Analog Communications

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Analog Communication

- Receivers for CW modulation
- Multiplexing systems
- Phase locked loops
- Television systems

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Receivers for CW Modulation

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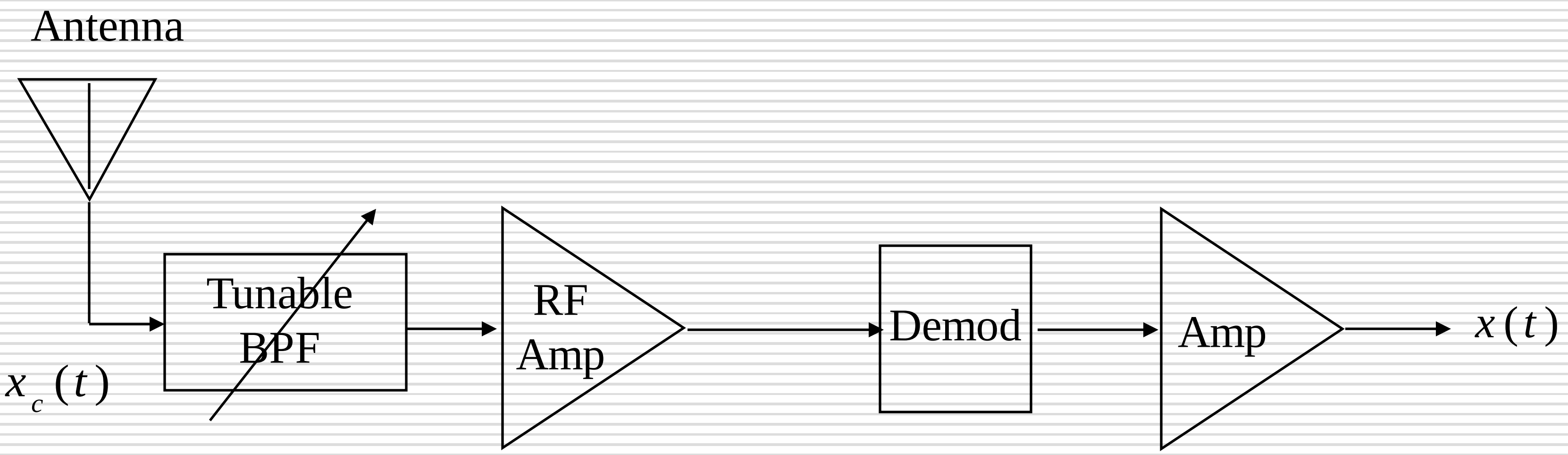
Types of Receivers

- Early days, the radio communication suffered from co-channel and adjacent-channel interference (CCI, ACI) from other stations. Then, resonance phenomenon was exploited to select desired signal at the Rx antenna and following circuit.
- Tuned RF receiver
- Superhetrodyne
- Direct conversion

Tuned RF Receiver (TRF)

- RF amplifier + demodulator
- All gain is accomplished with RF amplifier
- For the product detector TRF, selectivity and station selection is accomplished via a tuned RF amplifier
- "Crystal radio" is classic TRF



Superhetrodyne Receiver

- Input bandpass signal at f_c is mixed with a LO output to be hetrodyned (or "beat") down to an intermediate frequency f_{IF} before detection.
- Tuning done via changing the local oscillator
- Adjacent channels are rejected via a selective BPF, called a CS (channel select) filter in the IF stage.
- The IF stage $\Rightarrow$ additional stage of gain $\Rightarrow$ the RF amplifier is not required to supply all the gain $\Rightarrow$ better stability

Superhetrodyne Equations

Superhet based on property of

$$\cos\alpha\cos\beta = \frac{1}{2}\cos(\alpha-\beta) + \frac{1}{2}\cos(\alpha+\beta)$$

Multiplier output $\Rightarrow\ f_{LO} \pm f_c$ (sum and difference)

We usually choose "high side conversion" $\Rightarrow\ f_{IF} = f_{LO} - f_c$

$\Rightarrow$ For fixed $f_{IF} \Rightarrow$ tuning done via varying f_{LO}

Note: $f_{IF} = \left| f_{LO} - f_c \right|$

Superhet continued

Often the case we use

$$f_{LO} > f_{IF}$$

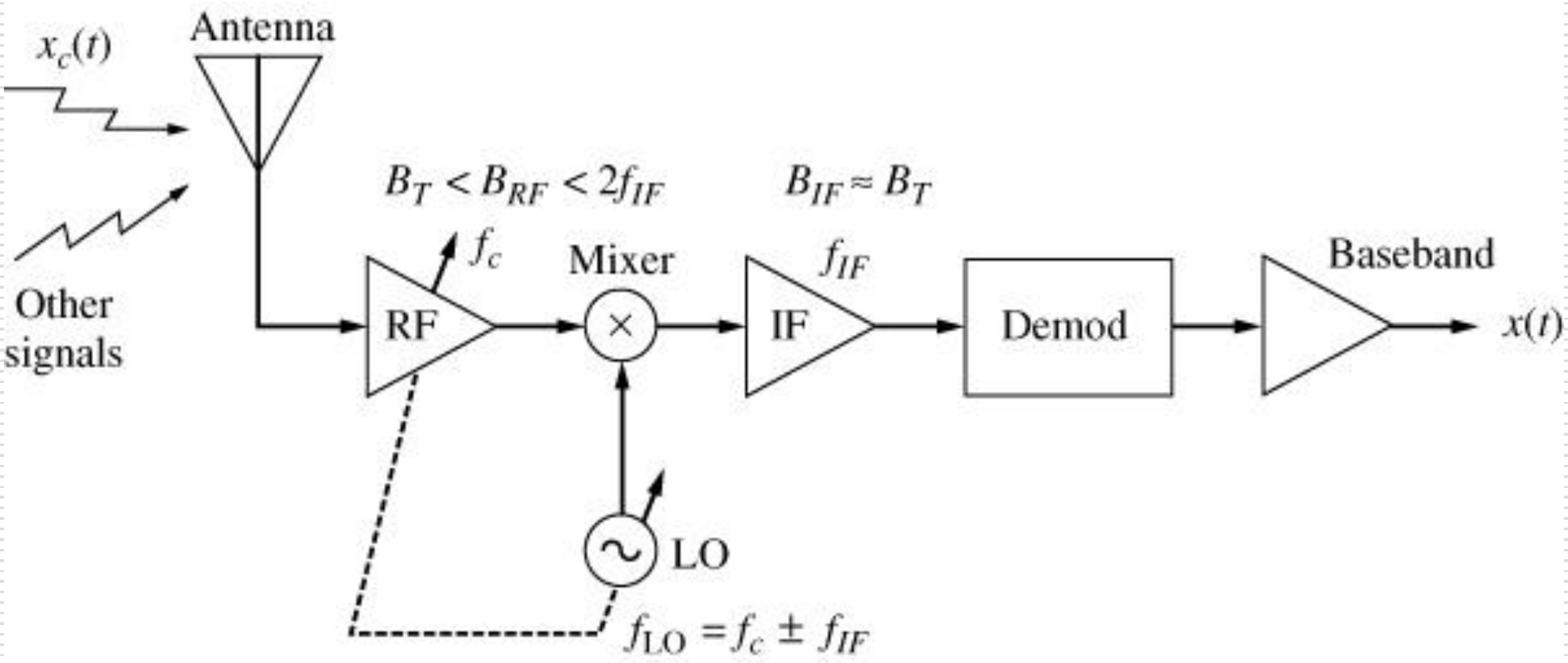
$$f_{IF} < f_c \text{ (the difference selected)}$$

$$f_c = f_{LO} - f_{IF} \Rightarrow \text{ "high side conversion"}$$

$$\Rightarrow \text{ increasing } f_{LO} \Rightarrow \text{ increases } f_c$$

High side conversion does cause sideband reversal for SSB

Superhetrodyne Receiver



Why the Superhetrodyne vs the Tuned RF

- Easier to design a CS filter, = a selective IF BPF, with fixed frequency for adjacent channel rejection versus a tunable filter

- 2 stages of gain versus 1 stage of gain $\Rightarrow$ inherently more stable (i.e. it's more difficulty to design a high gain stable RF amp)

Superhets and Images (spurious signals)

Recall mixer output $f_{IF} = \left| f_{LO} - f_c \right| \Rightarrow$

$$\Rightarrow f_{IF} = f_{LO} - f_c \text{ and } f_{IF} = f_c - f_{LO}$$

For fixed $f_{IF} \Rightarrow$

$$f_c = f_{LO} - f_{IF}$$

and

$$f_c' = f_c + 2 f_{IF} \Rightarrow \text{ image frequency}$$

Superhet receiver waveforms

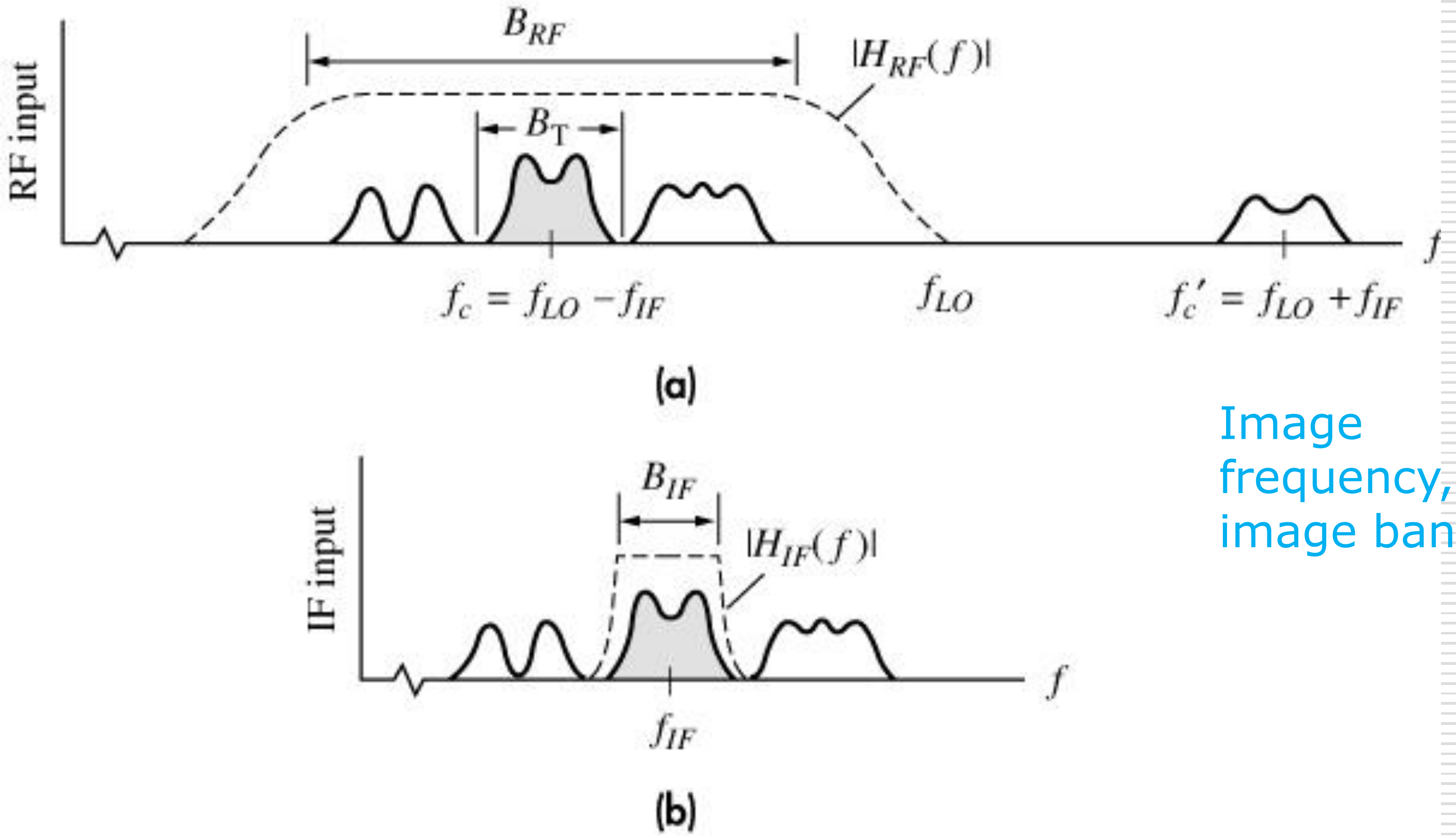


Image frequency, image band

The signal at the image frequency $f_c^{'}$ is also passed through the IF BPF

$\Rightarrow$ the listener may not be certain of the input signal's frequency, is it f_c or $f_c^{'}$?

Image Example

Broadcast AM receiver with $f_{IF} = 455$ kHz, $f_c = 1000$ kHz

$\Rightarrow \; f_{LO} = 1455$ kHz.

$\left| f_{LO} - f_c \right| = \left| 1455\text{-}1000 \right| = 455$ kHz $\Rightarrow$ expected signal is accepted

What other input frequency is accepted?

With the above values of $f_{LO} = 1455$ and $f_{IF} = 455 \Rightarrow f_c^{'} = 1910$ kHz

Test: If the receiver input is 1910 kHz $\Rightarrow$ multiplier output is

$\left| f_{LO} - f_c^{'} \right| = \left| 1455\text{-}1910 \right| = 455$ kHz $\Rightarrow$ image signal is accepted

Image Minimization

- fd
- Add selective BPF or LPF at front end, called an IR (image reject) filter
- Use higher value of IF in combination with a lower order LPF or BPF at front end

Miscellaneous for Superhet

- **LO Harmonics**

The superhet is further subject to spurious inputs if the local oscillator has harmonics.
Harmonics may leak into the mixer stage.

- **Interfering signal feedthrough by nonlinearity of IF amp**

- **Gain Control**

an automatic gain control (AGC)
an automatic volume control (AVG) in an AM radio
an automatic frequency control (AFC) in an FM radio

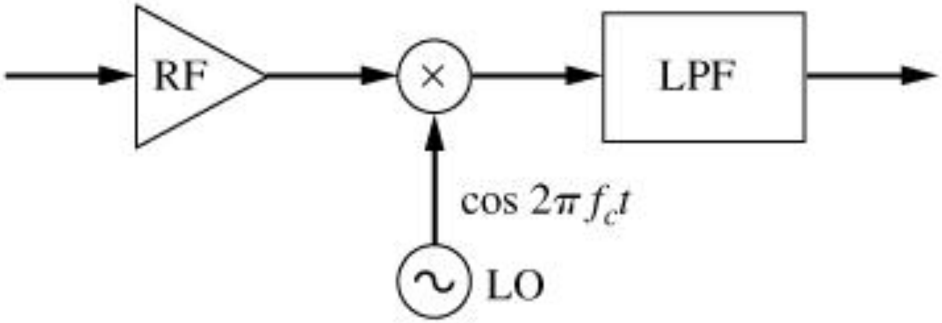
Direct Conversion Receivers

- TRF using a product detector
- Station selected via the local oscillator
- Selectivity for adjacent channel rejection in LPF stage
- Also called zero-IF or homodyne receiver
- Strictly speaking there are no images, but is subject to interference on the other sideband (see next 2 slides)
- Simple design and is often used

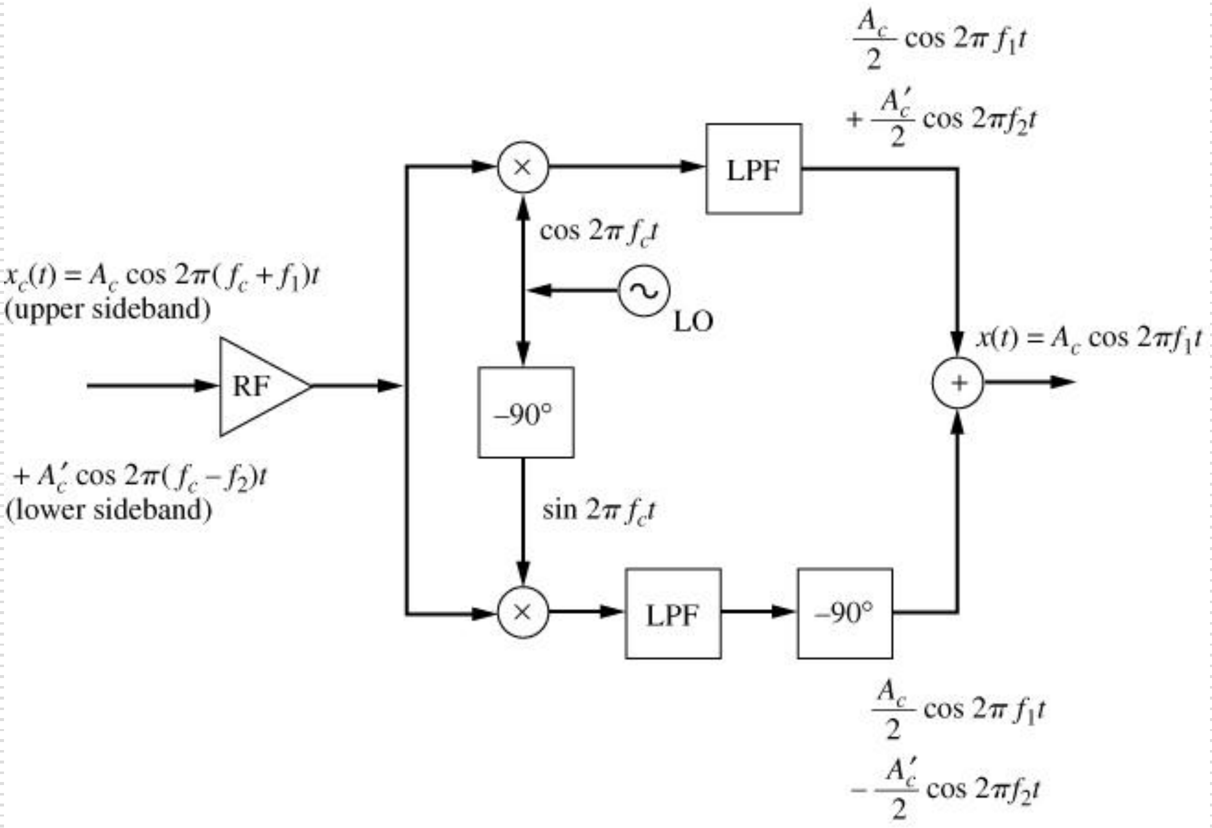
Direct conversion receiver

$$x_c(t) = A_c \cos 2\pi(f_c + f_1)t \text{ (upper sideband)}$$
$$+ A_c' \cos 2\pi(f_c - f_2)t \text{ (lower sideband)}$$

$$x(t) = \frac{A_c}{2} \cos 2\pi f_1 t + \frac{A_c'}{2} \cos 2\pi f_2 t$$



Direct conversion receiver with opposite sideband rejection



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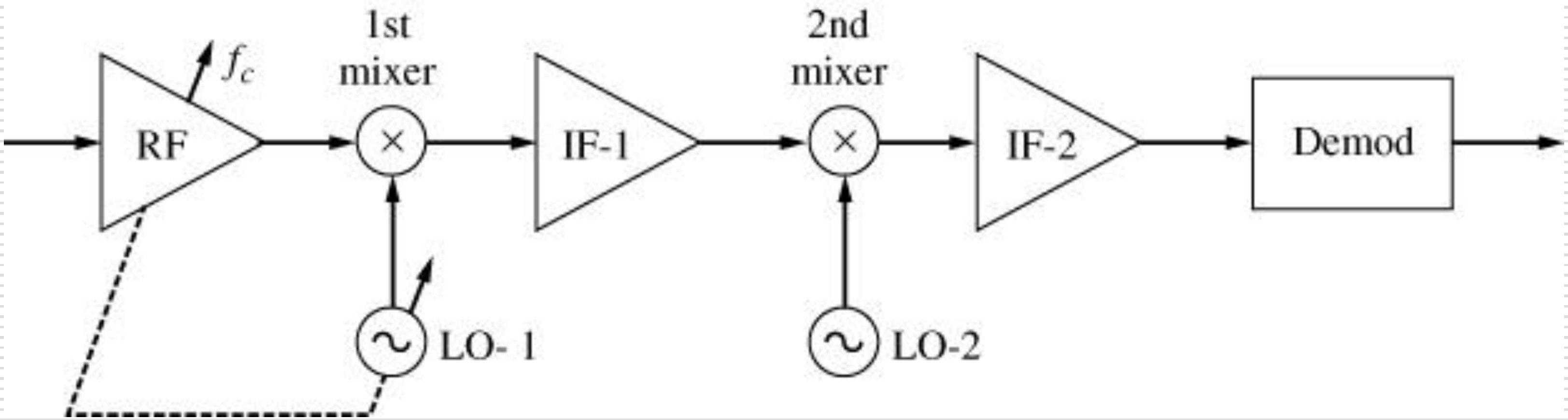
Double Conversion Receiver

- Additional IF stage, first stage with high IF for better image rejection.
- Put adjacent channel selectivity in the second IF stage BPF
- Additional gain
- Add a frequency converter to an existing receiver
- Can be subject to more spurious inputs

Double conversion receiver



Hetrodyne Receiver

- Superhet without the RF amplifier
- Often used at microwave frequencies with diode mixer

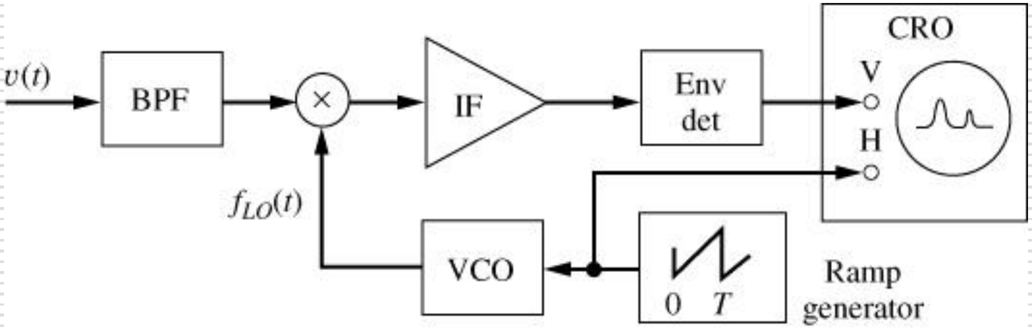
Receiver Performance Specifications

- **Sensitivity**: minimum input voltage required for a given signal-to-noise ratio
- **Dynamic range**: ability to retain linearity for varying signal strengths
- **Selectivity**: ability to reject adjacent channel signals
- **Noise figure**: how much noise does the receiver add to the signal
- **Image rejection**

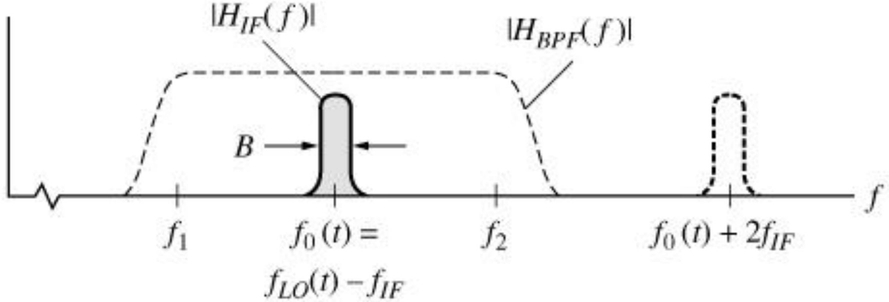
Scanning Spectrum Analyzer

- Power Spectral Density (PSD)
- Spectrum Analyzer
  - Scanning spectrum analyzer
  - DFT/FFT spectrum analyzer

Scanning spectrum analyzer (a) block diagram (b) amplitude response

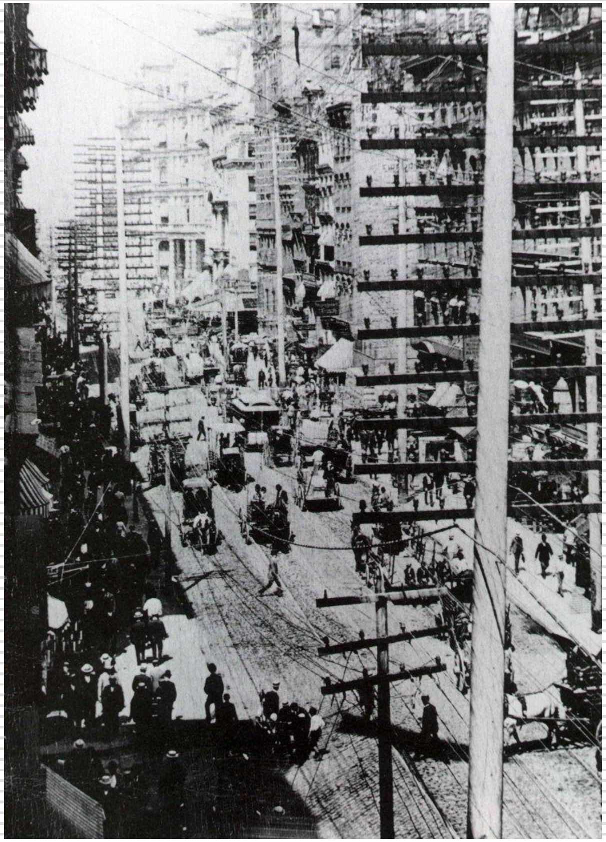


(a)



(b)

Multiplexing Systems



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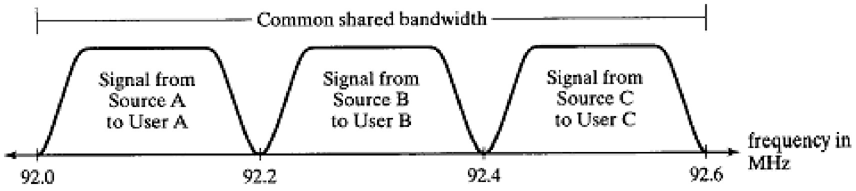
Multiplexing Systems

- Ordinarily a means to have several users **share** a channel
- A means of **diversity** to improve the reliability of the signal to reach its destination
- A means to **achieve** **Hartley-Shannon** by dividing the message in pieces, send it over different means and thereby maximize its transmission rate

Multiplexing Methods

- Frequency-division multiplexing (FDM)
- Time-division multiplexing (TDM)
- Quadrature-carrier multiplexing or quadrature amplitude modulation (QAM)
- Code-division multiplexing (see Chap. 15)
- Spatial multiplexing
  - Antenna direction
  - Signal polarization

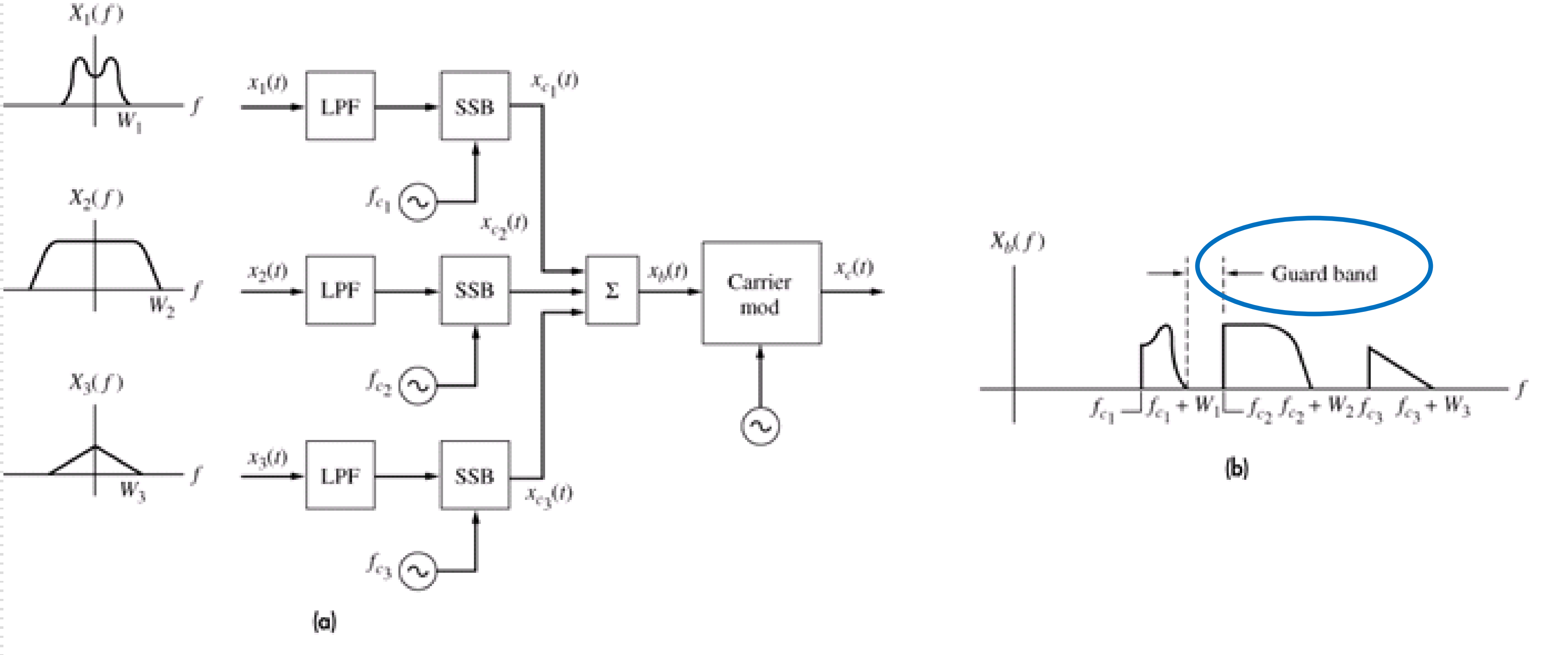
Q. Hinted by rainbow, explain how frequency-division multiplexing works.



7.2.1 Frequency-Division Multiplexing (FDM) and Frequency-Division Multiple Access (FDMA)

- Each user or message carrier is assigned a specific frequency
- Simple example is the FM broadcast band with multiple stations transmitting simultaneously from 88.1 to 107.9 MHz in 200 kHz increments.
- Spacing of stations is tradeoff between adjacent channel interference (ACI) versus # of users assigned to a channel $\Rightarrow$ Quality of service versus economics.
- **Guard bands** = spacing between users

FDM transmitter (a) input spectra & block diagram (b) baseband FDM spectrum



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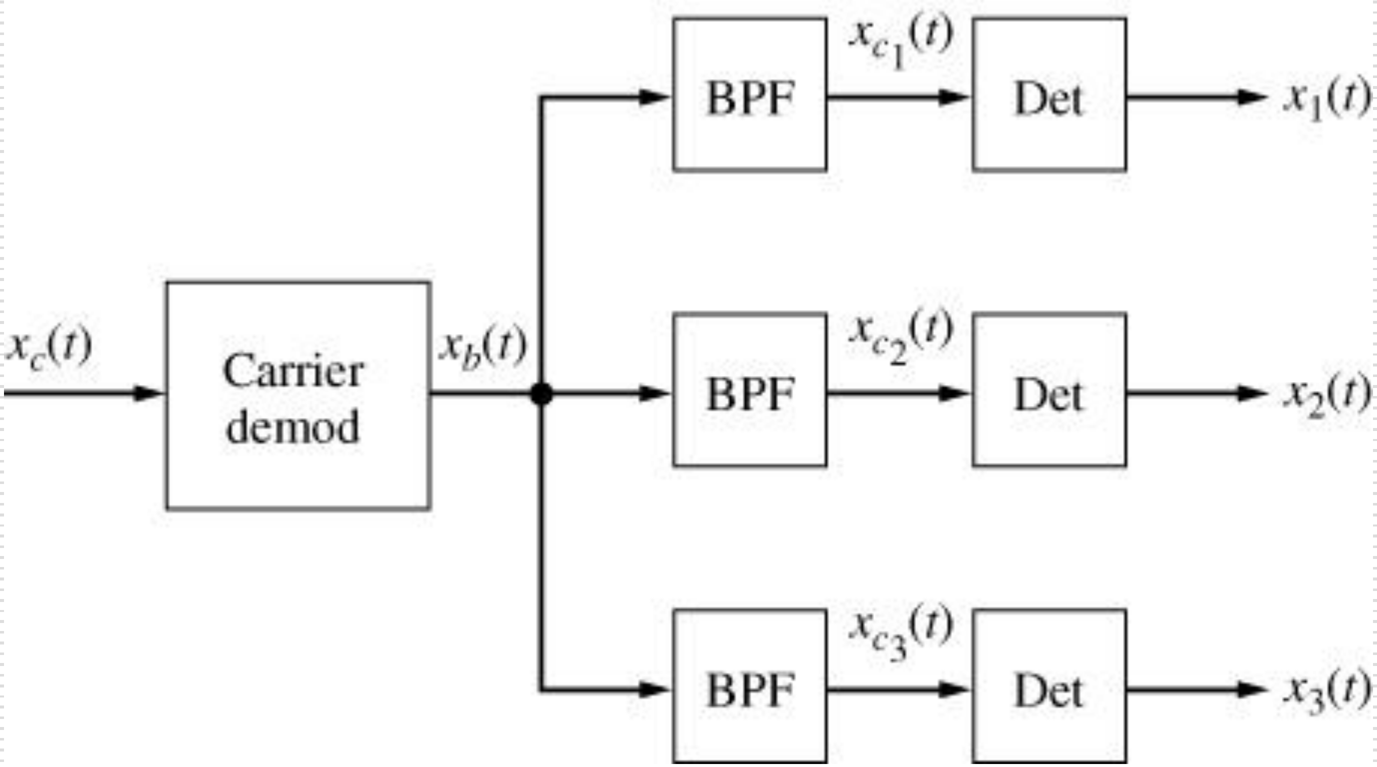
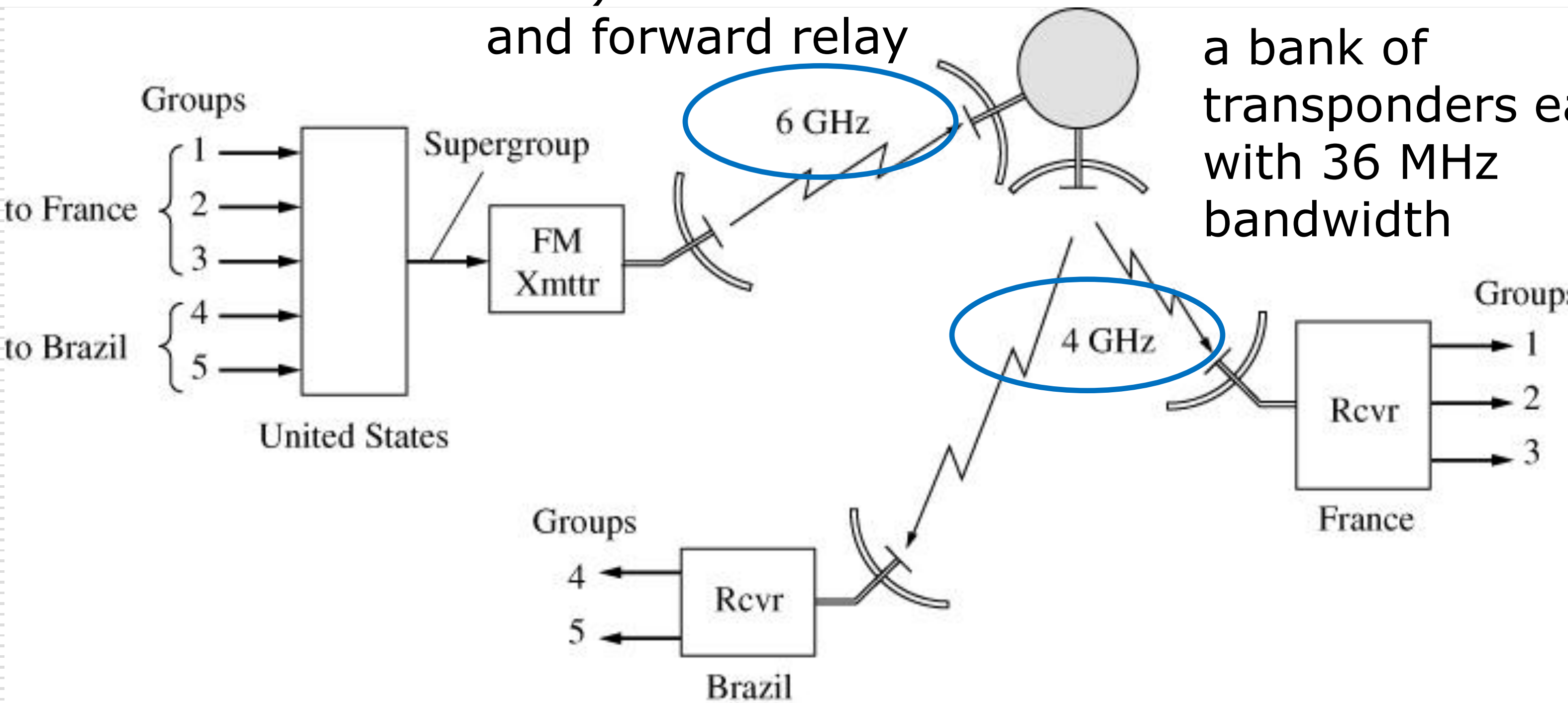
FDM Receiver



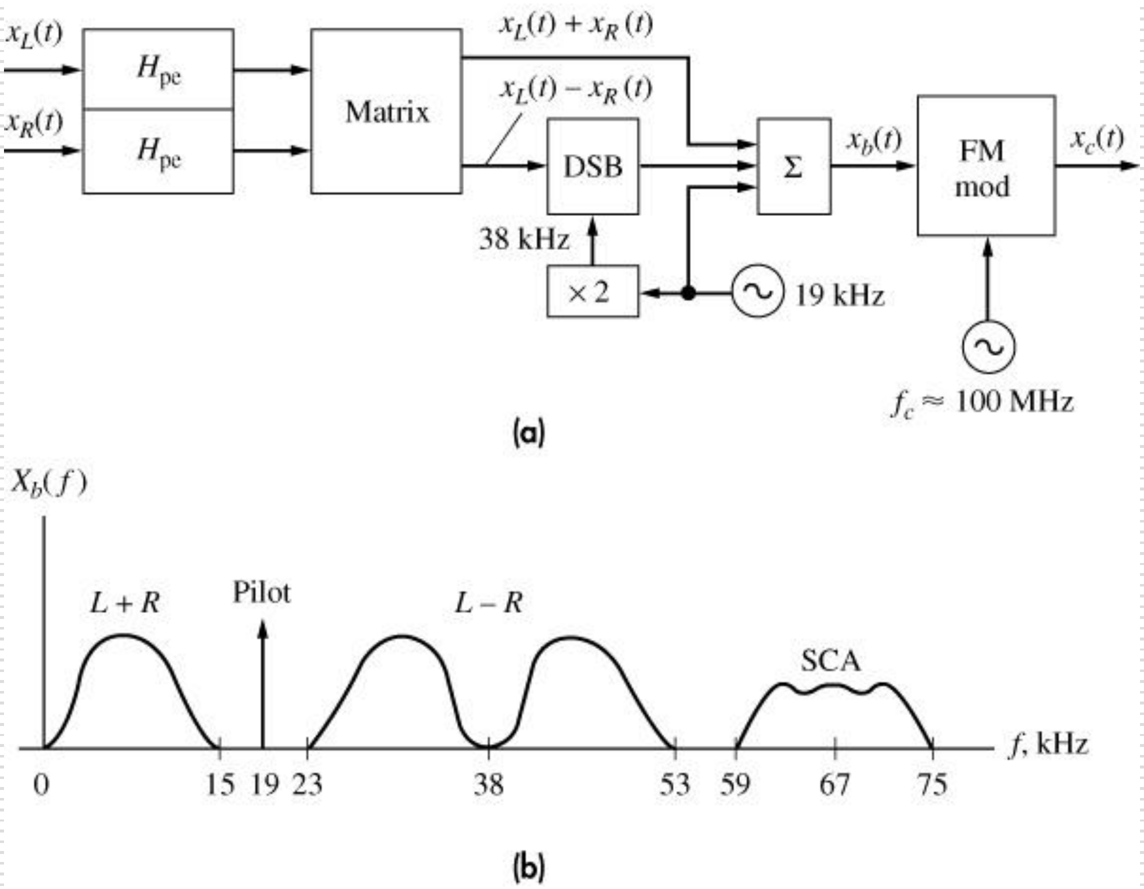
FDMA satellite system

an amplify (frequency shift)
and forward relay

a bank of transponders each with 36 MHz bandwidth



FM stereo multiplexing (a) transmitter (b) baseband spectrum



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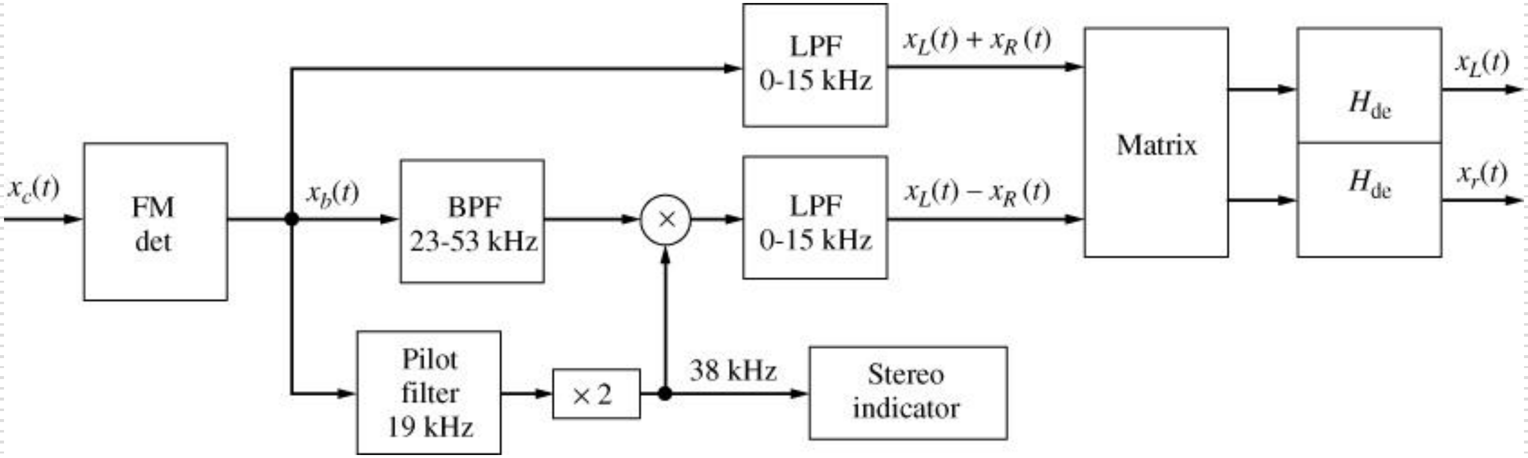
FM stereo multiplex receiver



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Other FDM Examples

- AM, FM, television broadcasts
- GSM, a 2G cellular standard, and other wireless phone technologies (often a hybrid with TDM and/or CDM)

Quadrature-Carrier Multiplexing

Orthogonality property permits 2 signals to simultaneously be transmitted on same frequency.

Two signals $x_1(t)$ and $x_2(t)$ transmitted using orthogonal carrier signals such that

$$x_c(t) = A_{c1}x_1(t)\cos\omega_c t \pm A_{c2}x_2(t)\sin\omega_c t$$

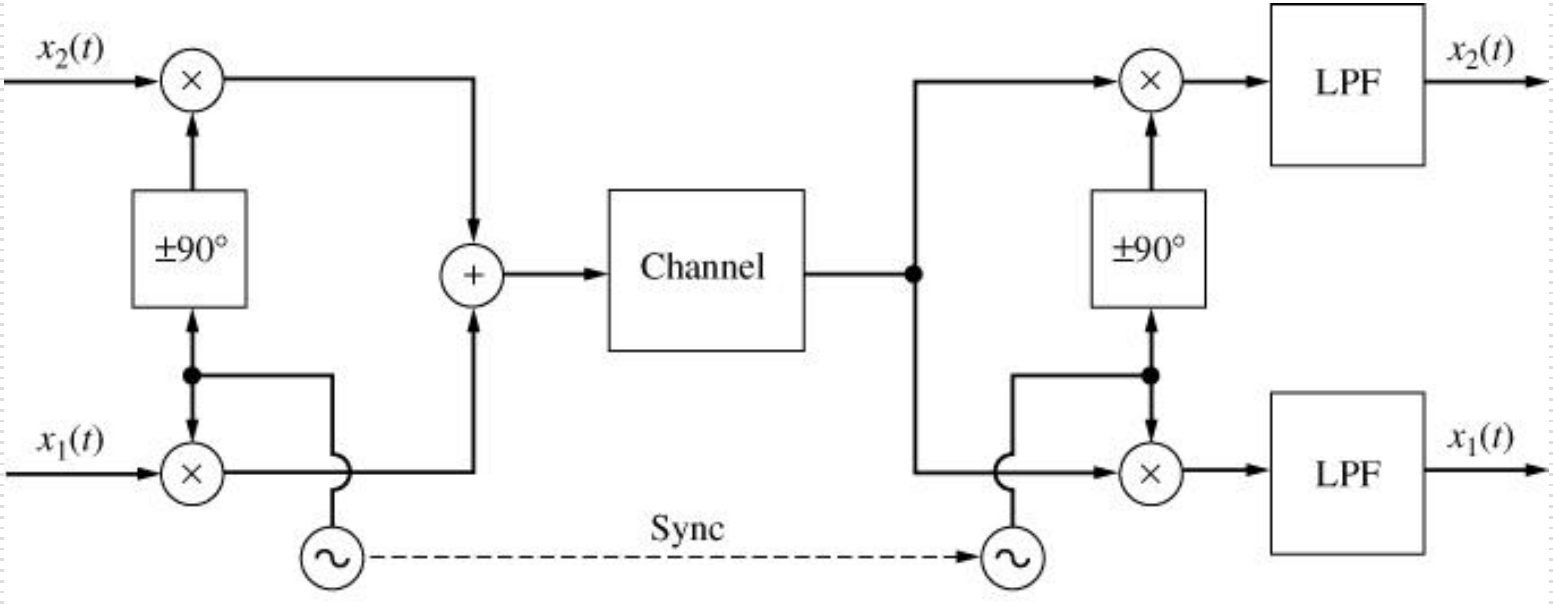
At the receiver

$$x_c(t)\times\cos\omega_c t + \text{LPF} \rightarrow x_1(t)$$

and

$$x_c(t)\times\sin\omega_c t + \text{LPF} \rightarrow x_2(t)$$

Quadrature-carrier multiplexing



an analog quadrature amplitude modulation (QAM)

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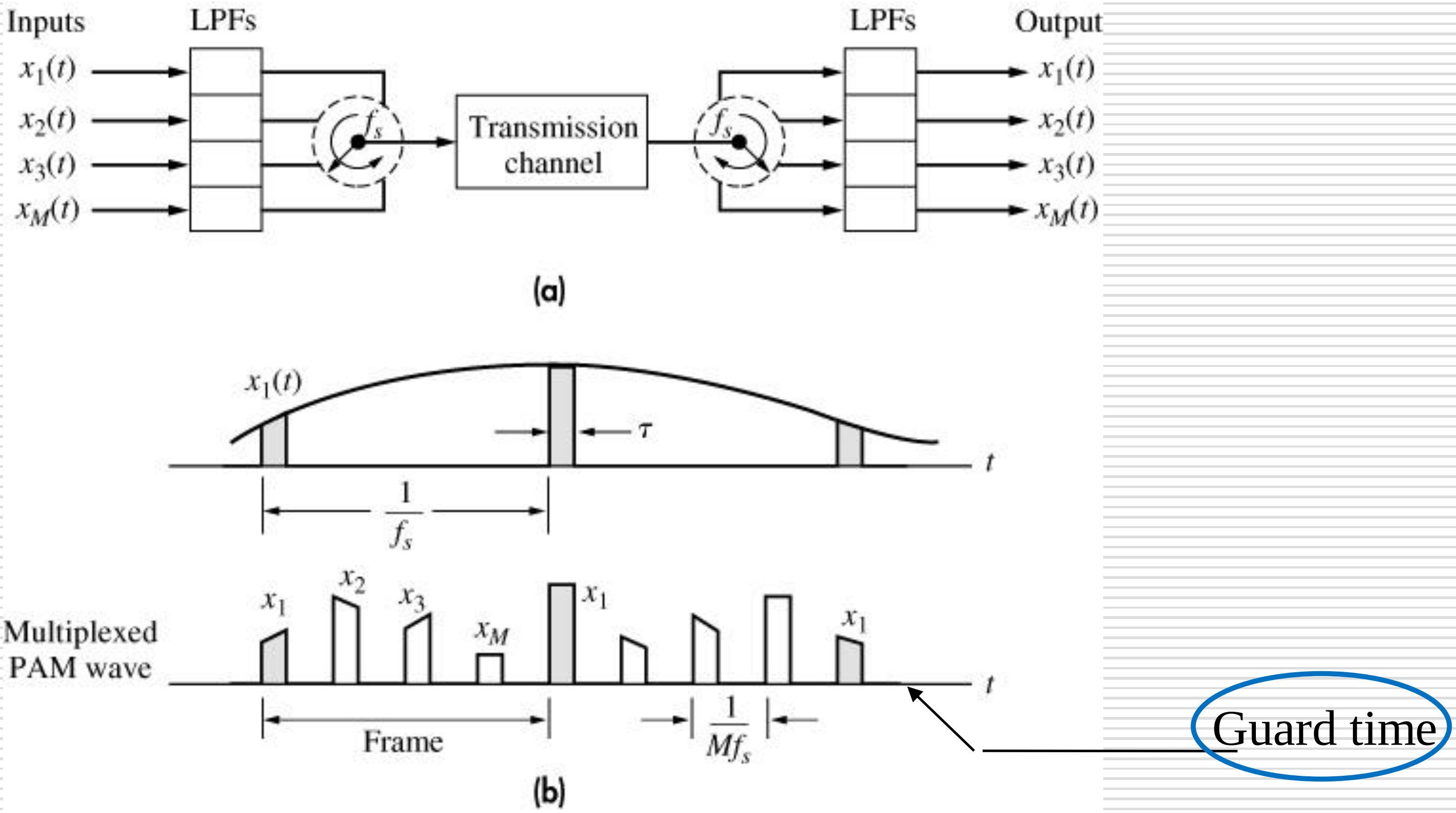
By using additional carriers that are mutually orthogonal the quadrature-carrier method can be extended to become Orthogonal Frequency Division Multiplexing (OFDM)

Time Division Multiplexing (TDM) and Time Division Multiple Access (TDMA)

- Sample different waveforms and interleave them in time so they appear to be sent simultaneously
- Guard times to prevent **intersymbol interference** (ISI)
- Time diversity

TDM system (a) block diagram (b) waveforms



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TDM Equations

A particular signal is sampled at $f_s \geq 2W \Rightarrow T_s \leq \frac{1}{2W}$

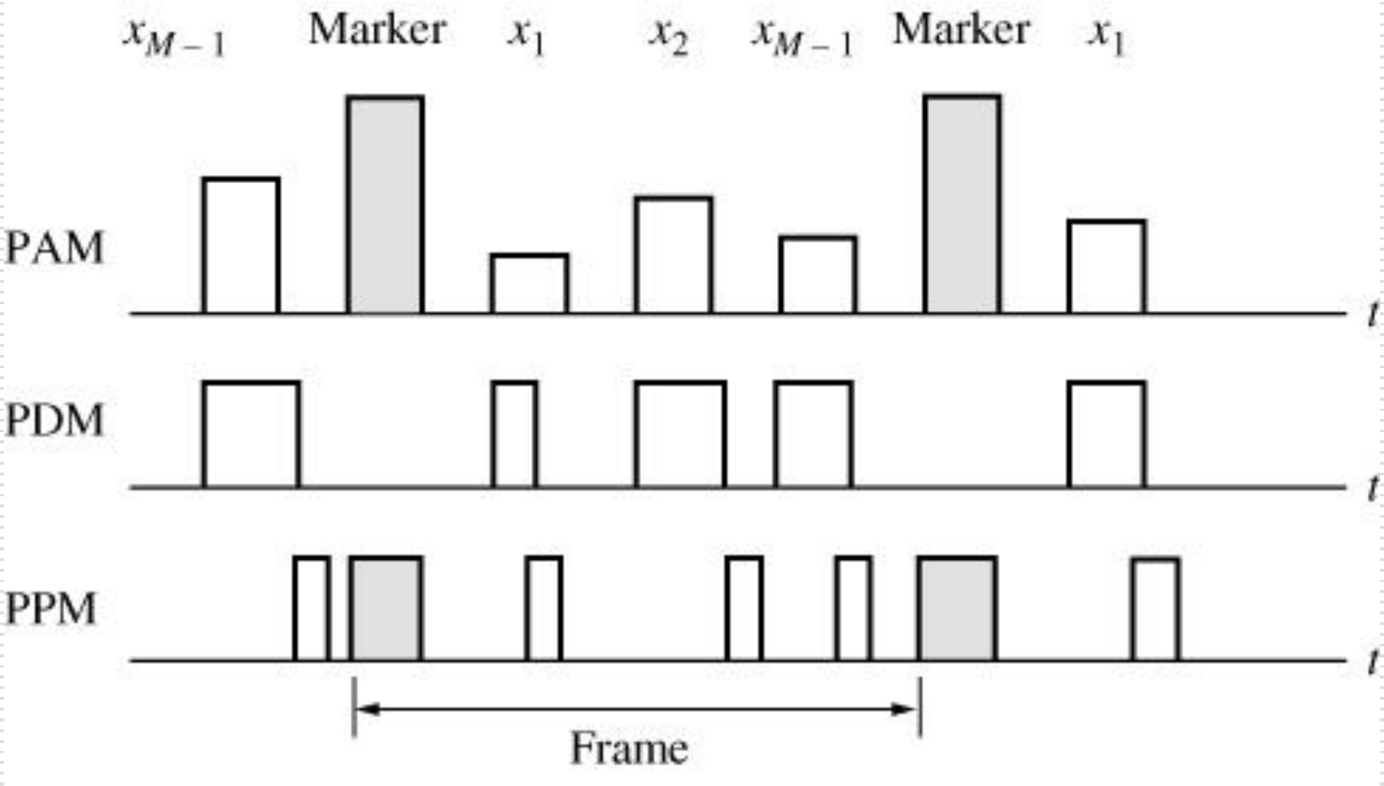
With TDM and M signals $\Rightarrow$ channel date rate $\Rightarrow$ $r = Mf_s$

and $r = 2MW$

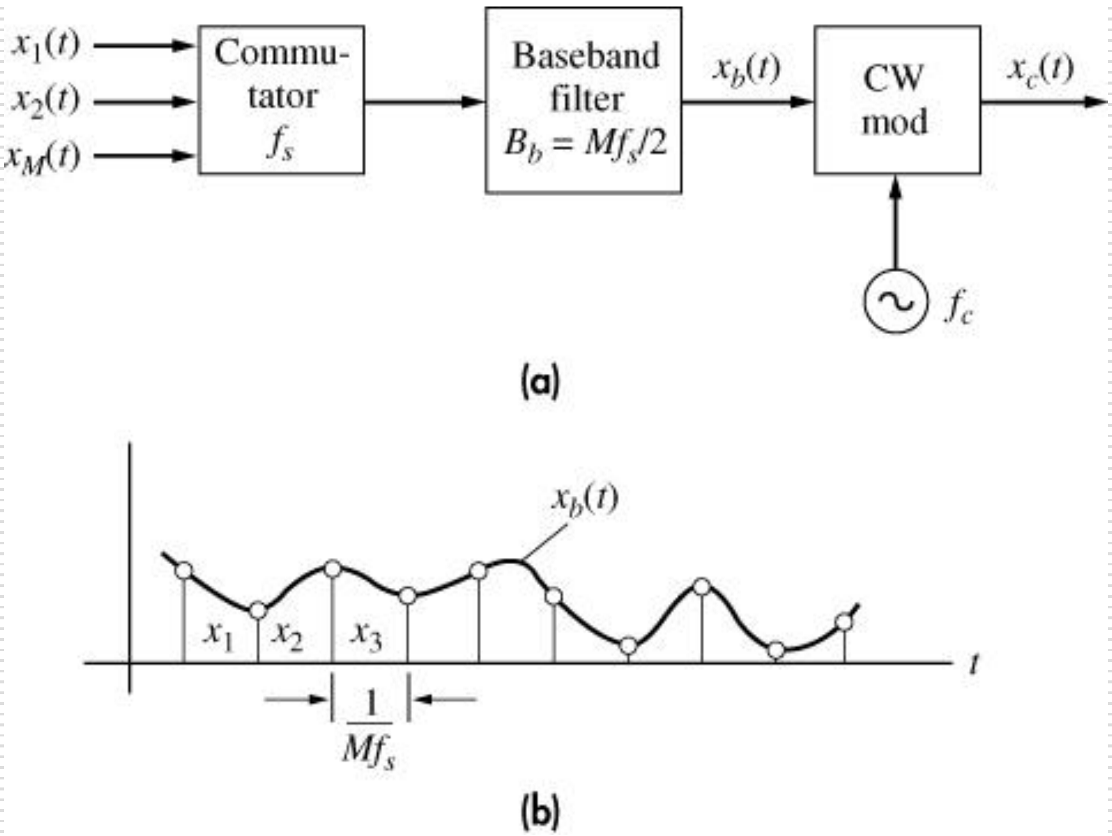
To reduce intersymbol interference (IS), we have guard times between message bits

Each set of *M* message bits makes up a *frame*

TDM synchronization markers



(a) TDM transmitter with baseband filtering (b) baseband waveform



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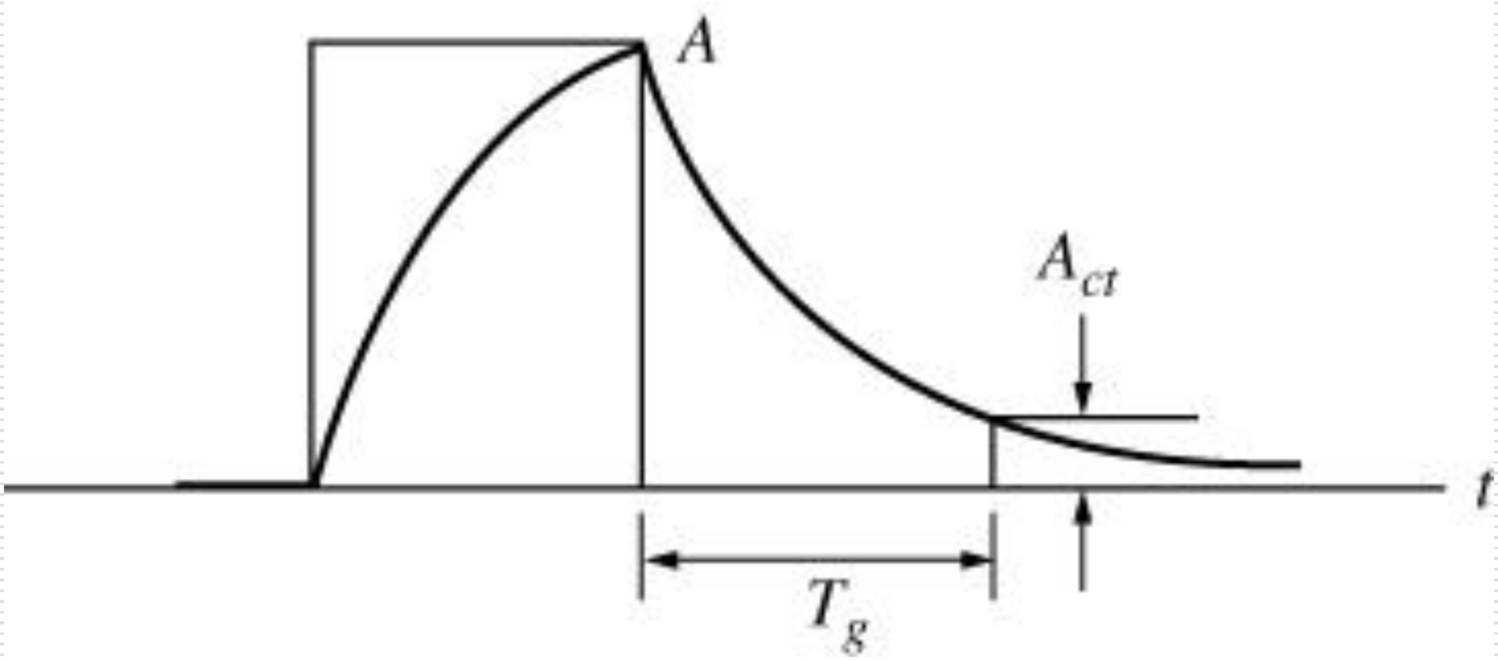
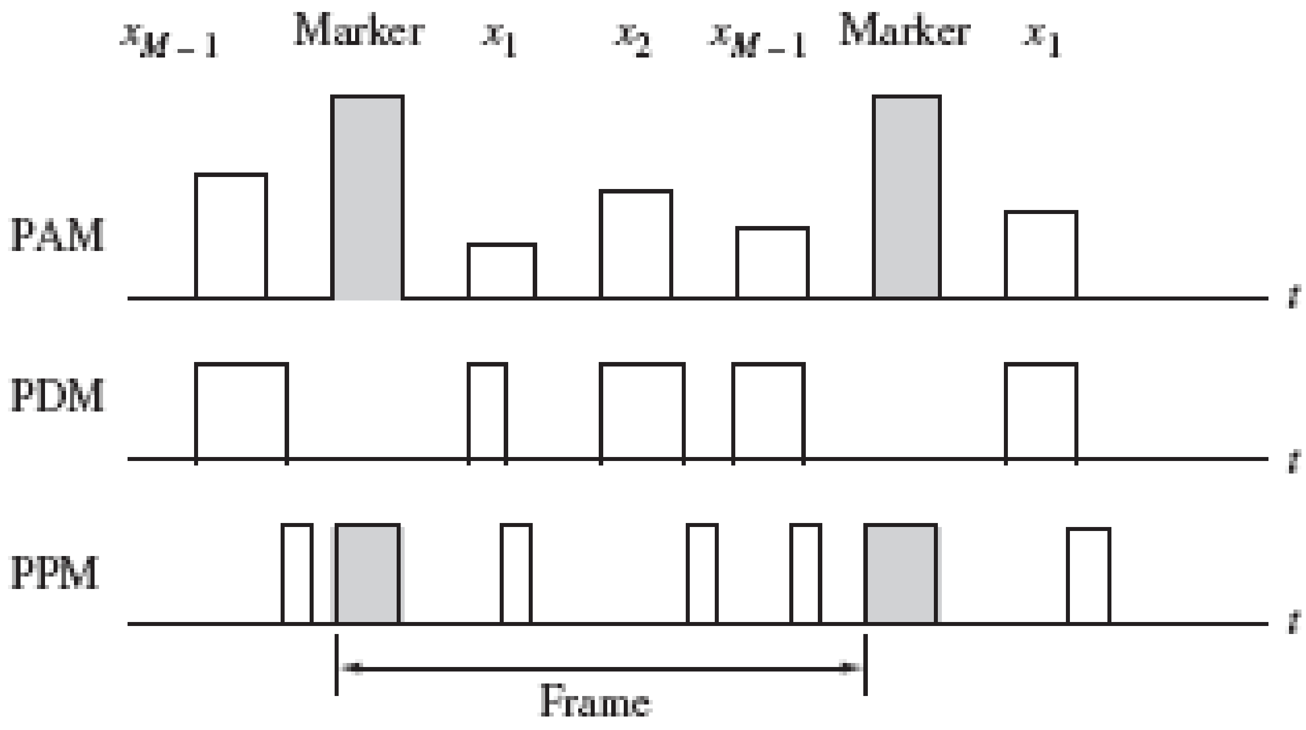
Intersymbol Interference in TDM



T_g = guard time

Postcursor from previous symbol

TDM/PPM With Guard Times And Synchronization Markers



TDM and FDM Comparison

- Many systems such as wireless phones are a hybrid of FDM and TDM or FDM, and CDM
- Without taking implementation issues into account, they are all the same.
- When 2G GSM was designed,
  - TDM lends itself to digital systems and low cost VLSI implementation
  - With submultiplexers, TDM can more easily accommodate different types of signals
  - Wideband fading $\Rightarrow$ may only affect some TDM pulses, but may all FDM channels
- When 4G LTE was designed,
  - OFDM …

Phase Locked Loops (PLL)

- Modulators,
- Demodulators,
- Frequency Synthesizers,
- Multiplexers, etc.

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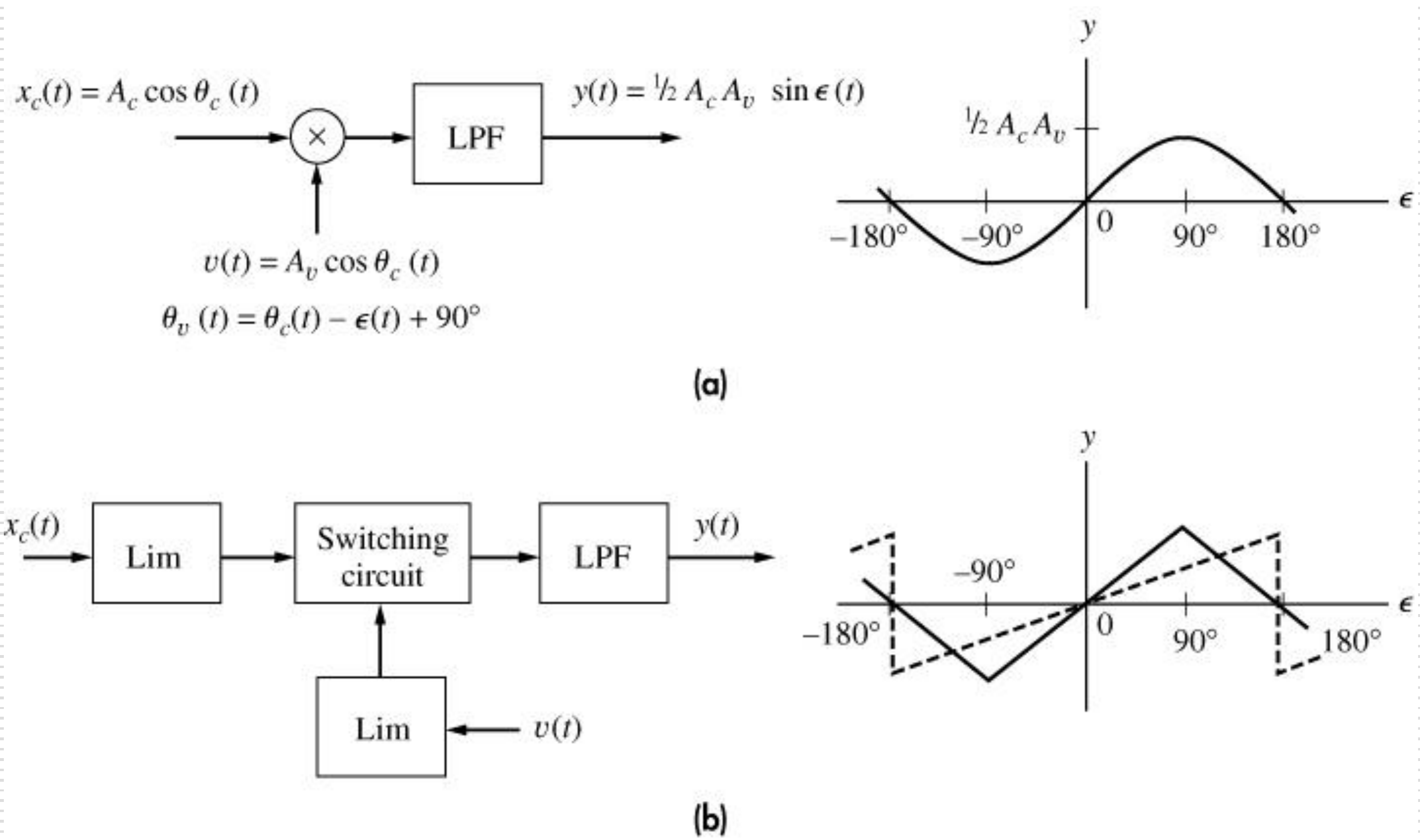
PLL Operations

- To lock or synchronize the instantaneous angle of a VCO output to that of an external bandpass signal
- Phase comparison is performed.
- DSB detection (Costas loop)
- Frequency synchronizer

PLL Applications

- Synchronous detection
- FM and PM detection
- DSB detection (Costas loop)
- Frequency synchronizer

Phase comparators (a) analog (b) digital



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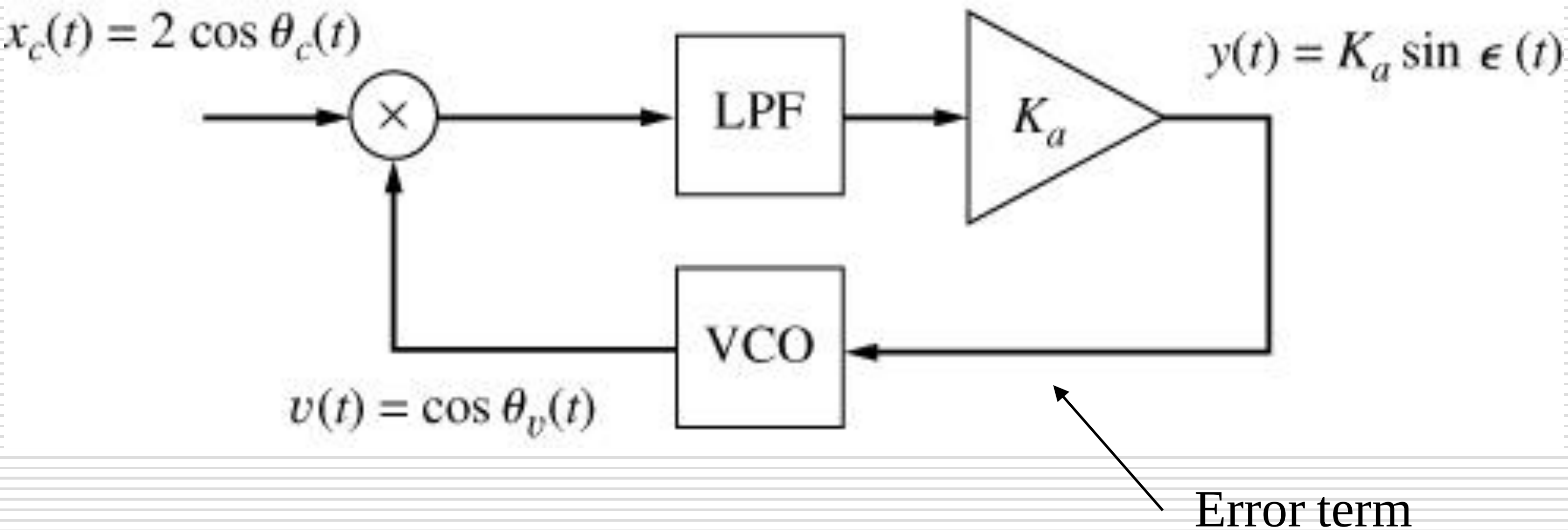
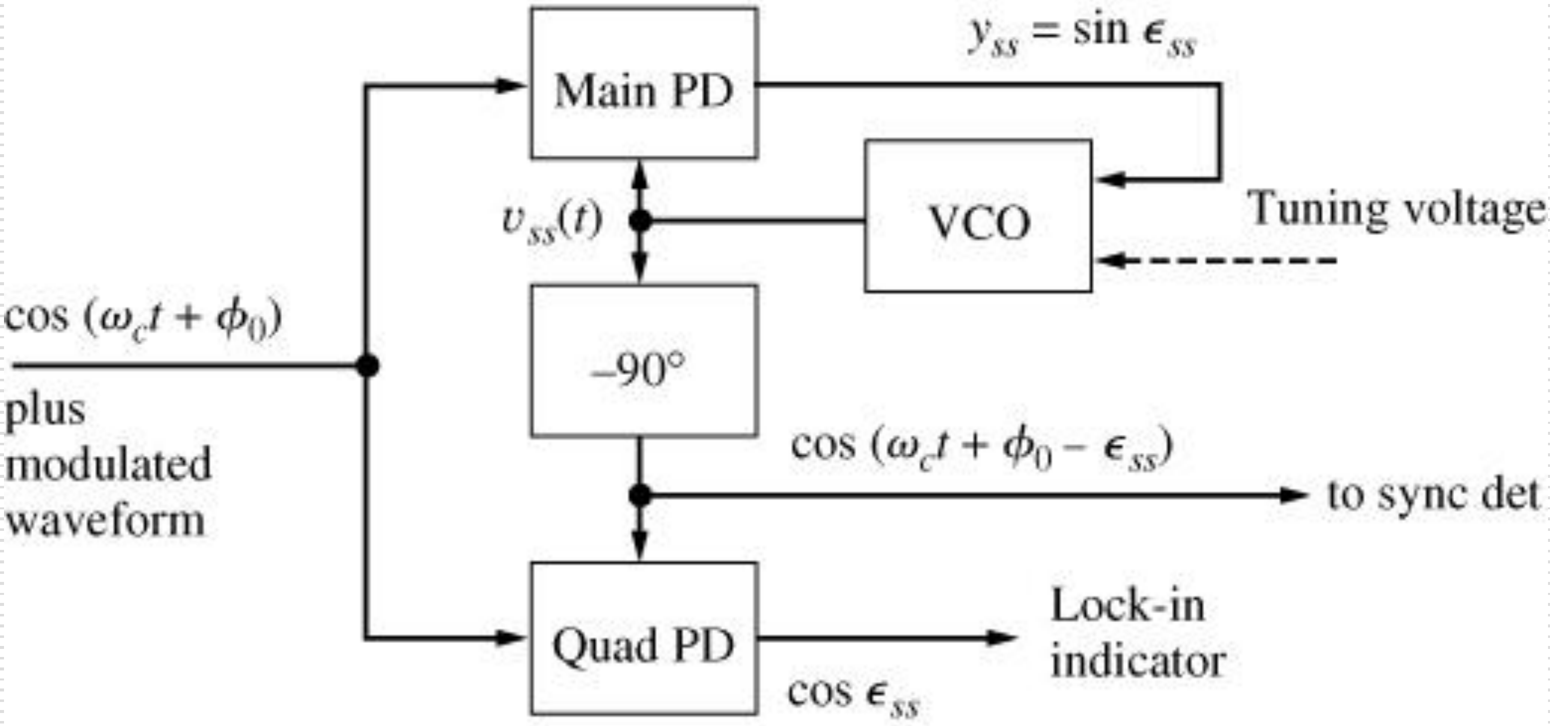
Phase-locked loop

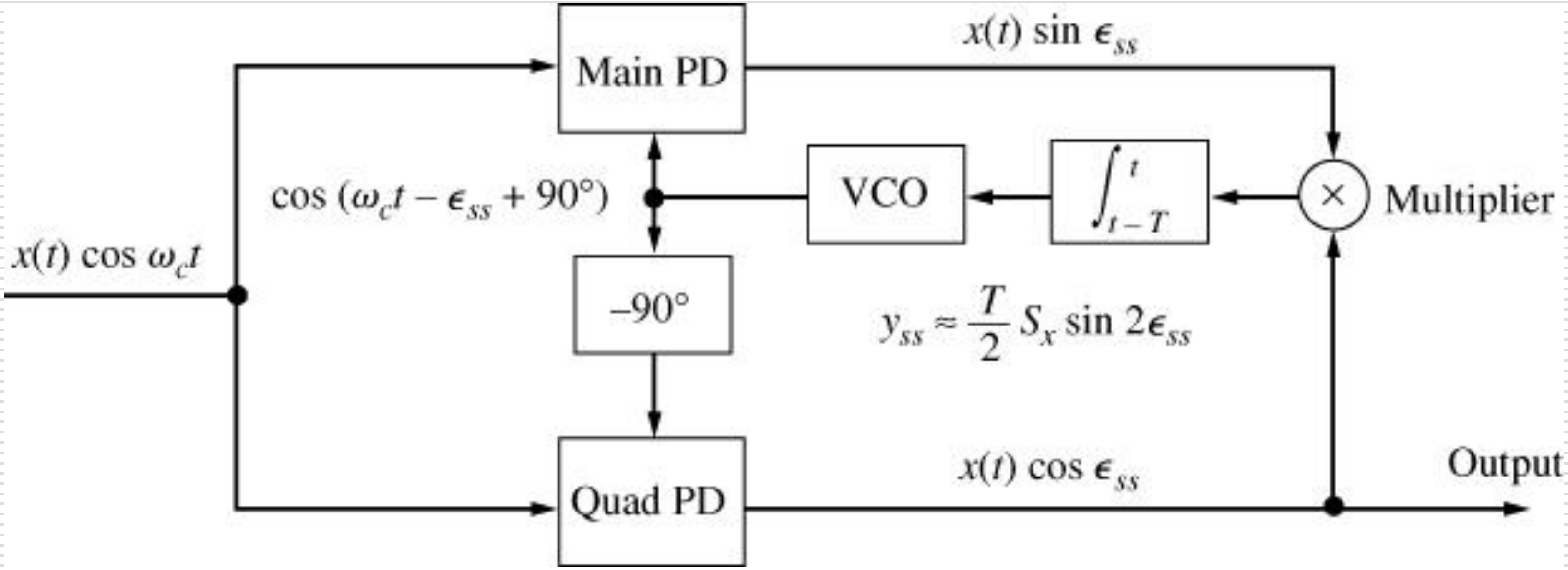


Note: $\sin[\varepsilon(t)] \approx \varepsilon(t)$ if $|\varepsilon(t)| < 1$

PLL pilot filter with two phase discriminators

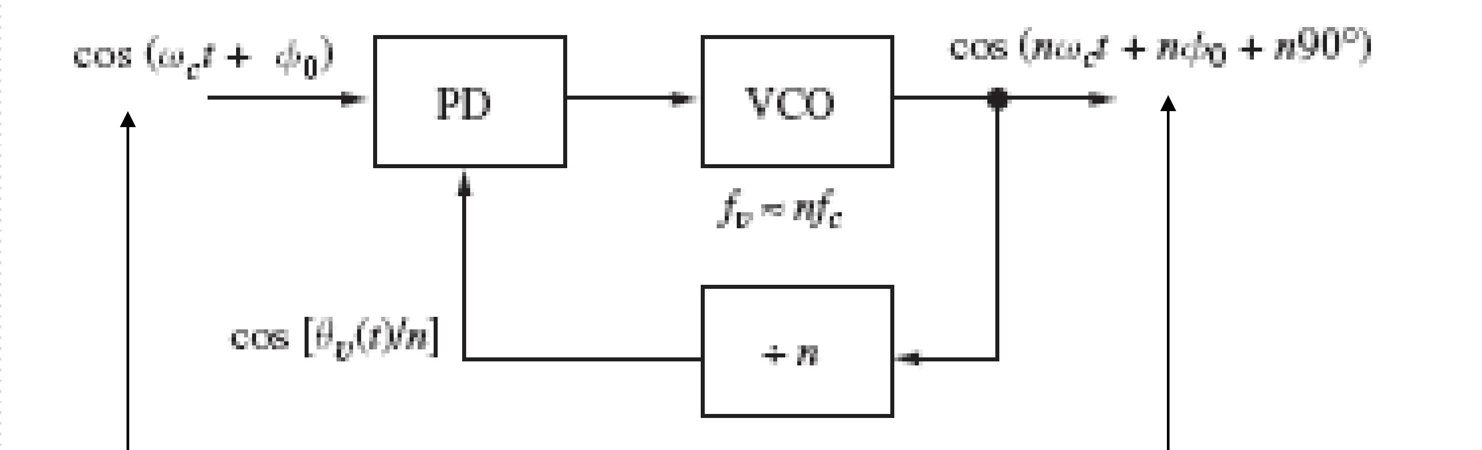


Costas PLL System For Synchronous Detection (DSB)*



*Cannot be used to detect SSB

Adjustable Local Oscillator Using a Frequency Synthesizer (e.g. for double conversion receiver)



Original local oscillator signal

Adjustable LO in increments of 0.01MHz

Frequency synthesizer with fixed and adjustable outputs