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TE 364: Communication Circuits

Lecture 4

Radio Receivers & Characterization

2015.01.05

Abdul-Rahman Ahmed

Outline

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- Radio Recivers
  - Superheterodyne Receivers
    - Analog
    - Digital
- Receiver Characterization
  - Receiver Noise
  - Receiver Sensitivity
  - System Non-linearity
  - Receiver Dynamic Range
  - Receiver Selectivity

The Super Heterodyne Receiver- Analog System…

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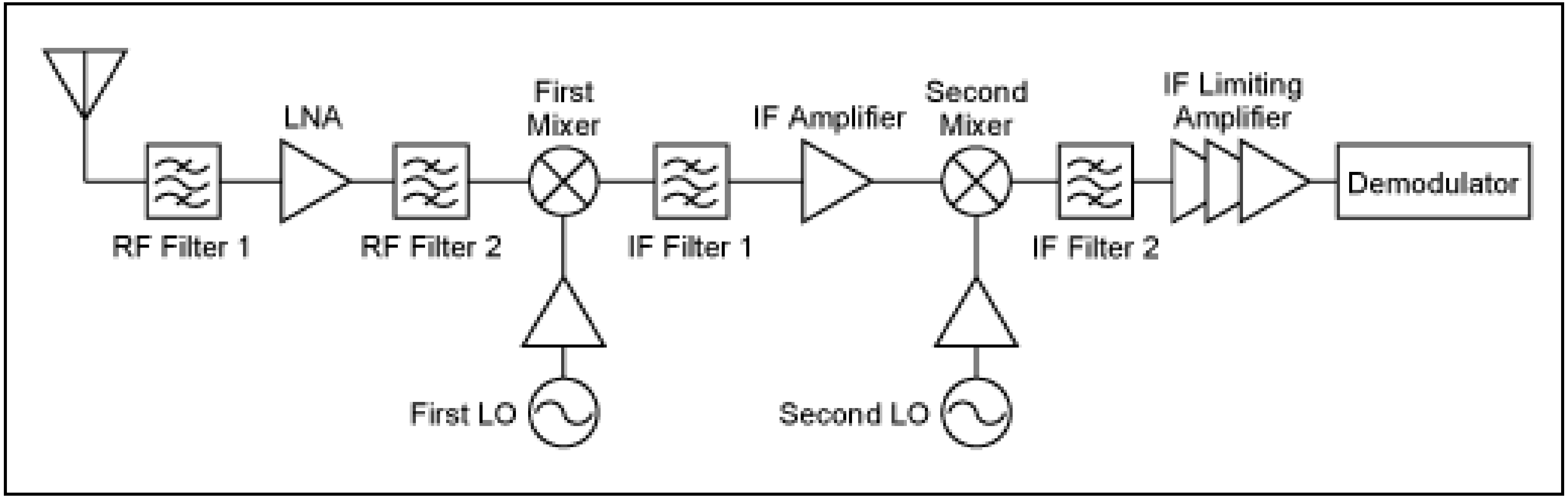

Fig. 1 The Superheterodyne receiver

The Super Heterodyne Receive-Analog System…

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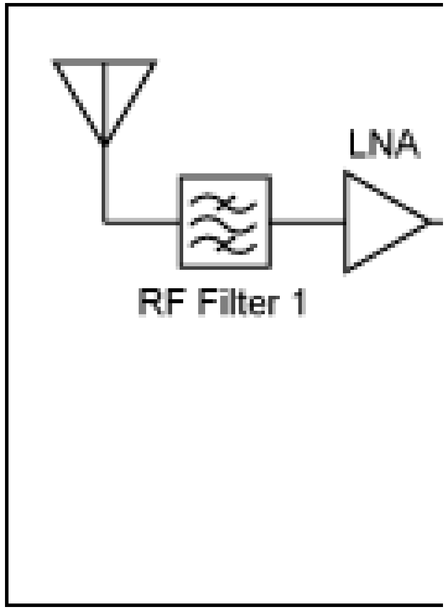
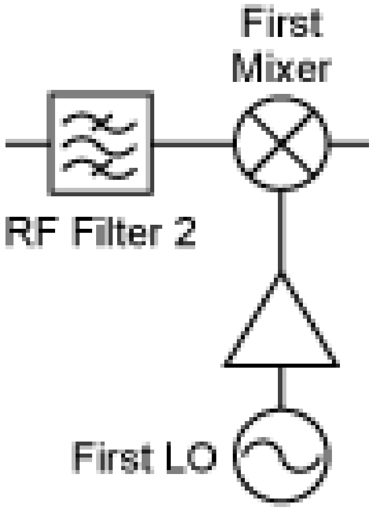
- The antenna: functions as described earlier
- RF Preselector
  - Filter out all unwanted frequencies outside RF band
  - Eliminate spurious response
- RF Amplifier
  - linearly amplify input signal & minimize added noise
  - Low noise amplifiers are typically used for this purpose



The Super Heterodyne Receiver- Analog System…

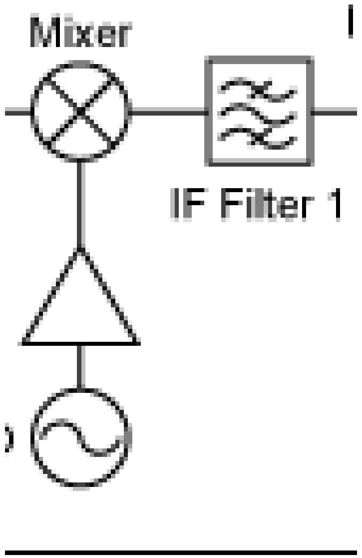
- The Interstage selector
  - suppresses gain of any undesired signal responses at spurious frequencies
    - and at image frequencies in particular
  - Thus maintaining system noise figure
- The Local Oscillator (LO)
  - Tuned across a bandwidth equal to the RF bandwidth
  - Generates strong carrier signal for mixing with mixer



The Super Heterodyne Receiver- Analog System…

The First Mixer

- translates signals @ RF to IF frequency signal
  - Depending on the frequency of the LO
- Phase information of signal preserved by the mixer
  - Due to linear translation of frequency
- IF frequencies from 45 to 82 MHz are common
  - for mobile radio receivers in the 800 MHz band.



The IF Filter

- Rejects spurious signals generated by the mixer

The Super Heterodyne Receiver-Analog System…

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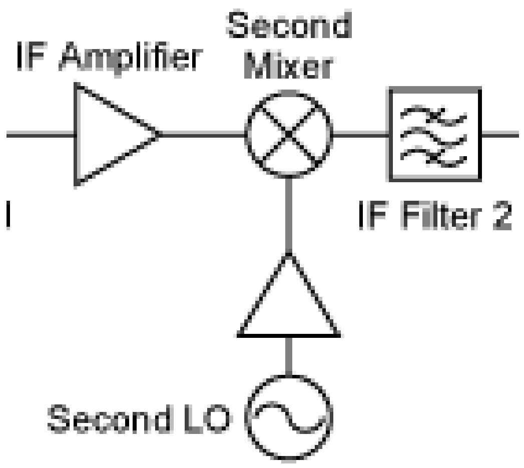
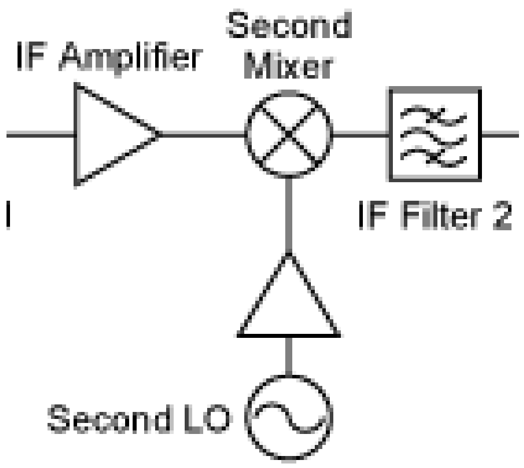
- The IF amplifier
  - provides adequate gain to the IF signal
    - To drive the next stage
    - Can provide high gain and is well-stabilized
  - IF frequencies from 45 to 82 MHz are common
    - for mobile radio receivers in the 800 MHz band.



- The Second mixer, LO and second IF Filter
  - Mirror the function of the first IF strip
  - Narrows in and select the desired channel fro the entire passband

The Super Heterodyne Receiver-Analog System…

- The Second mixer, LO and second IF Filter
  - Provides additional selectivity for the receiver
  - 455 kHz is a fairly standard second IF frequency
  - Mobile phone receivers’ IF frequency
    - Typically 10 MHz



- In some architectures,
  - second IF stage is omitted.
  - Single down-conversion to a low IF
  - IF filter then performs channel selection

The Super Heterodyne Receiver-Analog System…

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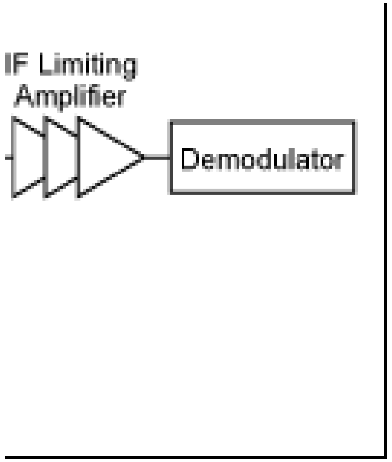
- The Demodulator
  - Extracts modulated signal from IF signal
  - Converts the modulated signal to baseband
    - AM or FM (Analog system)
    - Multi-amplitude symbols or multiphase levels symbol
      - Decoded to recover original signal.



- The Baseband amplifier
  - provides output power to drive output device
    - Typicall speaker, fax or video screen

The Super Heterodyne Receiver-Digital System

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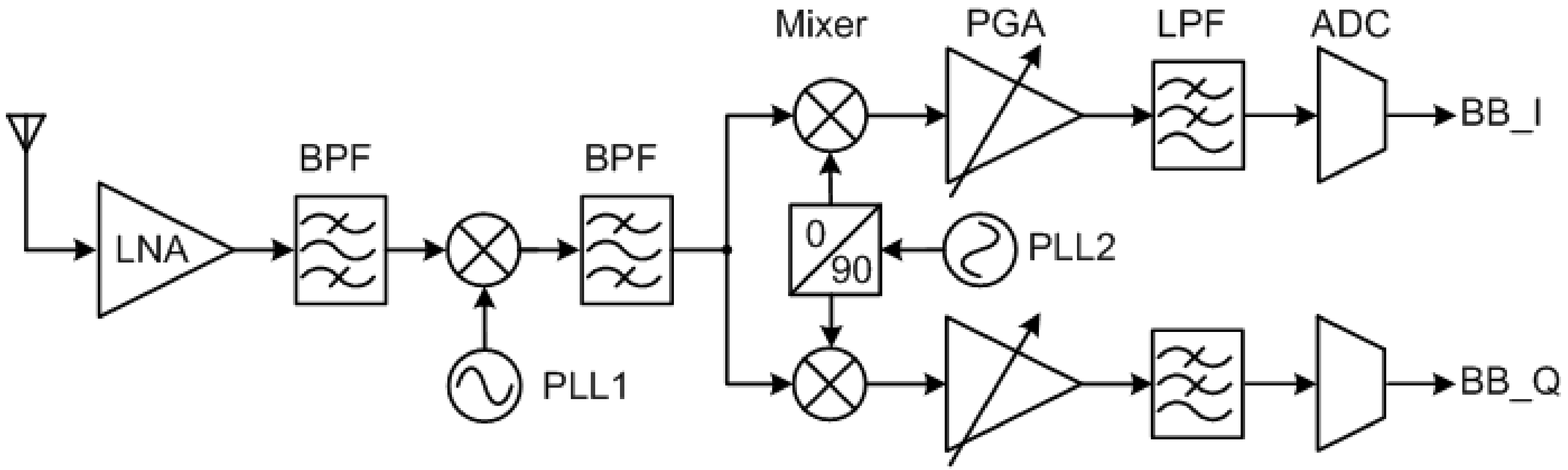

Fig. 2 The Superheterodyne receiver

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The Super Heterodyne Receiver-Digital System

- Two parallel output stages
  - In-phase (*I* signal)
  - Quadrature-Phase (*Q* signal)
- Allows both amplitude and phase information to be preserved.
- Requires two mixers
  - One driven by an LO signal of the form $\cos\omega_{LO}t$
  - The other $\sin\omega_{LO}t$
- *I* and *Q* channels ⇒ 1and 0 of binary signal.

A/D converter

- For flat top sampling
  - a sample-and-hold circuit is used
  - together with the chopper
  - This holds the amplitude of each pulse at constant level during sampling time

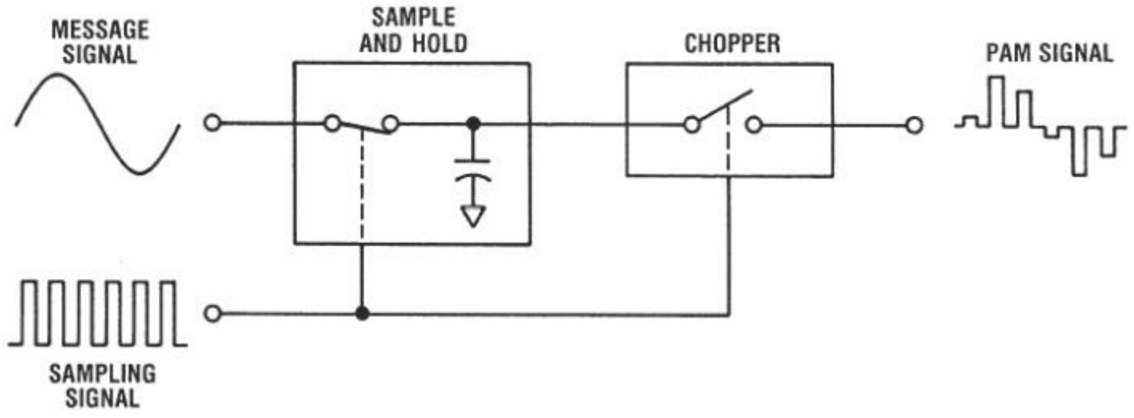

Fig. 3: Flat-top Sampling

Analog Transceiver System

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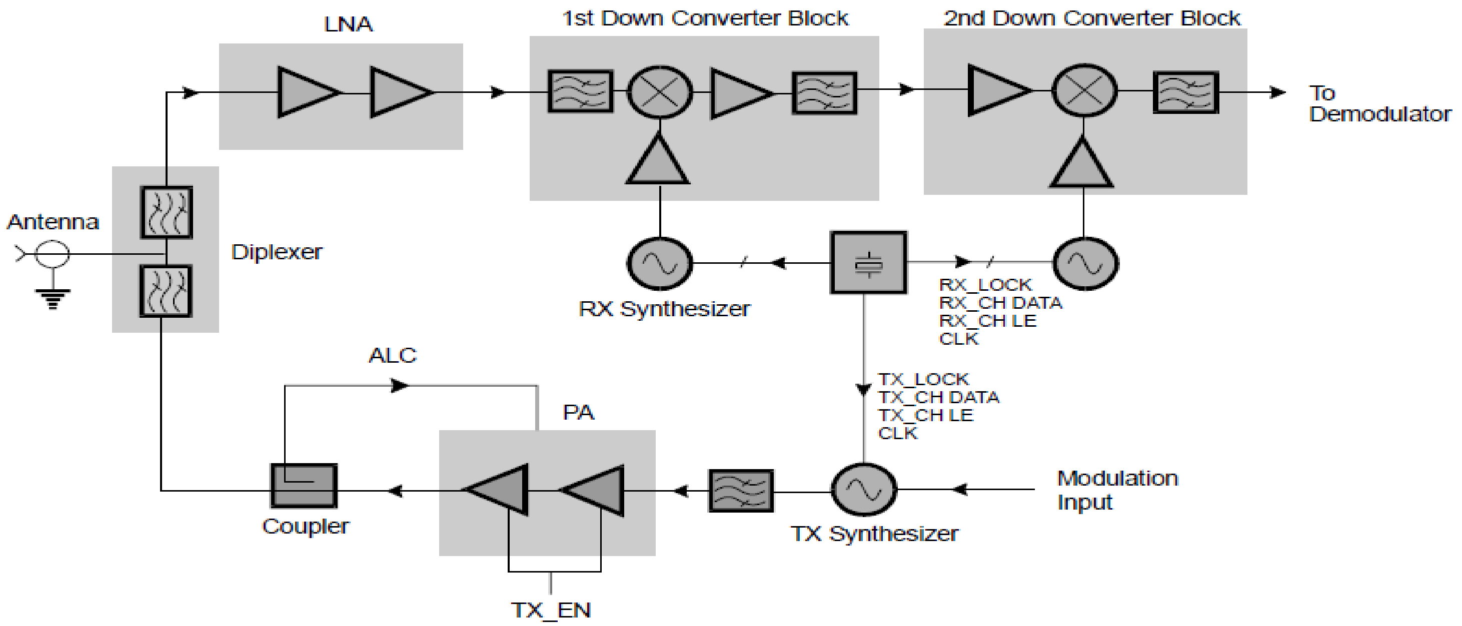

- A block diagram of an analog mobile phone handsets

The Communication Channel

❑ Hartley-Shannon Theorem

- Relates Channel Capacity to
  - Channel Bandwidth, B and
  - Signal-to-Noise Ratio, S/N

$$C = B\log_2\left(1+\frac{S}{N}\right) \quad \text{bits/sec}$$

- It is a trade-off relation
  - Between bandwidth and S/N ratio
  - GSM vs CDMA

Receiver Noise

- Sources of Noise
  - The channel, through to the antenna
  - The RF preselector filter:
    - Thermal noise contribution
  - The active devices:
    - Thermal noise
    - Shot noise
    - Flicker noise ($1/f$ noise)

Receiver Noise…

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- Thermal Noise Power

$$P_N = kTB$$

- k is Boltzmann's constant,
- T is temperature,
- B is the bandwidth over which measurement is made.

$$P_N = \left(1.38\times10^{-23} J/K\right)\left(293K\right)\left(1Hz\right)$$
$$= 4.057\times10^{-21} W$$
$$=-174 \text{ dBm}$$

Receiver Noise…

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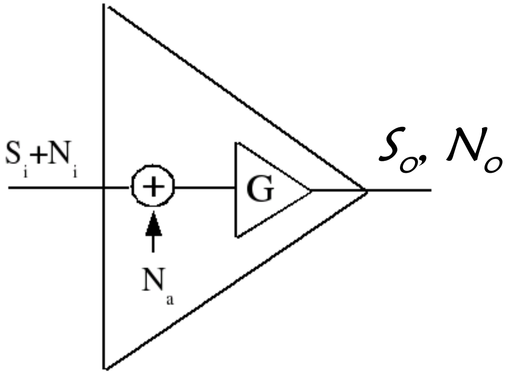
- Noise Factor

$$F = \frac{N_o}{kT_oBG} = \frac{N_oS_i}{kT_oBS_o} = \frac{S_i/N_i}{S_o/N_o}$$



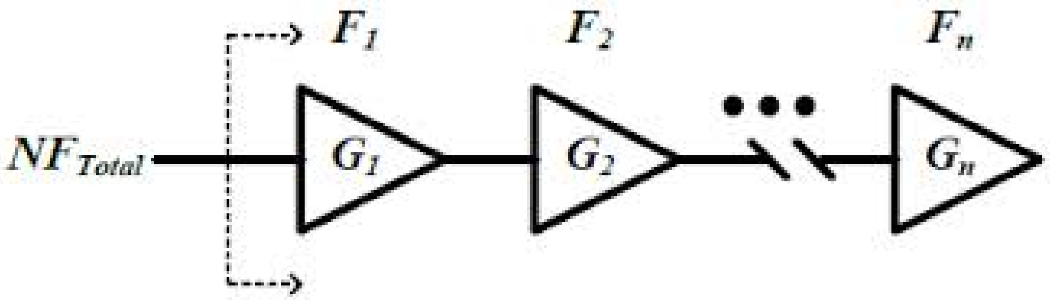
  - S_o, N_o is output signal, noise power from device
  - G is gain of device
  - S_i, N_i is input signal, input noise

- Noise Figure

$$NF = 10\log_{10} F$$

Receiver Noise…

- Noise Factor of cascaded system



- Total Noise Factor

$$F_{tot} = F_1 + (F_2 - 1)/G_1 + (F_3 - 1)/G_1 G_2 + \cdots + (F_n - 1)/G_1 G_2 \cdots G_{n-1}$$

Receiver Sensitivity

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- Noise floor of the receiver prior to detection determines
  - How strong the input signal must to be correctly interpreted as
    - 0 or 1 in a digital system or
    - High-quality analog waveform in analog system
- Receiver Sensitivity is
  - Minimum input signal strength to produce quality output signal in the receiver.

Receiver Sensitivity

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- Noise floor of the receiver referred to the input, called
  - Minimum detectable signal is used as measure of sensitivity
  - Signal to noise ratio of 10 dB considered minimum for audiofiles
    - S_o/N_o of 10 dB is used to measure sensitivity
    - Or a SINAD (Signal in Noise and Distortion) of 10 dB
  - BER (Bit Error Rate) is another measure of sensiti-vity in digital systems: BER of 1% specified

System Nonlinearity

- A component is nonlinear when
  - Its output amplitude is not linearly proportional to its input amplitude or
  - Its output phase is not linearly proportional to its input phase.
- Gross nonlinearity
  - Results from cut-off and saturation effects
    - Occurs as device exceeds the limits of its normal active region
  - gain compression, intermodulation distortion

System Nonlinearity

- In most active devices,
  - nonlinearity is due to
    - Amplitude induced change in device transconductance
  - collector or drain current modelled as a nonlinear function of the input voltage, v_{in}.

$$I_o = I_Q + g_m v_{IN} + g_{m2} v_{IN}^2 + g_{m3} v_{IN}^3 + \cdots$$

- leads to 3rd order intermodulation products
  - Harmonic powers increase nonlinearly with input

System Nonlinearity

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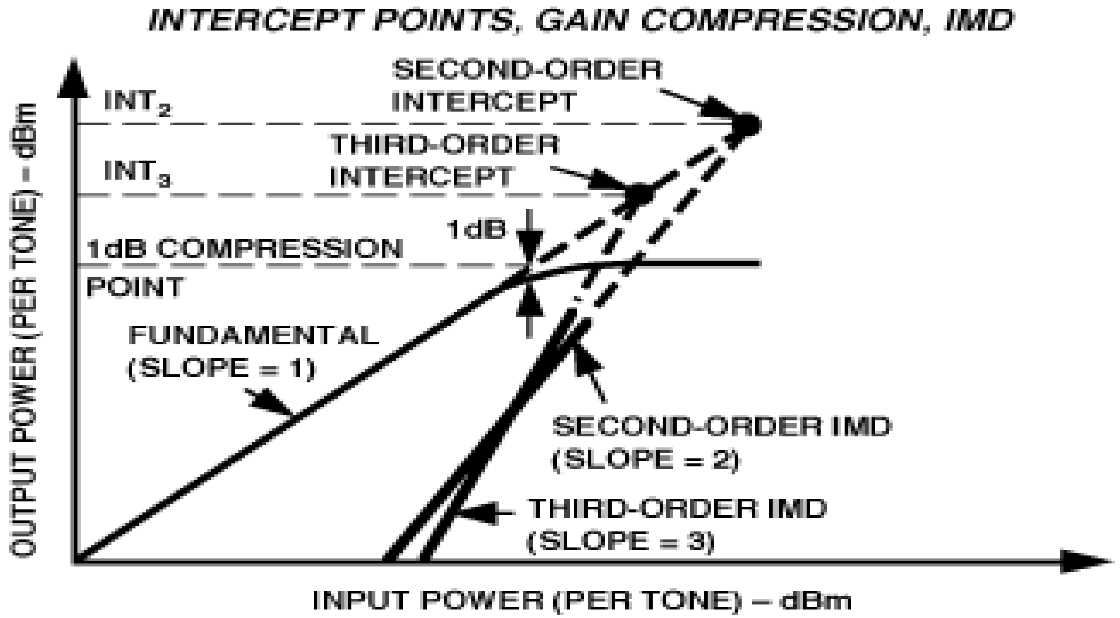
- Third-order distortion and gain compression



- Other measure of nonlinearity includes
  - Adjacent Channel Power Ratio (ACPR)

System Nonlinearity

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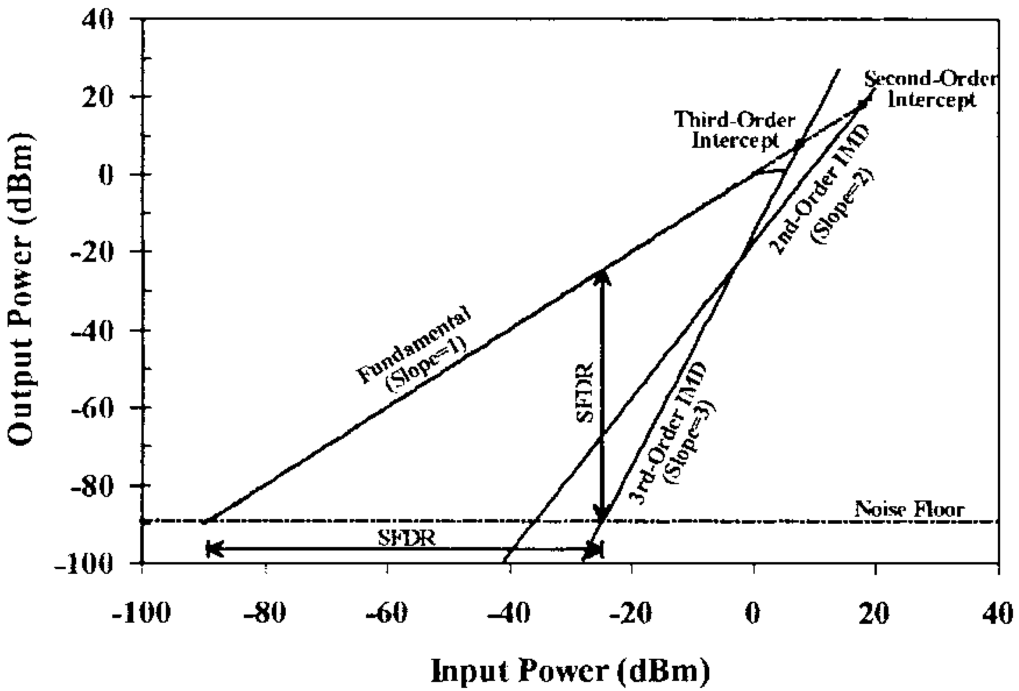
❑Receiver Dynamic Range

- ❖Difference between the minimum detectable signal and the maximum signal



SFDR is Spurious-free dynamic range

System Nonlinearity

- Automatic Gain Control (AGC)
  - Gain of a system automatically controlled such that:
    - Decrease gain when strong signal cause overload or distortion
  - Thus increasing the useful range of a receiver
- Trade of is sometimes required
  - Example: AGC verses noise performance of LNA
  - Attenuation in front of LNA
    - Reduces gain but
    - Worsens noise figure of LNA

System Nonlinearity

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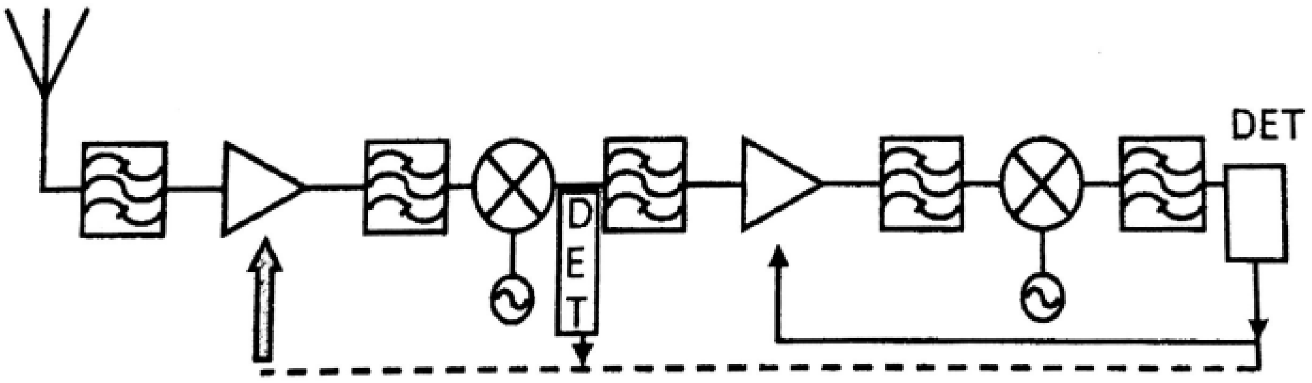
- Automatic Gain Control (AGC)



- Gain reduced to minimize distortion
  - Output stage gain ideally reduced first
    - This prevents noise figure of system rising
  - AGC is then introduced progressively ahead of them

System Nonlinearity

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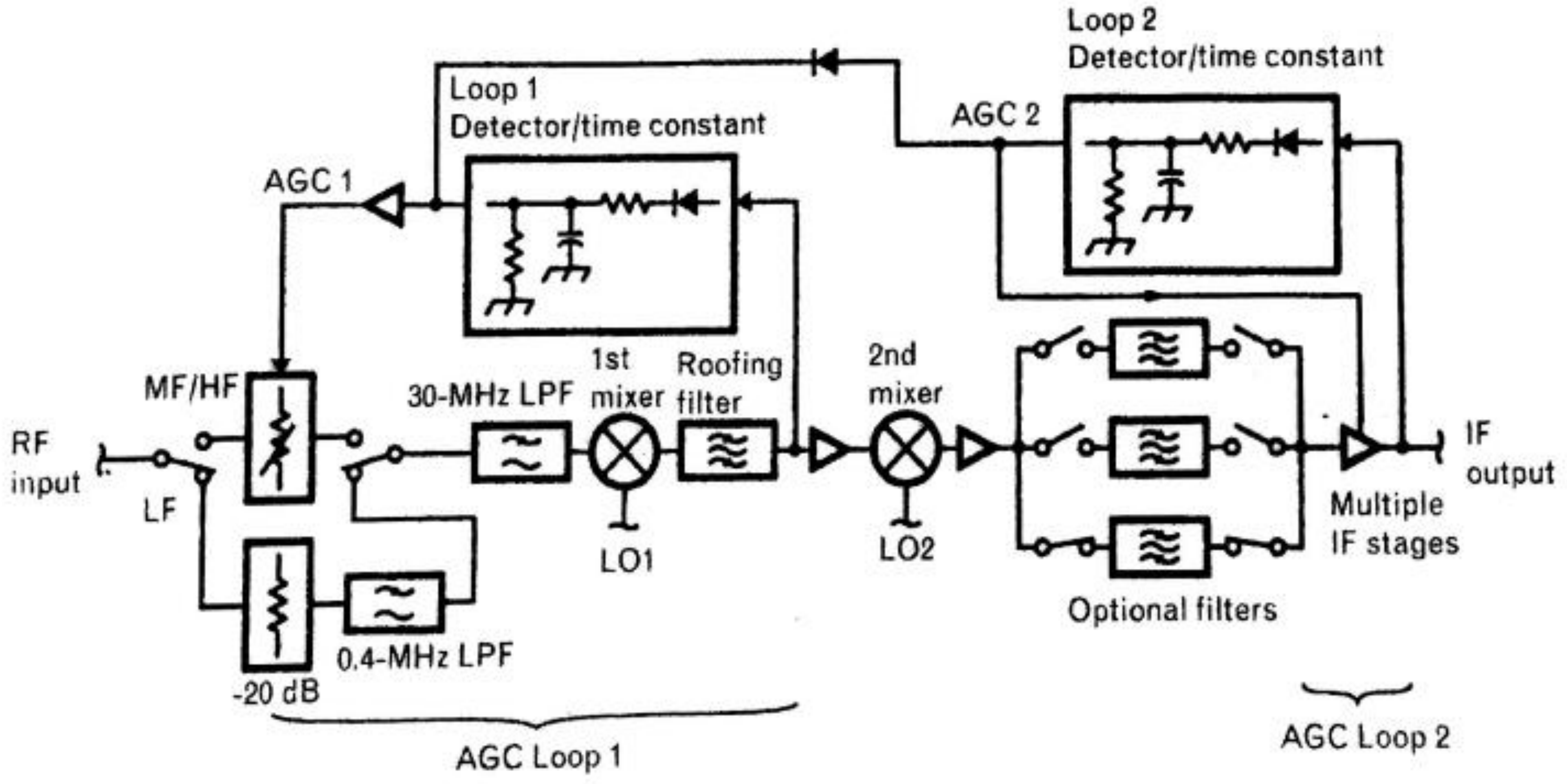
❑Dual Loop AGC System



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Receiver Selectivity

- Selectivity
  - Refers to the ability of a filter to reject signal outside its pass-band.
  - Defined by the attenuation of a signal at some frequencies offset from its center frequency.
  - For channel selection filters in radio receivers,
    - Selectivities of 60 dB to 80 dB are typical
- Selectivity of radio receiver measured in terms of
  - Relative strength of adjacent signal compared to desired signal.
    - Eg. 60 dBc to 80 dBc.

Receiver Selectivity

- Spurious responses
  - Outputs that arise from unwanted frequency components
  - Demodulating a channel whose carrier is at 895 MHz
    - A signal at 890 MHz can create a response in the receiver that interferes with the channel at 895 MHz.
    - The 890 MHz signal is thus a spurious signal
  - Spurious response can reduce the selectivity of a receiver.

Receiver Selectivity

Spurious responses

- Although the amplitudes of spurious signals cannot be quantitatively determined, their frequencies can be known.
- Looking at the mixer as a source of spurious responses
  - f_T is desired signal frequency to which receiver is tuned
  - f_s is unwanted spurious frequency
  - In the mixer, sum and difference frequencies will produce with the mixer's L O frequency, f_o

Receiver Selectivity

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- Spurious responses
  - For sum mixer: $f_o + f_T = f_{IF}$
  - For difference mixer (high side LO): $f_o - f_T = f_{IF}$
  - For difference mixer (Low side LO): $f_o - f_T = -f_{IF}$
- At multiple harmonics, spurious response could also map to IF
  - For sum mixer: $nf_O + mf_S = f_{IF}$
  - For difference mixer (high side LO): $nf_O - mf_S = f_{IF}$
  - For difference mixer (Low side LO): $nf_O - mf_S = -f_{IF}$

Receiver Selectivity

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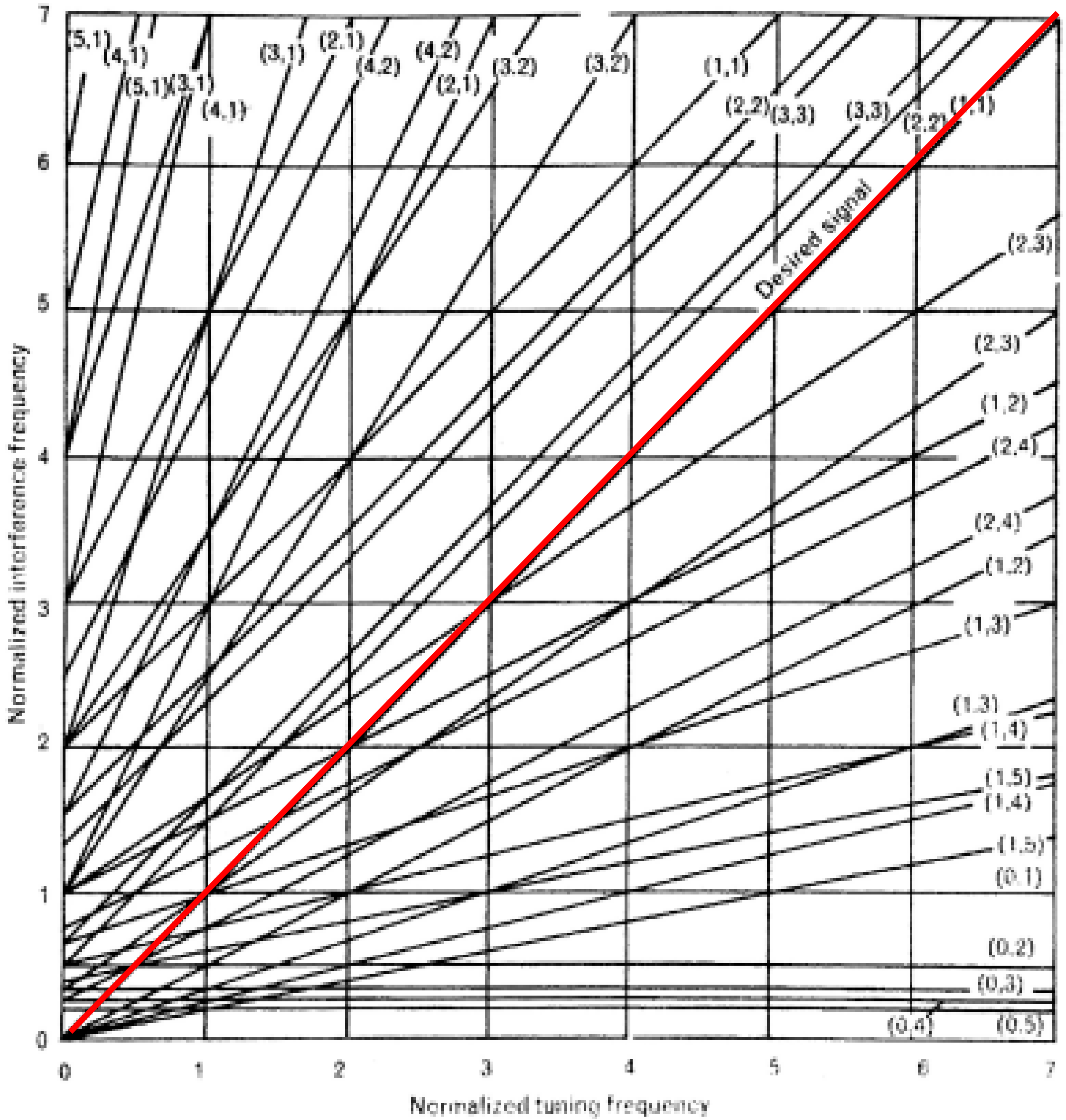
- Normalizing by f_{IF} and defining

$$T = f_T / f_{IF}$$
$$O = f_o / f_{IF}$$
$$S = f_s / f_{IF}$$

- Eliminating O from both sets of equations
  - For sum mixer: $n(1-T)+mS=1$
  - For difference mixer (high side LO): $n(T+1)-mS=\pm 1$
  - For difference mixer (Low side LO): $n(T-1)-mS=\pm 1$

Spurious response Chart



Difference Mixer

If f_{IF} is 45 MHz
And f_T is 135 MHz
Then f_O is 180 MHz
T=135/45=3
Spurious response will
be caused by a spurious signal at the same frequency as the tuned signal
S=3 generated by (2,3) mixing produ
cts
Consider f_T between 90 and 180 MHz

CDMA Receiver Handset

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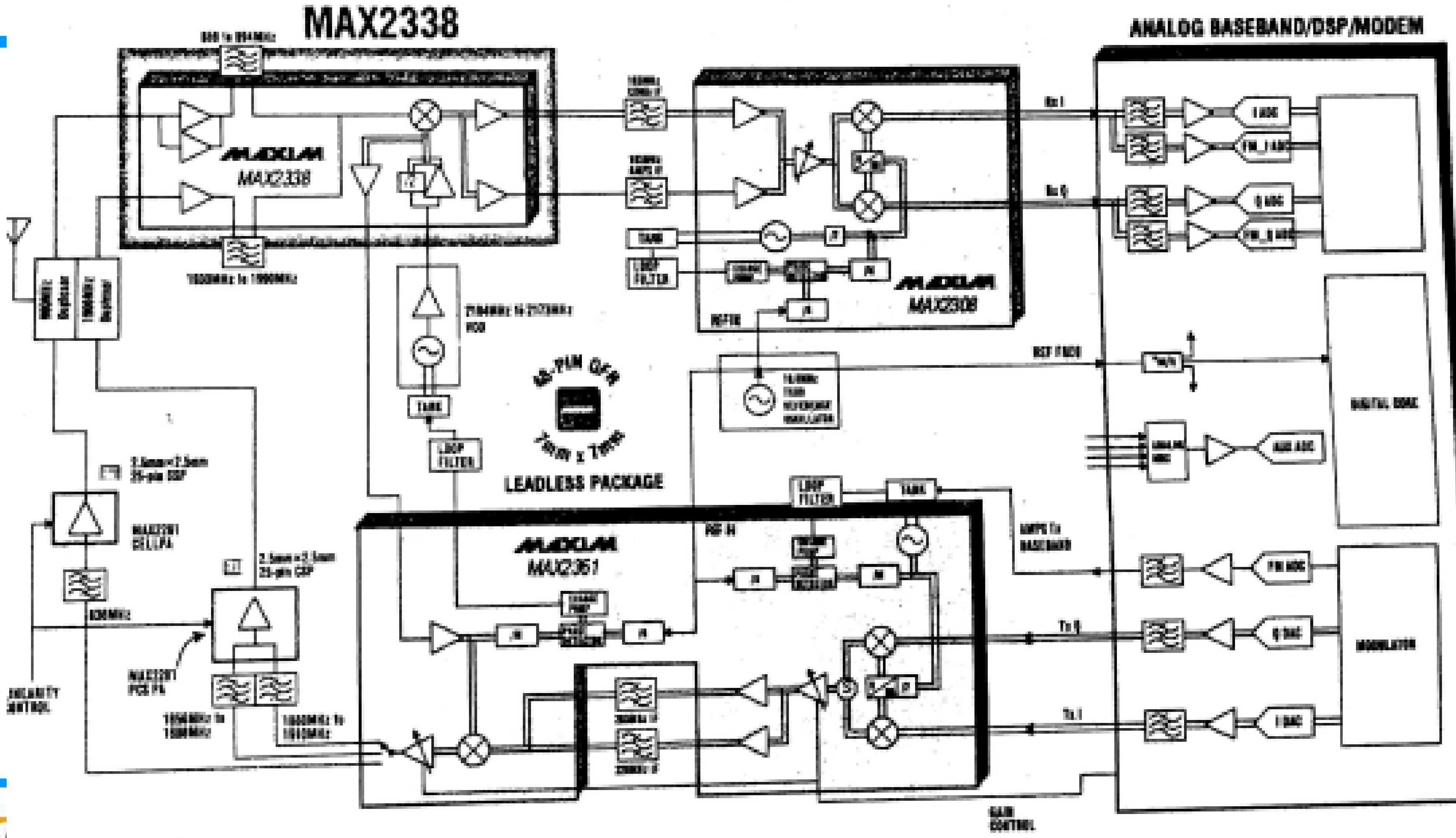

Air-Interface specification for PCS CDMA Mobile Handset

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TABLE 3.1 SOME PARAMETERS FROM THE IS-95/98 AIR-INTERFACE SPECIFICATIONS FOR THE PCS CDMA MOBILE HANDSET

MEASUREMENT PARAMETER	SPECIFICATION
Receive frequency band	1,930–1,990 MHz
Transmit frequency band	1,850–1,910 MHz
Peak frequency deviation (channel bandwidth)	1,230 kHz
Maximum input power (total power at antenna connector) for error rate < 1/2%	–25 dBm
Minimum detectable signal (total power at antenna connector) for error rate < 1/2%	–104 dBm
Detection in presence of low level interference (error rate < 1%)	Detect a tone at –101 dBm in the presence of two interfering tones at –43 dBm each, offset 900 kHz and 1,700 kHz from center of channel
Transmitter output power	+23 dBm to –50 dBm
Maximum adjacent channel strength at 885-kHz offset	–42 dBc integrated over a 30-kHz bandwidth
Maximum alternate channel strength at 1,980-kHz offset	–54 dBc integrated over a 30-kHz bandwidth

CDMA Receiver Handset

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❖Core components in the receiver chain