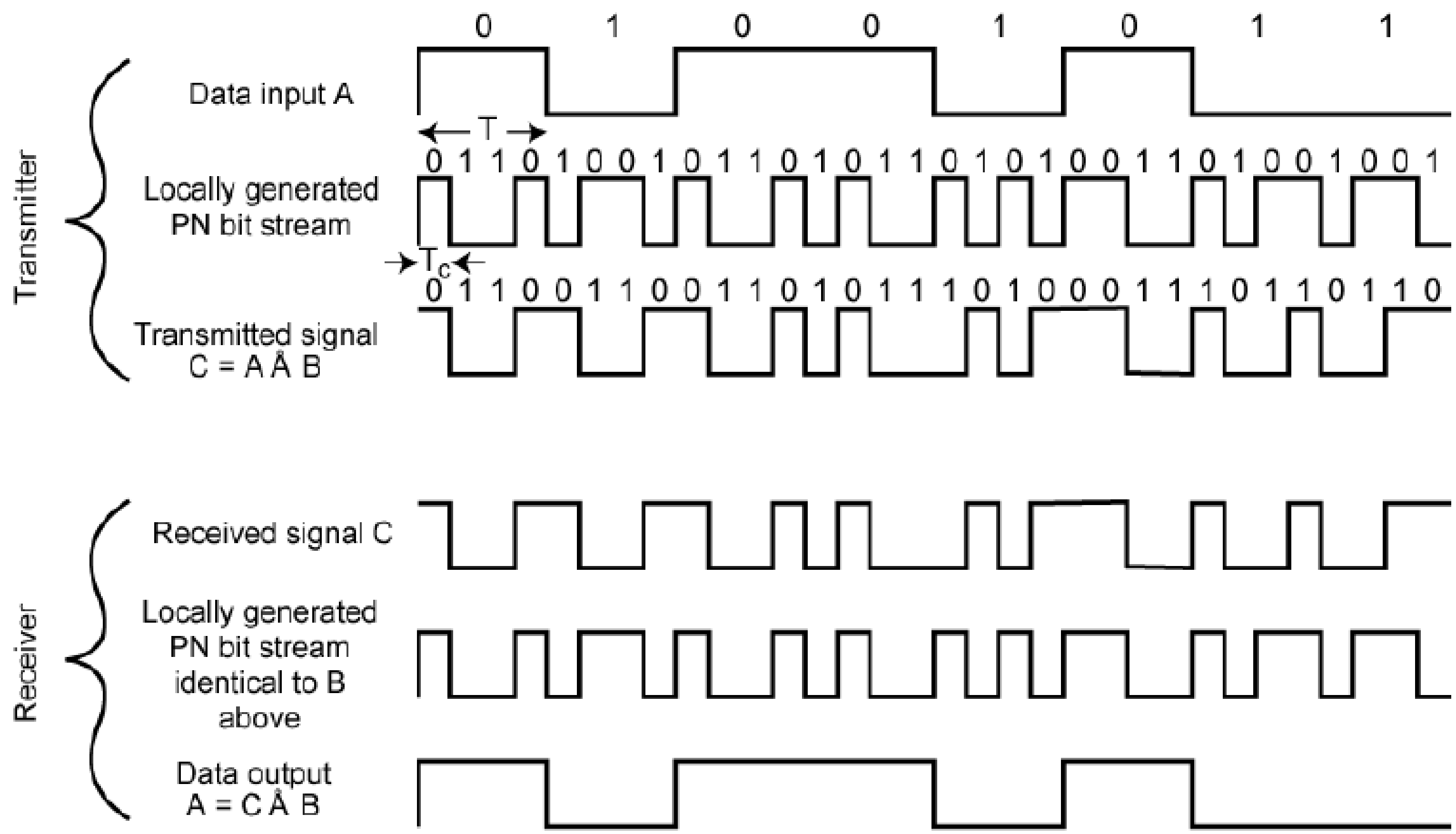
Spread Spectrum Multiple Access

- Direct Sequence Spread Spectrum (DSSS)
  - A carrier is modulated by a digital code in which the code bit rate is much larger than the information signal bit rate. These systems are also called pseudo-noise systems.
  - Also called code division multiple access (CDMA)
  - A short code system uses a PN code length equal to a data symbol.
  - A long system uses a PN code length that is much longer than a data symbol.

Direct Sequence Spread Spectrum (DSSS)

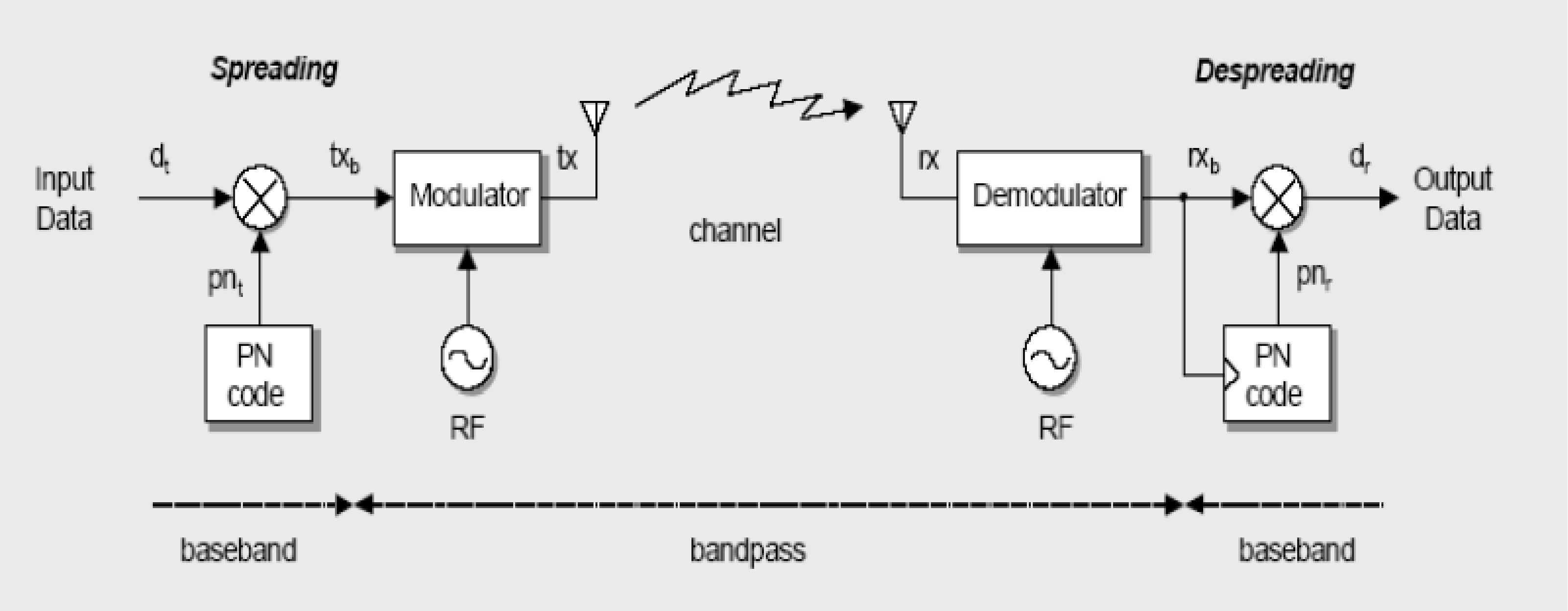
- Each bit represented by multiple bits using spreading code
- Spreading code spreads signal across wider frequency band
  - In proportion to number of bits used
  - 10 bit spreading code spreads signal across 10 times bandwidth of 1 bit code
- One method:
  - Combine input with spreading code using XOR
  - Input bit 1 inverts spreading code bit
  - Input zero bit doesn't alter spreading code bit
  - Data rate equal to original spreading code
- Performance similar to FHSS

Direct Sequence Spread Spectrum Example



Spread Spectrum Multiple Access

- Basic principle of DSSS
  - For BPSK modulation



Frequency Hopping

- Frequency hopping is a form of FDMA
- Each transmitter is allocated a group of channels, known as *hop set* .
- The transmitter transmits data in short bursts, choosing one of these channels on which to transmit each burst.

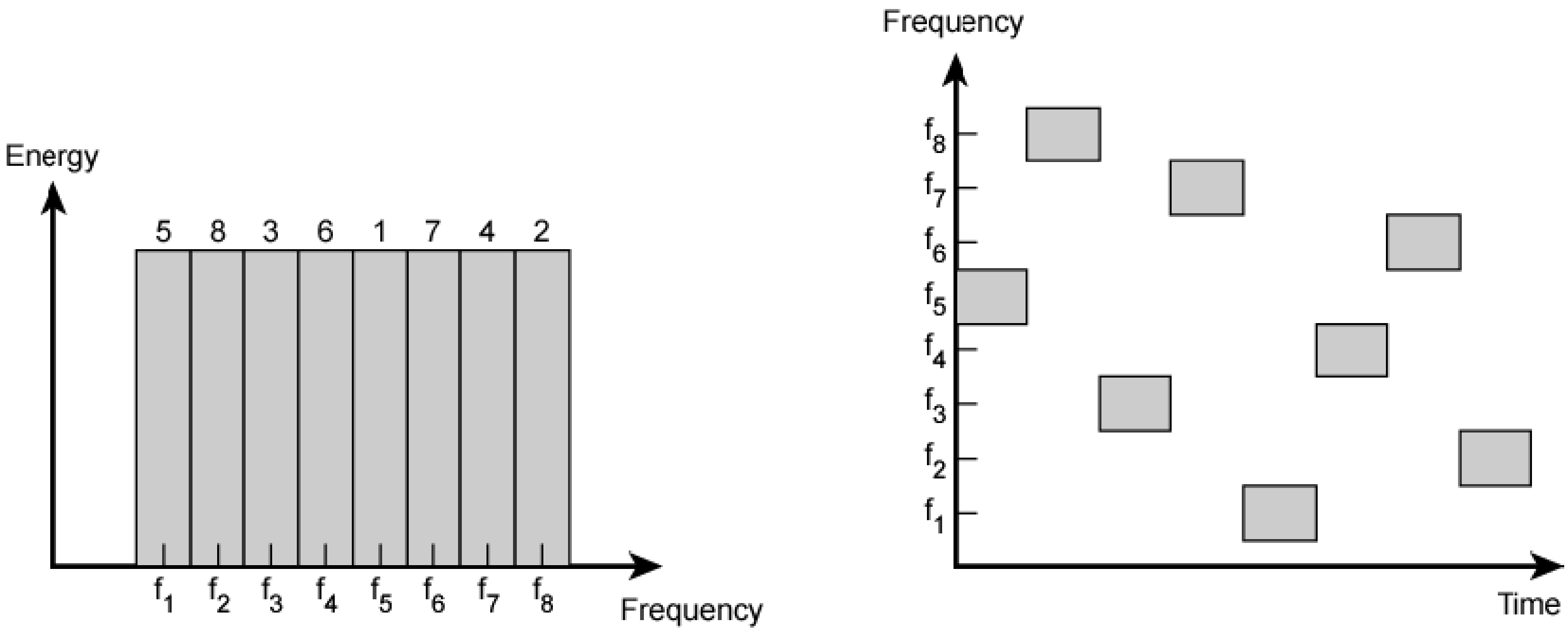
Frequency Hopping Spread Spectrum (FHSS)

- Signal broadcast over seemingly random series of frequencies
- Receiver hops between frequencies in sync with transmitter
- Jamming on one frequency affects only a few bits

Basic Operation

- Typically 2^k carriers frequencies forming 2^k channels
- Channel spacing corresponds with bandwidth of input
- Each channel used for fixed interval
  - 300 ms in IEEE 802.11
  - Some number of bits transmitted using some encoding scheme
    - May be fractions of bit (see later)
  - Sequence dictated by spreading code

Frequency Hopping Example

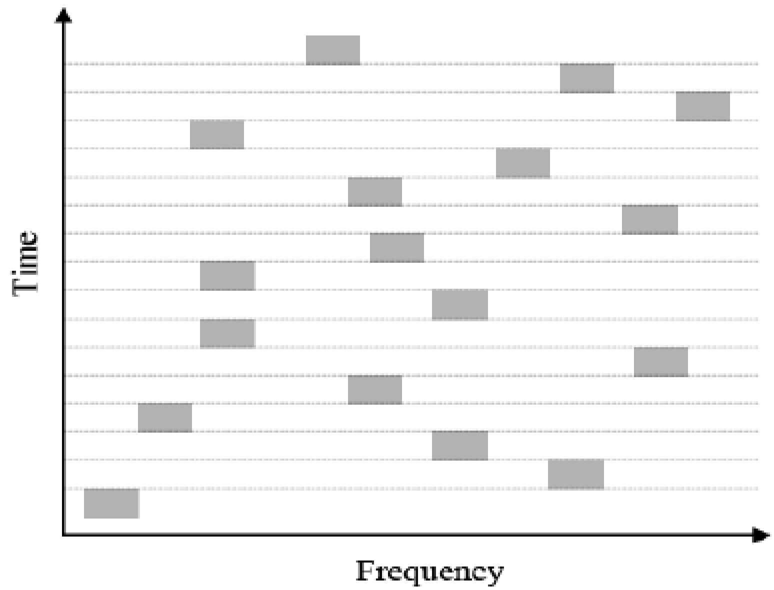


(a) Channel assignment

(b) Channel use

Frequency Hopping

- Time-frequency characteristic of a single transmitter.



Spread Spectrum Multiple Access

- Frequency Hopping Spread Spectrum (FHSS)
  - It divides available bandwidth into N channels and hops between these channels according to the PN sequence.
  - Fast hopping
  - Slow hopping

FHSS Performance Considerations

- Typically large number of frequencies used
  - Improved resistance to jamming

▪Spreading Codes

▪cdmaOne systems use two types of code sequences:

- Orthogonal sequences (Walsh codes).
- Pseudorandom Noise (PN) sequences.

▪ Long codes (2^{42} =4400 Billion)

▪ Short codes (2^{15} =32768)

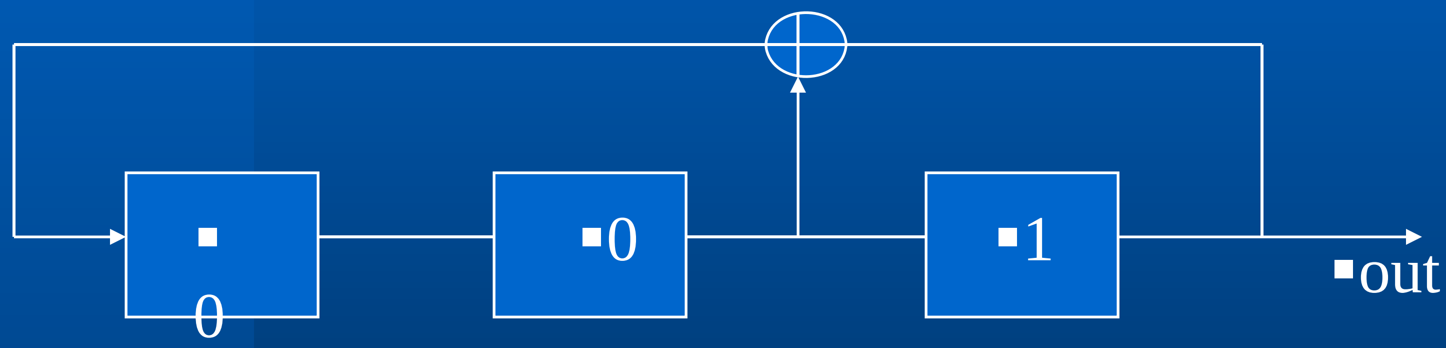
- **Walsh Codes:-**
- In CDMA the traffic channels are separated by Unique “Walsh” code. These are
- **(a) 64 codes of 64 Bit Length.**
- **(b) Forwarded traffic channel Codes.**
- **(c) All codes are orthogonal to each other.**
- **(d) These codes provide Isolation between multiple signals transmitted by base stations**

- Walsh codes are orthogonal to each other. The individual subscriber now can start communication using one of these codes. These codes are traffic channel codes and are used for orthogonal spreading of the information in the entire bandwidth. Orthogonality provides nearly perfect isolation between the multiple signals transmitted by the base station.

▪PN Code Generation

- PN Codes are generated from prime polynomials using modulo-2 arithmetic.

- State machines generating PN Codes consists of shift registers & XOR gates.



▪Output will be a 7-digit sequence that repeats continually 1001011

▪

- The length of the PN Code is equal to 2^N-1 (N= no. of shift registers).

- **LONG CODE**

- (a) 2^{42} Bits polynomials.
- (b) Forwarded channel Data (traffic and paging chls)
- scrambled.
- (c) Provides channelizations for the reverse chls.
- (d) This code is unique for every subscriber.
- (e) It is known as user address mask or user
- identification.
- (f) Subscriber are differentiated as no two same codes are used.
- (g) Repeats every 41 days (at a clock rate of 1.2288
- Mcps)

- **SHORT CODES**
- (a) This PN sequence is based on 2^{15}
- characteristics polynomial.
- (b) Differentiates cells and sectors.
- (c) Identifies cells and sectors.
- (d) Consist of codes for I & Q chls.
- (e) Each cell uses different codes.
- (f) Repeats every 26.67 msec (at a clock
- rate of 1.2288 Mcps)

Comparison SDMA/TDMA/FDMA/CDMA

Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantage	very simple, increases capacity per km²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantage	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

Autocorrelation of Sequences

- Autocorrelation refer to the degree of correspondence between a sequence and phage shifted replica of itself.
- An autocorrelation plot shows number of agreements minus disagreement for overall length of two sequences being compared.

INTRODUCTION TO CORREALATION

- IT IS FREQUENTLY NECESSARY TO BE ABLE TO QUANTIFY THE DEGREE OF INTERDEPENDANCE OF ONE PROCESS UPON ANOTHER, OR TO ESTABLISH THE SIMILARITY BETWEEN ONE SET OF DATA AND ANOTHER.
- IN OTHER WORDS CORRELATION BETWEEN THE PROCESS OR DATA IS SOUGHT
- CORREATION CAN BE DEFINED MATHMATICALLY AND CAN BE QUANTIFIED.

CORRELATION APPLICATIONS

- MANY APPLICATIONS IN SIGNAL PROCESSING, TELECOMMUNICATIONS, MEDICAL ELECTRONICS, PHYSICS ETC.....

- IN RADAR AND SONAR SYSTEMS FOR RANGE AND POSSITION FINDINGD IN WHICH TRANSMITTED AND REFLECTED WAVEFORMS ARE COMPARED.

- Detect a wanted signal in the presence of noise or other unwanted signals.
- Recognise patterns within analogue, discrete-time or digital signals.
- Allow the determination of time delays through various media, eg free space, various materials, solids, liquids, gases etc . . .

- Correlation is a comparison process.

- The correlation betweeen two functions is a measure of their similarity.

- The two ‘functions’ could be very varied. For example fingerprints: a fingerprint expert can measure the correlation between two sets of fingerprints.

- This section will consider the correlation of signals expressed as functions of time. The signals could be continuous, discrete time or digital.
- When measuring the correlation between two functions, the result is often expressed as a correlation coefficient, ρ, with ρ in the range –1 to +1.

$\rho = -1$	$\rho = 0$	$\rho = +1$
Similar but opposite	**No similarity**	**Exactly similar**

- **Correlation involves multiplying, 'sliding' and integrating**

AUTO CORRELATION AND CROSS CORRELATION FUNCTIONS

- **Auto Correlation**
- In auto correlation a signal is compared to a time delayed version of itself. This results in the Auto Correlation Function or ACF.
- Consider the function v(t), (which in general may be random or deterministic).
- The ACF, R(τ) , is given by

$$R(\tau) = \frac{1}{T} \int_{\frac{-T}{2}}^{\frac{T}{2}} v(t)v(t-\tau)dt$$

- Of particular interest is the ACF when τ = 0, and v(t) represents a voltage signal:

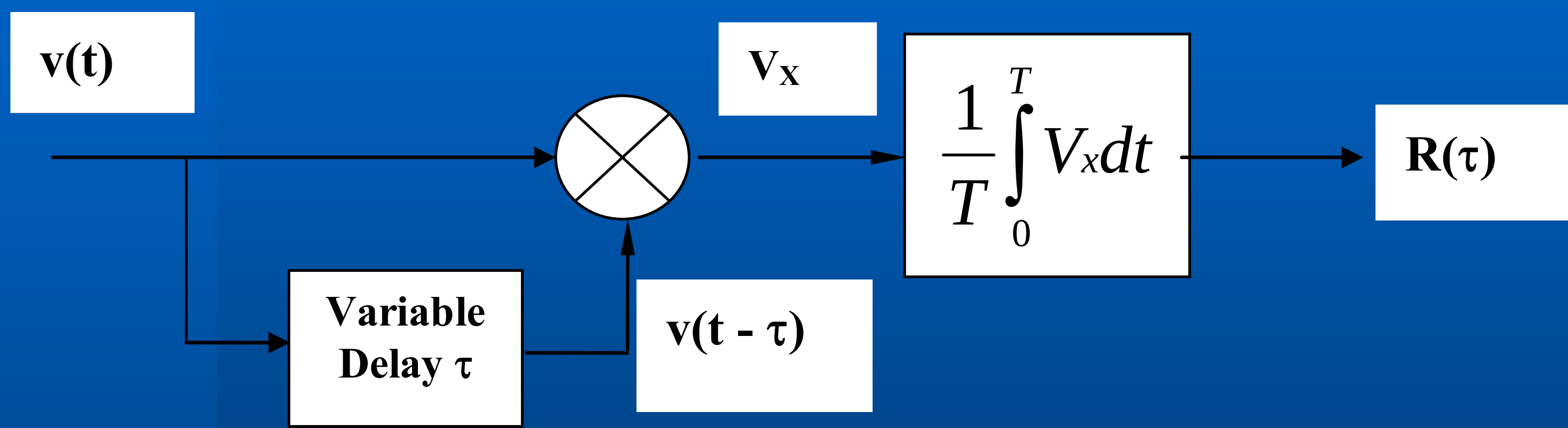
$$R(0) = \frac{1}{T} \int_{\frac{-T}{2}}^{\frac{T}{2}} v(t)^2 \, dt$$

- R(0) represents the mean square value or normalised average power in the signal v(t)

- **Cross Correlation**
- In cross correlation, two ‘separate’ signals are compared, eg the functions v1(t) and v2(t) previously discussed.
- The CCF is

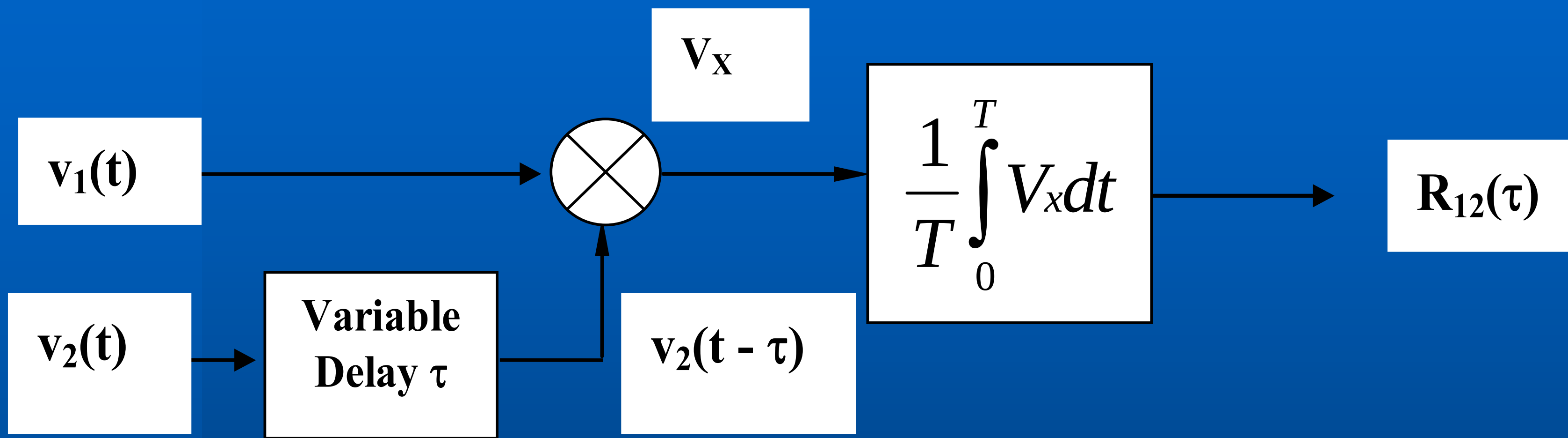
$$R_{12}(\tau) = \frac{1}{T} \int_{\frac{-T}{2}}^{\frac{T}{2}} v_1(t) v_2(t-\tau) dt$$

- Diagrams for ACF and CCF
- Auto Correlation Function, ACF



- Note, if the input is v1(t) the output is R11(τ)
- if the input is v2(t) the output is

- # Cross Correlation Function, CCF



- **CORRELATION COEFFICIENT**
- The correlation coefficient, ρ, is the normalised correlation function.
- For cross correlation (ie the comparison of two separate signals), the correlation coefficient is given by:

$$\rho = \frac{R_{12}(\tau)}{\sqrt{R_{11}(0).R_{22}(0)}}$$

- Note that $R_{11}(0)$ and $R_{22}(0)$ are the mean square values of the functions $v_1(t)$ and

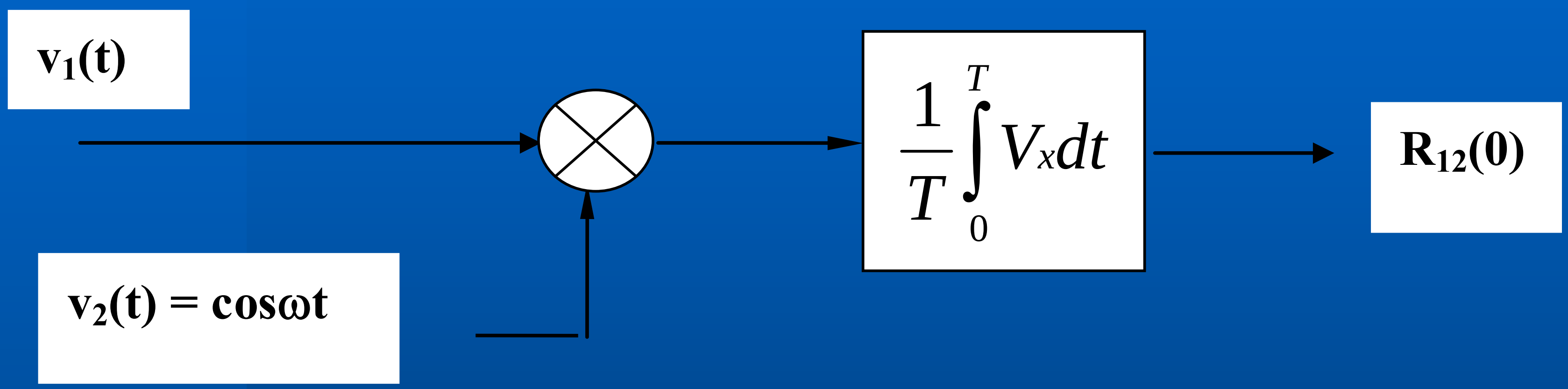
- For auto correlation (ie the comparison of a signal with a time delayed version of itself), the correlation coefficient is given by:

$$\rho = \frac{R(\tau)}{\sqrt{R(0).R(0)}} = \frac{R(\tau)}{R(0)}$$

- For signals with a zero mean value, ρ is in the range $-1 < \rho < +1$

- If ρ = +1 then the are equal (Positive correlation).
- If ρ = 0, then there is no correlation, the signals are considered to be orthogonal.
- If ρ = -1, then the signals are equal and opposite (negative correlation)

EXAMPLES OF CORRELATION – CONTINUOUS TIME FUNCTIONS



DS Acquisition & Tracking

- A direct-sequence-spread-spectrum receiver must despread the received signal to recover the transmitted data
- The receiver performs this task by correlating the received signal with a locally generated replica of the spreading code
- This locally generated code must be synchronized (in phase and frequency) to the received code to despread the received signal successfully.

Acquisition

- Initially, neither the phase nor the frequency of the spreading code of the received signal are known to the receiver.
- During acquisition, the receiver tries to find this phase and frequency. Normally, a good estimate can be given of the phase uncertainty range of *Delta_T* seconds and the frequency uncertainty to a range of *Delta_Omega* (expressed in radians/second).

Acquisition

- This limits the search area to the so called "phase/frequency uncertainty region".
- This phase/frequency uncertainty region may be graphically represented as a rectangle with dimensions *Delta_T* by *Delta_Omega*,

Acquisition

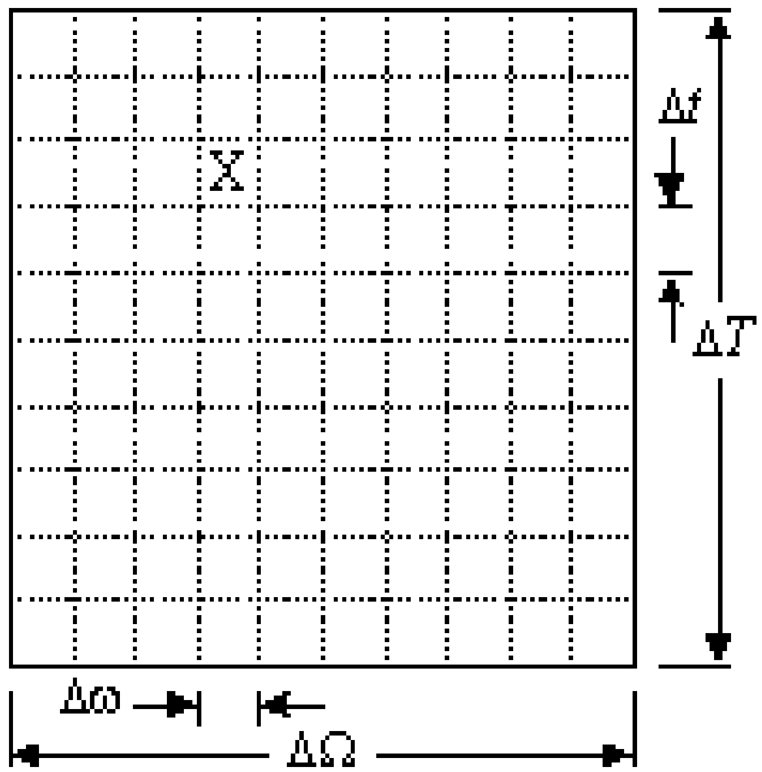


Figure: Phase/frequency uncertainty region.
X denotes the received frequency and phase of the wanted signal.

Acquisition

- As the time and frequency resolution is limited during each trial, this rectangle can be subdivided into smaller rectangles with dimension *Delta_t* and *Delta_omega* .
- These smaller rectangles are called cells.
- By searching these cells the receiver can determine the correct code- phase and frequency
- Various techniques exist for finding the correct code- phase and frequency, i.e., searching the cells in the phase/frequency uncertainty region.

Acquisition

- One such technique is single-dwell serial-search technique
- The name of this technique means that integration in the system takes place over a fixed time (single-dwell) and that the phase/frequency uncertainty region is linearly searched (serial-search).

Acquisition

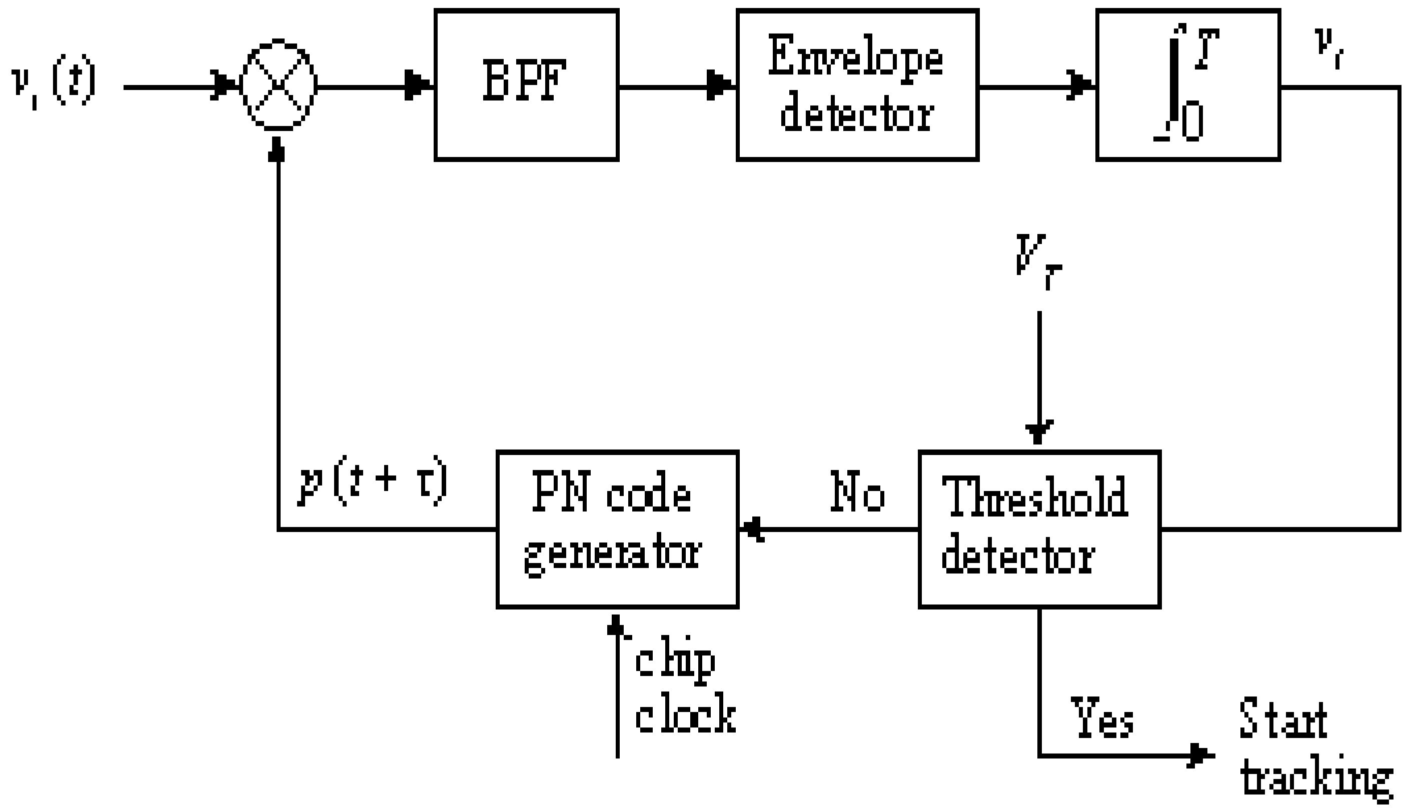


Figure: Block diagram of the single-dwell serial-search system.

Single-Dwell Serial-Search

- The output of the local code generator is a time-shifted version $p(t + tau)$ of the code sequence used by the transmitter
- The bandpass filter (BPF) is centered at the carrier frequency of the received signal and has a bandwidth equal to the data bandwidth.
- It filters the product of the received signal and the locally generated code.

Single-Dwell Serial-Search

- The output of the integrator is proportional to the autocorrelation function of the code, with offset *tau*.
- Then the integrator output is compared against a threshold *V_T*.

Single-Dwell Serial-Search

- If the signal is below the threshold, the phase or the frequency of the locally generated code will be increased to the next cell.
- If the signal is above the threshold, then the correct code phase and frequency have been found and the receiver will start tracking.

Tracking Technique-Delay-Lock Code-Tracking Loop

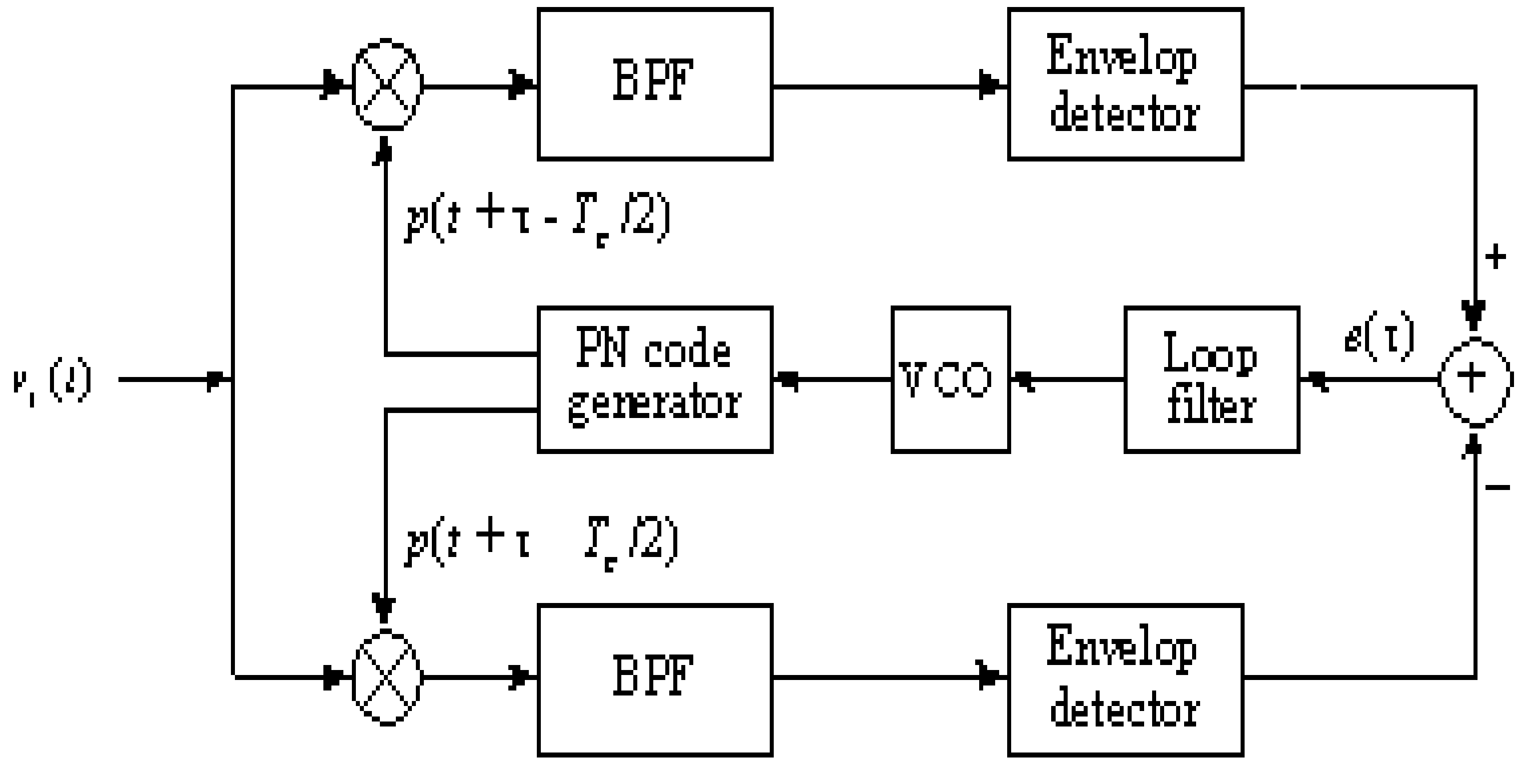


Figure: Block diagram of a DLL.

Tracking Technique-Delay-Lock Code-Tracking Loop

- The received signal is divided (by a constant factor of two to remove BPSK modulation) and then multiplied with an early (half-chip early) and a late (half-chip late) version of the locally generated code.
- Both signals are then bandpass filtered. this gives the "early and late" correlation signals.

Tracking Technique-Delay-Lock Code-Tracking Loop

- After filtering, these correlation signals are envelope-detected.
- Then, the outputs of the envelope detectors are subtracted from each other.
- This results in an error signal which can be used to control a voltage-controlled oscillator which drives the local code generator

Tracking Technique-Delay-Lock Code-Tracking Loop

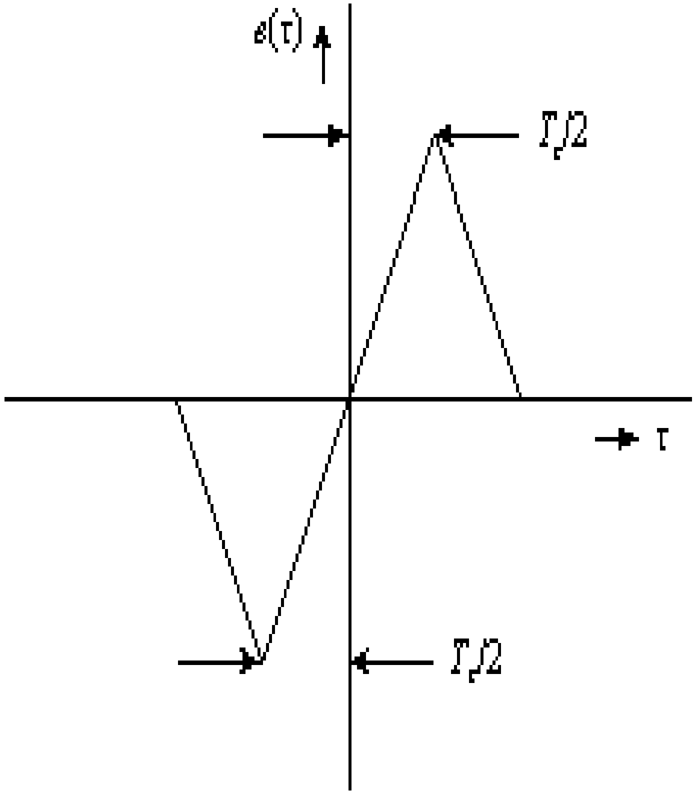


Figure: Error voltage in DLL, versus time offset *tau* between receive signal and the locally generated copy.