COMS3100/7100 Introduction to Communications

Lecture 16/17: Receivers for CW modulation

This lecture:

- Receiver Specifications
- Superheterodyne Receiver
- Direct Receiver

Ref: Carlson, Chapter 7; Dixon Ch 2-4

Receivers for CW modulation

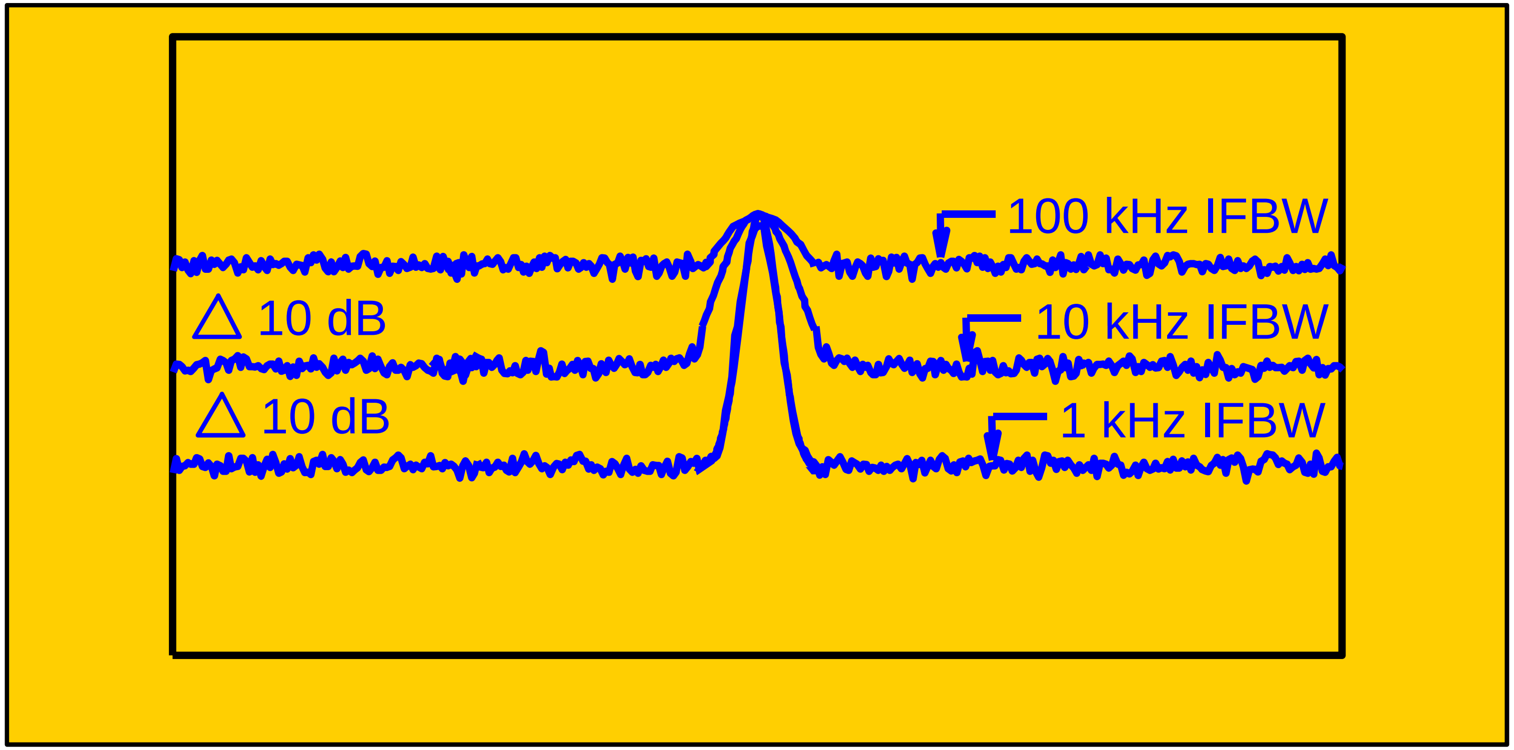
- **Different types of CW modulation share the same generic hardware**
  - In the past three weeks we have discussed different types of CW modulation: AM, FM, PM.
  - They are different in many respects, however, they have in common the property that a sinusoidal bandpass signal with time varying envelope and/or phase conveys the message information.
  - Therefore, the same generic hardware including oscillators, mixers, filters are the building blocks for all CW modulation communication systems
- **In this lecture we will look at one of the most important systems – the receiver for CW demodulation**

Receiver

- A receiver's job is to collect signal (containing information) form the medium in which it exists and convert it to a form in which it may be assimilated by the receiver's user.
- Functionally the receiver must perform the following tasks
  - Transduction and matching (antenna, matching network)
  - Selection of desired signals
  - Rejection of undesired signals
  - Amplification by very large factors
  - Demodulation (in this case CW)
  - Error detection and correction (digital)
  - Received information conditioning and output (e.g., AGC)
- We will first consider several parameters that determine the ability of a receiver to successfully demodulate signal. These parameters are termed ***Receiver Specifications***

Receiver Specifications - Sensitivity

- ***Sensitivity is a minimum input signal that will produce a specified signal-to-noise ratio (SNR)***
- The **sensitivity** of any receiver is an indication of how well it can measure small signals.
- Noise Level is a Function of IF Filter Bandwidth; Decreased BW = Decreased Noise -> increased sensitivity



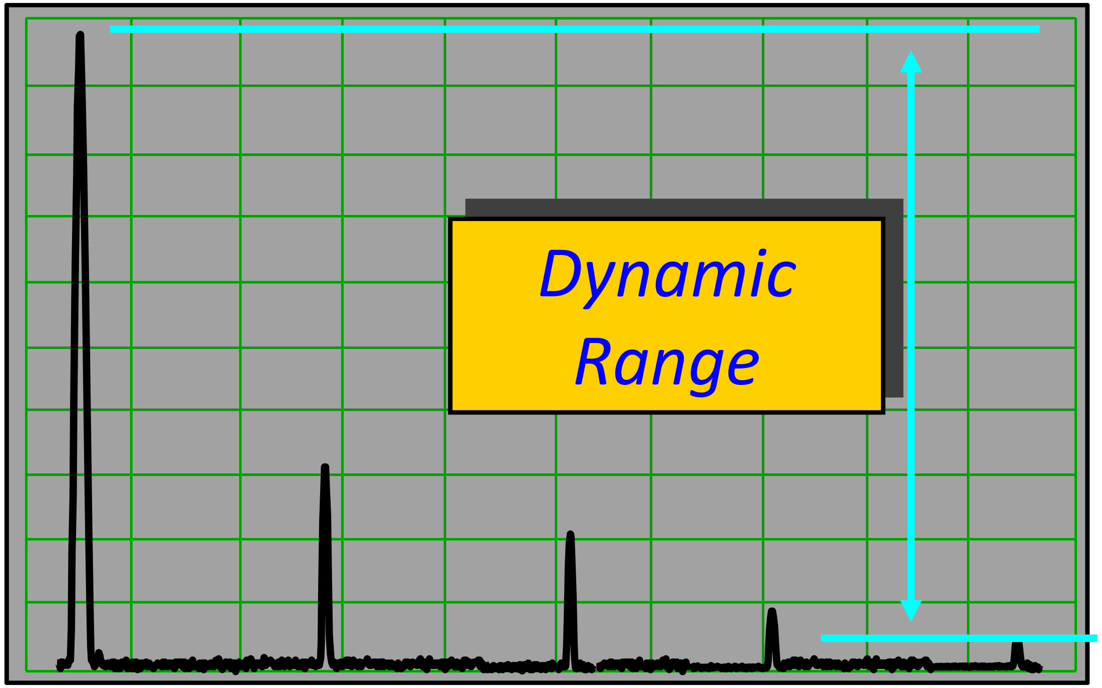
Receiver Specifications - Dynamic range

- ***Dynamic range* specifies the difference between the largest input signal that will not become distorted and the smallest input signal that can still be discerned (usually measured in dB)**
- Frequently up to 100 dB, for some special purpose microwave receivers can be up to 130 dB
  - μV ↔ V

$$DR_{dB} = 10\log_{10}\left(\frac{P_{\max}}{P_{\min}}\right) = 20\log_{10}\left(\frac{V_{\max}}{V_{\min}}\right)$$

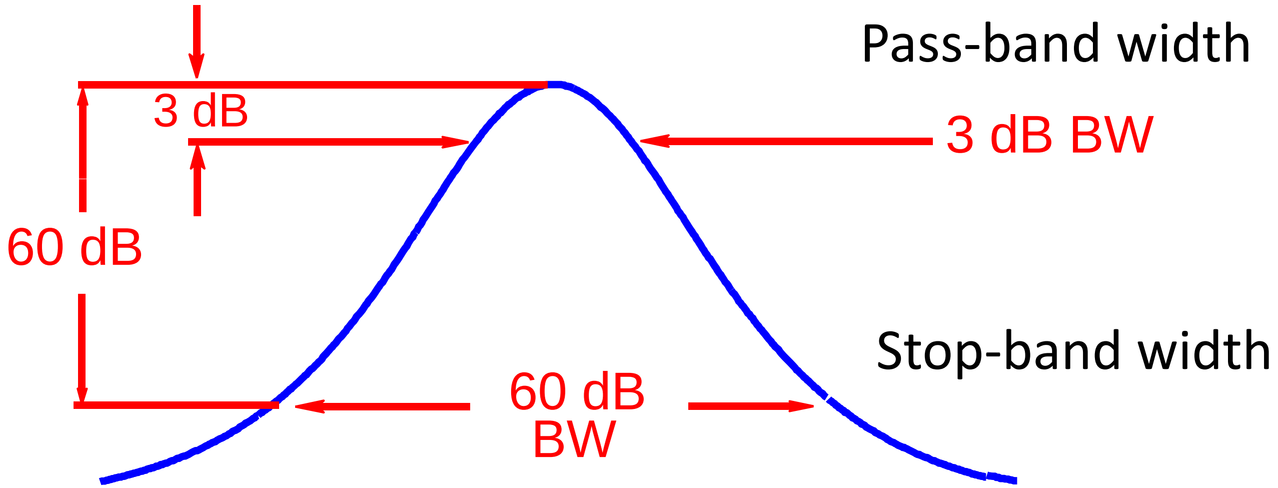
e.g., b-bit A2D converter

$$DR_{dB} = 20\log_{10} 2^b$$



Receiver Specifications - Selectivity

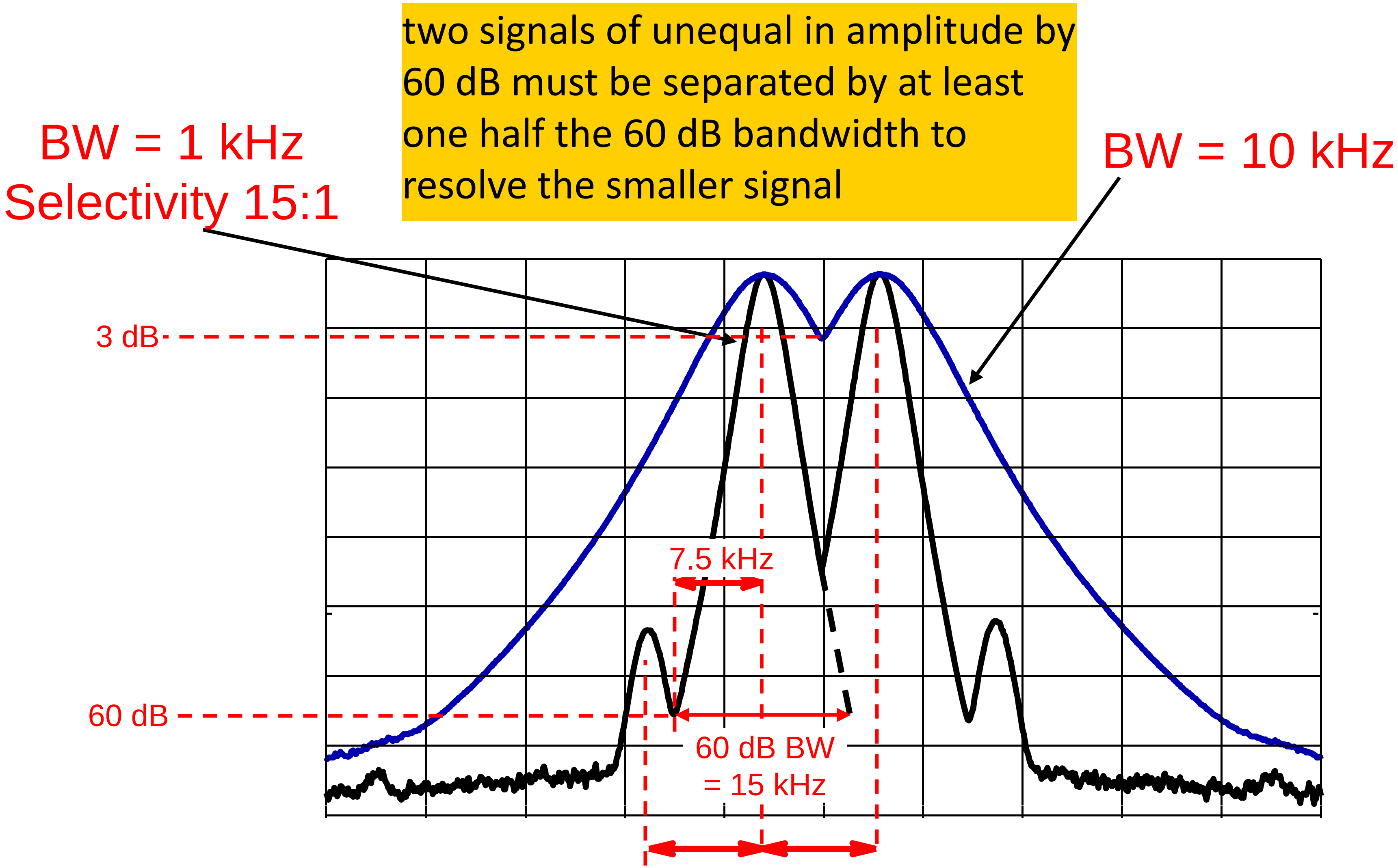
- ***Selectivity specifies a receiver's ability to discriminate against adjacent channel signals***
- Selectivity is the important characteristic for determining the resolvability of unequal amplitude signals. Selectivity is the ratio of the 60 dB to 3 dB filter bandwidth.
- Typical selectivities range from 11:1 to 15:1 for analog filters, and 5:1 for digital filters (i.e., higher order filters).



$$\text{Selectivity} = \frac{60\text{ dB BW}}{3\text{ dB BW}}$$

Receiver Specifications - Selectivity

- ***Selectivity specifies a receiver's ability to discriminate against adjacent channel signals***



Receiver Specifications - Noise-Figure

- ***The Noise Figure specifies how much the receiver degrades the input signal's signal-to-noise ratio***
- In other words it determines the amount of noise (in dB) that receiver adds to the input noise (kTB) within its noise bandwidth
- It ranges from tenths of a dB to 10 dB at the very highest frequencies

Noise factor

$$NF = \frac{(S/N)_{input}}{(S/N)_{output}}$$

Noise figure

$$F(\mathrm{dB}) = 10\log(NF) = 10\log\left[\frac{(S/N)_{input}}{(S/N)_{output}}\right]$$

- The total noise figure of the receiver is a combination of the noise figures of individual building blocks, the preamplifier being the main main contributor

$$F_{total} = 10\log\left(NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \dots\right)$$

Receiver Specifications

- ***Other parameters that are frequently specified are***
- Receiver ***gain*** (frequently 10^5 to 10^7 in total)
- ***Stability*** (linked to gain)
- ***Demodulator performance***
- ***Spurious responses*** including ***Image rejection*** (defines suppression of the carrier image f_c') ~50dB

$$IR_{dB} = 10\log_{10}\left|\frac{H_{RF}(f_c)}{H_{RF}(f_c')}\right|^2$$

- ***Linearity***

Receiver Operation

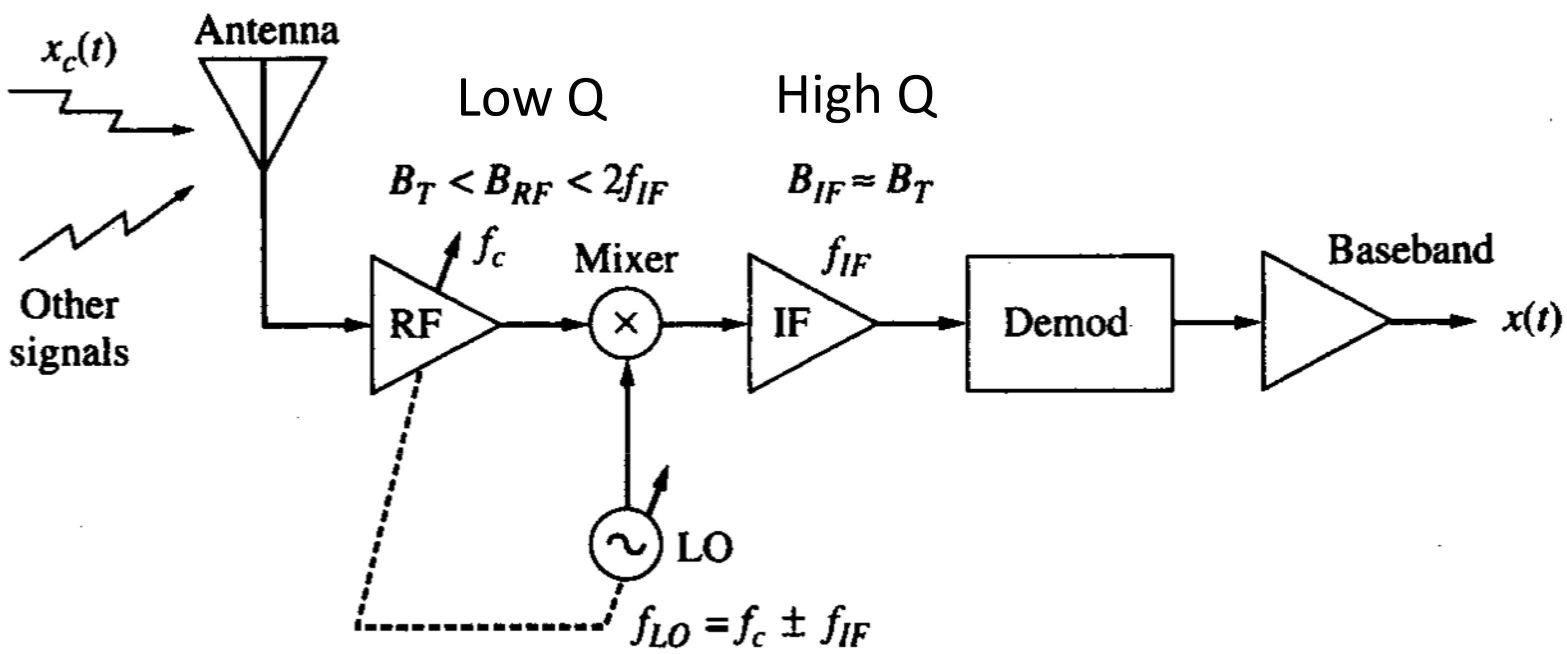
- Typical receiver functions
  1. Carrier Frequency Tuning (select desired signal)
  2. Filtering (select desired and attenuate other signals)
  3. Amplification (to compensate for transmission loss)
  4. Demodulation (e.g., envelope detection)
- However, requires high-gain tunable band-pass amplifier
  - Selective (High Q factor - $f_0/\Delta f$) and
  - Tunable
- Difficult and uneconomic
  - Therefore, ***Superheterodyne*** receiver is preferable

Receiver Types

- Superheterodyne receivers (superhets)
- Direct conversion Tuned Radio-Frequency receivers (TRF)
- Special purpose receivers (lecture 18)
  - Swept-frequency Spectrum Analysers
  - Instantaneous frequency receivers
  - Compressive (microscan) receivers
  - Radiometric receivers

Superheterodyne Receiver (superhet)

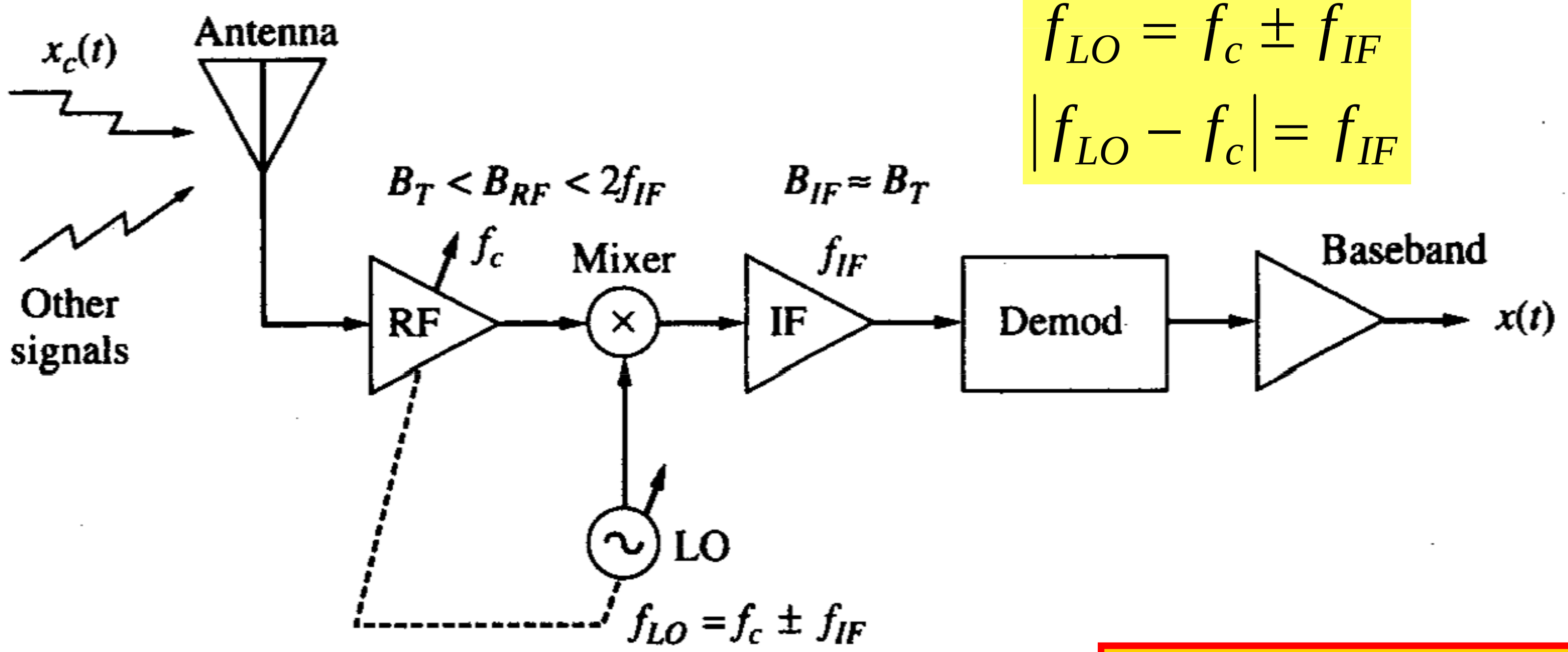
- Incoming signal $x_c(t)$ is first selected and amplified by a radio-frequency (RF) section tuned to the desired carrier f_c
- RF amplifier bandwidth B_{RF} partially passes adjacent channels along with the desired signal $x_c(t)$
- Frequency converter – mixer and the ***local oscillator*** (LO) perform down-conversion to an ***intermediate frequency*** (IF); $f_{IF} < f_c$

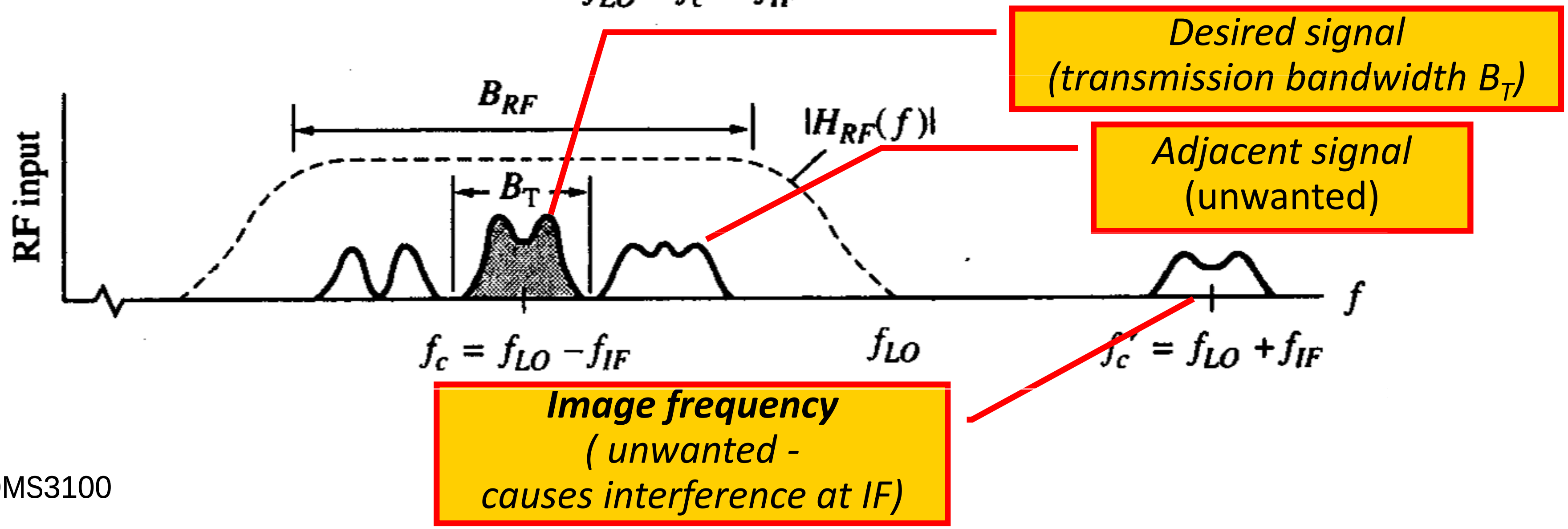


Superheterodyne Receiver (superhet)

- The adjustable LO frequency tracks with the RF tuning

$$f_{LO} = f_c \pm f_{IF}$$
$$|f_{LO} - f_c| = f_{IF}$$



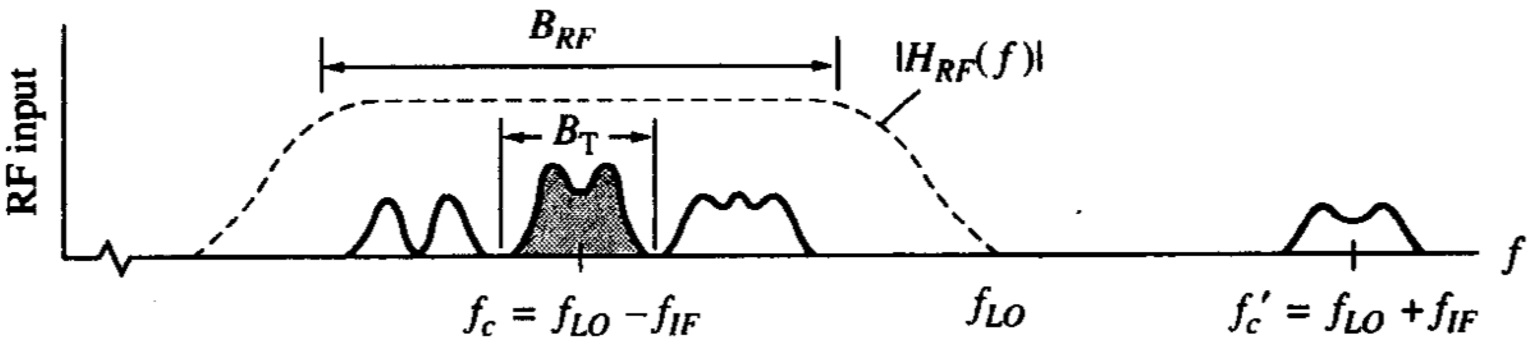


Superheterodyne Receiver (superhet)

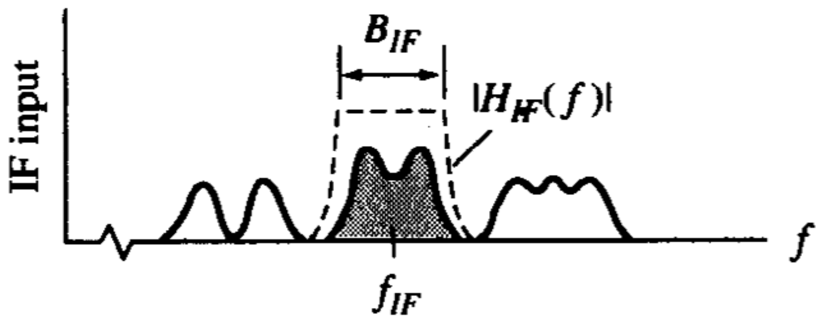
- The main task of the RF section is to pass $f_c \pm B_T/2$ while rejecting the image frequency signal f_c'
- If f_c' reaches the mixer it would be down converted to

$$f_c' - f_{LO} = (f_{LO} + f_{IF}) - f_{LO} = f_{IF}$$

- This would create co-channel interference → $B_T < B_{RF} < 2 f_{IF}$



- IF filter rejects the adjacent channels



Superheterodyne Receiver (superhet)

Superheterodyne architecture has several important benefits

- Tuning happens entirely in the front-end. The rest of the circuitry requires no tuning (difference between f_c & f_{IF} reduces stray feedback)
- Most of the gain and selectivity can be allocated to IF strip. IF can be designed with the fractional bandwidth B_{IF}/f_{IF} that allows ease of implementation
- When wide frequency range is required the suitable choice of f_{LO} may result in a smaller LO tuning ratio

e.g. AM radio:

540 kHz $< f_c <$ 1 600 kHz; for f_{IF}=455 kHz using $f_{LO} = f_c + f_{IF}$ *results in*

995 kHz $< f_{LO} <$ 2055 kHz, so the tuning range of LO is 2:1 (high-side conversion)

NB: low-side $f_{LO} = f_c - f_{IF}$
tuning range 13:1

LO must also be "pure"
Sinewave – no harmonics
in IF strip

Parameters of AM and FM radios

	AM	FM
Carrier frequency	540–1600 kHz	88.1–107.9 MHz
Carrier spacing	10 kHz	200 kHz
Intermediate frequency	455 kHz	10.7 MHz
IF bandwidth	6–10 kHz	200–250 kHz
Audio bandwidth	3–5 kHz	15 kHz

Automatic gain control (AGC)

- Also known as ***automatic volume control*** (AVC) in AM
- Receiver gain adjusted according to input signal level
  - Reduces gain if the signal is strong
  - Raises gain when signal is weaker
- Implemented as
  - Rectifier
  - Heavy low-pass filter
- On audio output
  - i.e., calculates average (DC) value
- This is fed back to adapt gain of IF or RF stage
- Also, ***automatic frequency control*** (AFC) to adjust LO drift in FM

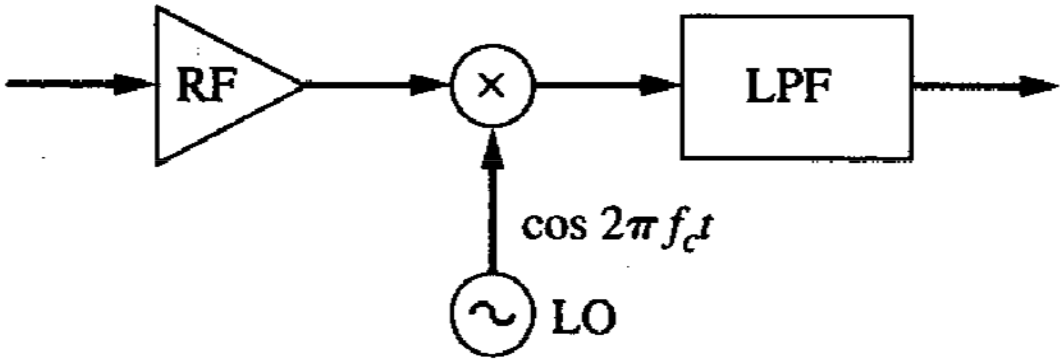
Direct Conversion Receivers (DC)

- In a Tuned RF (TRF) receiver the signal is demodulated directly at the frequency at which it is received (homodyne receiver – zero IF).
- RF amplifier is followed by a product detector and suitable message amplification
- LPF attenuates adjacent channel interference
- Simple, can be miniaturized, e.g., wireless sensor networks
- Does not suffer from image problem at f_c' But both sidebands

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

Interfering sideband

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



DC receiver with opposite sideband rejection