# Overview of the Radio Design of a Cellular Phone

Walid Y. Ali-Ahmad, Ph.D.
Wireless Communications Group
Maxim Integrated Products
Sunnyvale, CA 94086

# TALK OUTLINE

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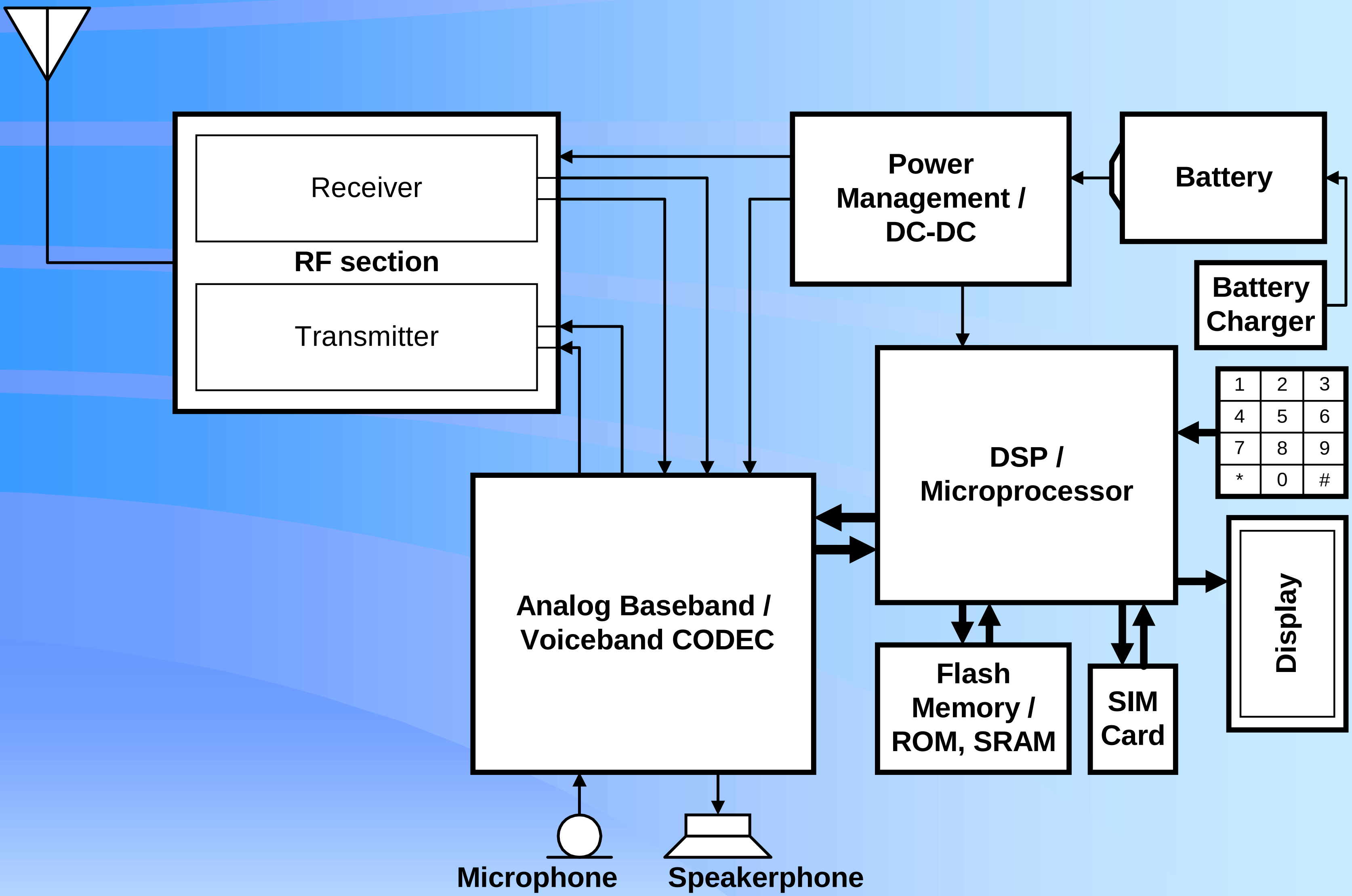
# INTRODUCTION

- **1912**: Sunday, April 14, shortly before midnight, the RMS *Titanic* struck an iceberg off the coast of Newfoundland. The radio operator, John Phillips, repeatedly transmitted the distress call CQD in Morse Code. Fifty-eight miles away, the *Carpathia* received the messages, and steamed toward the sinking liner. The *Carpathia* pulled 705 survivors out of their lifeboats. Phillips continued transmitting until power failed on the *Titanic* …This dramatic rescue established the power of wireless communications.
  - ☞ Since the *Titanic* disaster, wireless communications have expanded beyond the dreams of radio pioneers!
- **1946**:The first public mobile telephone was introduced in 25 major American cities. Each system, based on half-duplex mode, used a single high-powered FM transmitter and large tower in order to cover distances of over 50km.
- **1950 - 1960**:AT&T Bell Laboratories and other telecommunications companies throughout the world developed the theory and techniques of cellular radiotelephony - concept of breaking a coverage zone into small cells to increase spectrum usage by frequency reuse in different cells.
- **1979**:The world's first cellular system was implemented by Nippon Telephone and Telegraph company in Japan (600 FM duplex channels, 25kHz each, in the 800 MHz band).
- **1983**:The US Advanced Mobile Phone System (AMPS) was deployed (60 kHz for each FM Full duplex channel, in the 800MHz band)
- **1991**:The digital cellular standard GSM system (Global System for Mobile) was first deployed in the 900MHz band in Europe. Also, the first US Digital Cellular (USDC) system was installed in major US cities with 3 times more capacity compared to that of earlier AMPS.
- **2001**:NTT DoCoMo launches in Tokyo the first 3$^{rd}$ generation WCDMA cellular system, based on IMT-2000 standard (10 MHz for each WCDMA Full Duplex channel, in the 2GHz band).

# General Block Diagram of a Cellular Phone





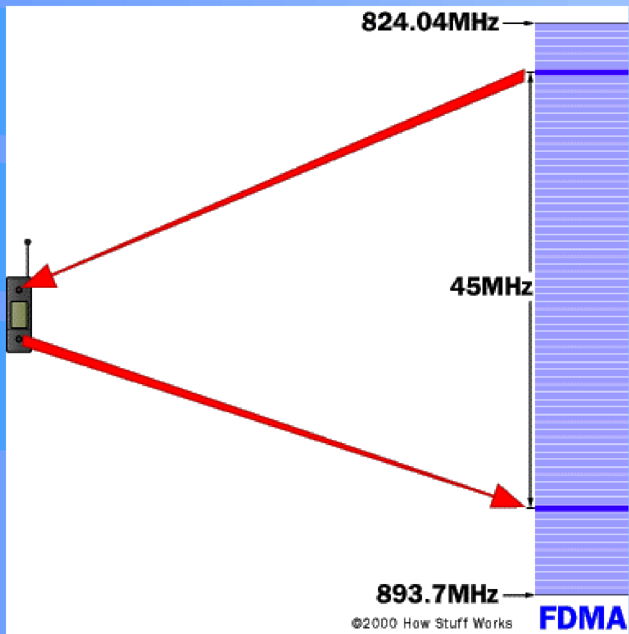
Walid Y. Ali-Ahmad

# Cell Phone Block Diagram Description

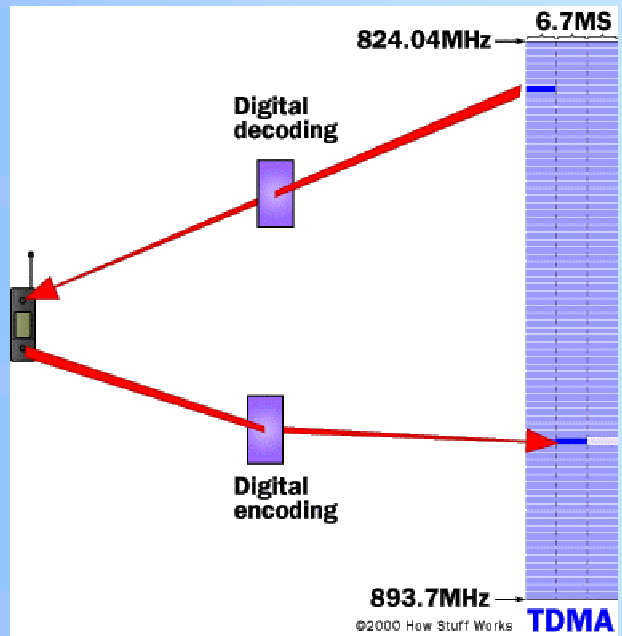
- **RF section:**
  This is where the RF signal is filtered and downconverted to analog baseband signals. It is also where analog baseband signals are filtered and then upconverted and amplified to RF.
- **Analog Baseband / Voiceband Codec:**
  - This is where analog baseband signals from RF receiver section are filtered, sampled, and digitized before being fed to the DSP section. It is also where coded speech digital information from DSP section are sampled and converted to analog baseband signals which are then fed to the RF transmitter section.
  - This is where voice speech from the microphone is digitized and coded to a certain bit rate (13kbps for GSM) using the appropriate coding scheme (balance between perceived quality of the compressed speech and the overall cellular system capacity and cost). It is also where the received voice call binary information are decoded and converted in the speakerphone.
- **DSP / Microprocessor:**
  The digital signal processor (DSP) is a highly customized processor designed to perform signal-manipulation calculations at high speed. The microprocessor handles all of the housekeeping chores for the keyboard and display, deals with command and control signaling with the base station and also coordinates the rest of the functions on the board.
- **Flash Memory, ROM, SRAM (SIM card):**
  The ROM, SRAM, and Flash memory chips provide storage for the phone's operating system and customizable features, such as the phone directory. The SIM card belongs to this category; it stores the subscriber’s identification number and other network information.
- **Power Management / DC-DC:**
  This section regulates from the battery all the voltages required to the different phone sections.

# Duplexing in Cellular Phones: FDD vs. TDD

- ***Duplexing*** in telephone systems denotes the effect of talking and listening simultaneously. In cellular phone systems, this translates to allowing the cell phone to send simultaneously information to the base station while receiving information from the base station. The transmitter and receiver must be isolated from each other or else the transmitter would saturate the receiver.




Analog cellular system



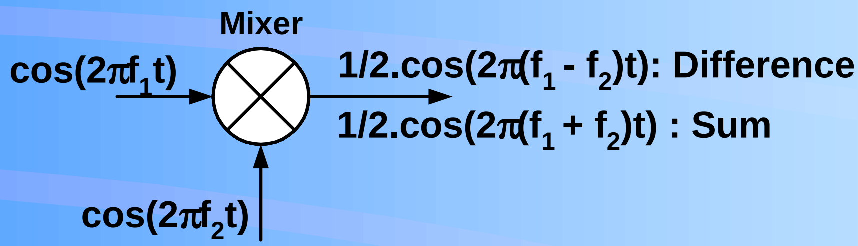

GSM like cellular system

- ***FDD*** or Frequency Division Duplexing provides each cell phone with two distinct frequencies for transmission and reception, respectively. A *Duplex* filter is used at the antenna for isolation.
- ***TDD*** or Time Division Duplexing provides each cell phone with two distinct time slots for transmission and reception, respectively, but at the same frequency. This is only possible with digital modulation and is very sensitive to timing. In GSM, both FDD and TDD are used simultaneously in order to provide improved system capacity and full duplex phone call quality.

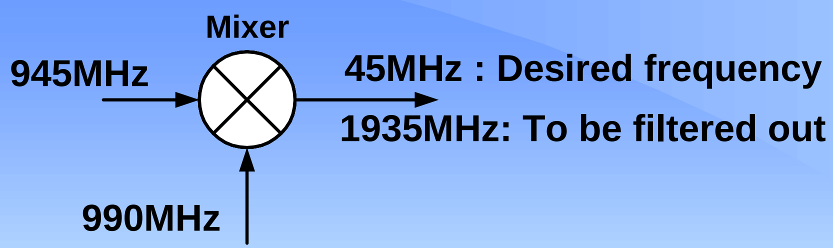
# Mixers

- In a radio receiver, we need to be able to convert from a radio frequency down to an audio frequency. In a radio transmitter, we must go the other way.
- The device that shifts frequency is called ***mixer***. A mixer effectively multiplies two signals, $\cos(2\pi f_1 t)$ and $\cos(2\pi f_2 t)$. The output contains two different frequencies that are the sum and difference of the original frequencies:

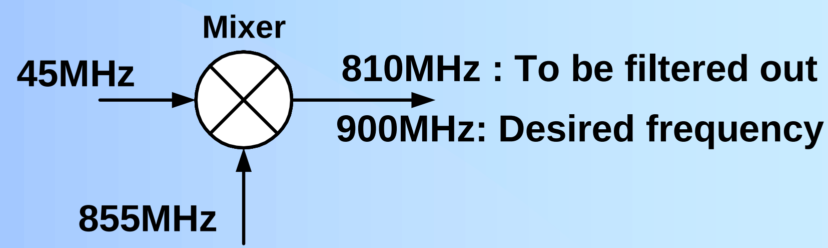
$$\Rightarrow \cos(2\pi f_1 t) \bullet \cos(2\pi f_2 t) = \tfrac{1}{2} \bullet \cos(2\pi(f_1 - f_2)t) + \tfrac{1}{2} \bullet \cos(2\pi(f_1 + f_2)t)$$




- In a radio receiver, frequency $f_1$ comes from the antenna and frequency $f_2$ comes from an oscillator inside the receiver.

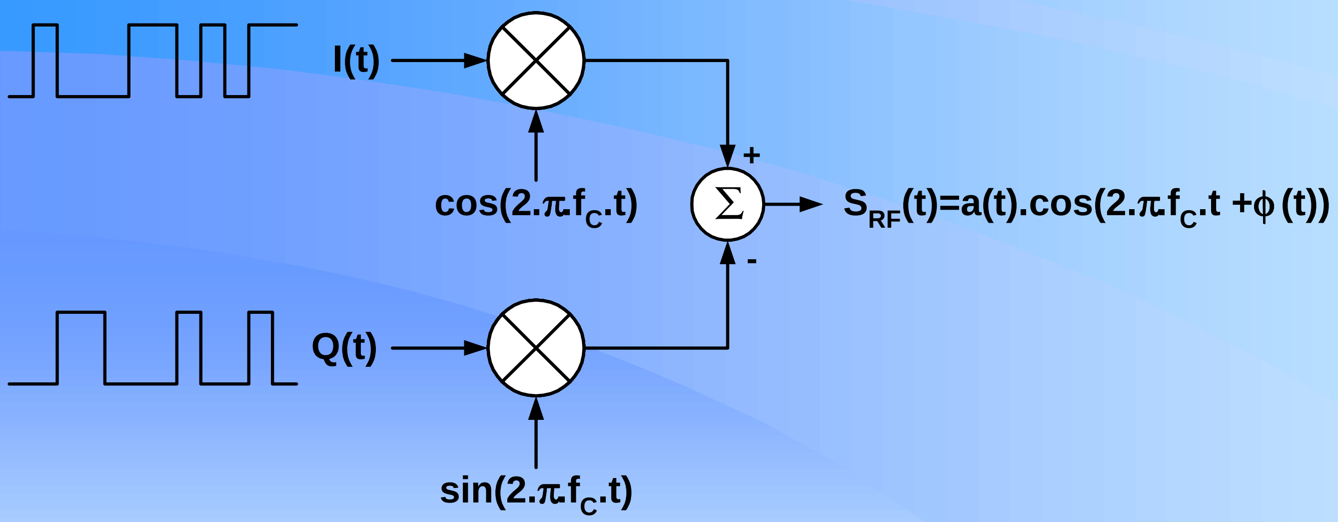


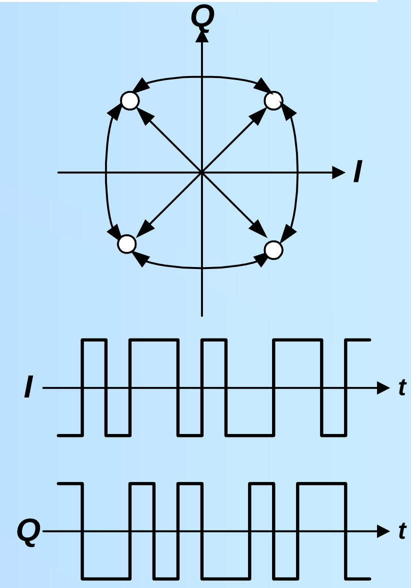

- In a radio transmitter, frequency $f_1$ comes from the modulator inside the transmitter and frequency $f_2$ comes from an oscillator inside the transmitter.



# Digital Modulators

- The Quadrature modulator is a universal modulator used in the transmitter section of most modern cellular systems to generate phase or frequency digitally modulated UHF or VHF signals from their baseband quadrature components. Most systems have two bits in one symbol (QPSK, GMSK), which is a compromise between spectral efficiency and accuracy requirements.
- Before the modulator, the bits are filtered to smooth the bit transitions. Without the pulse / bit filtering, the spectrum of the modulation has the shape of a sinc-function with relatively high side lobes.
- In modulator below, we can express a(t) and $\phi$(t) as: $a(t) = \sqrt{I(t)^2 + Q(t)^2}$; $\phi(t) = \tan^{-1}(\frac{Q(t)}{I(t)})$



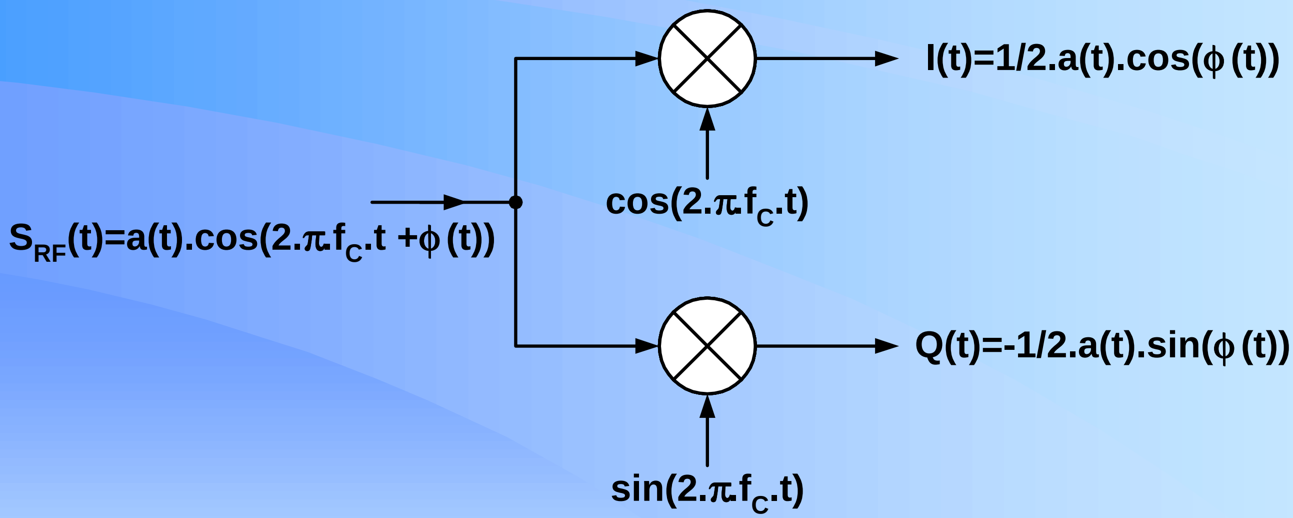




QPSK Constellation

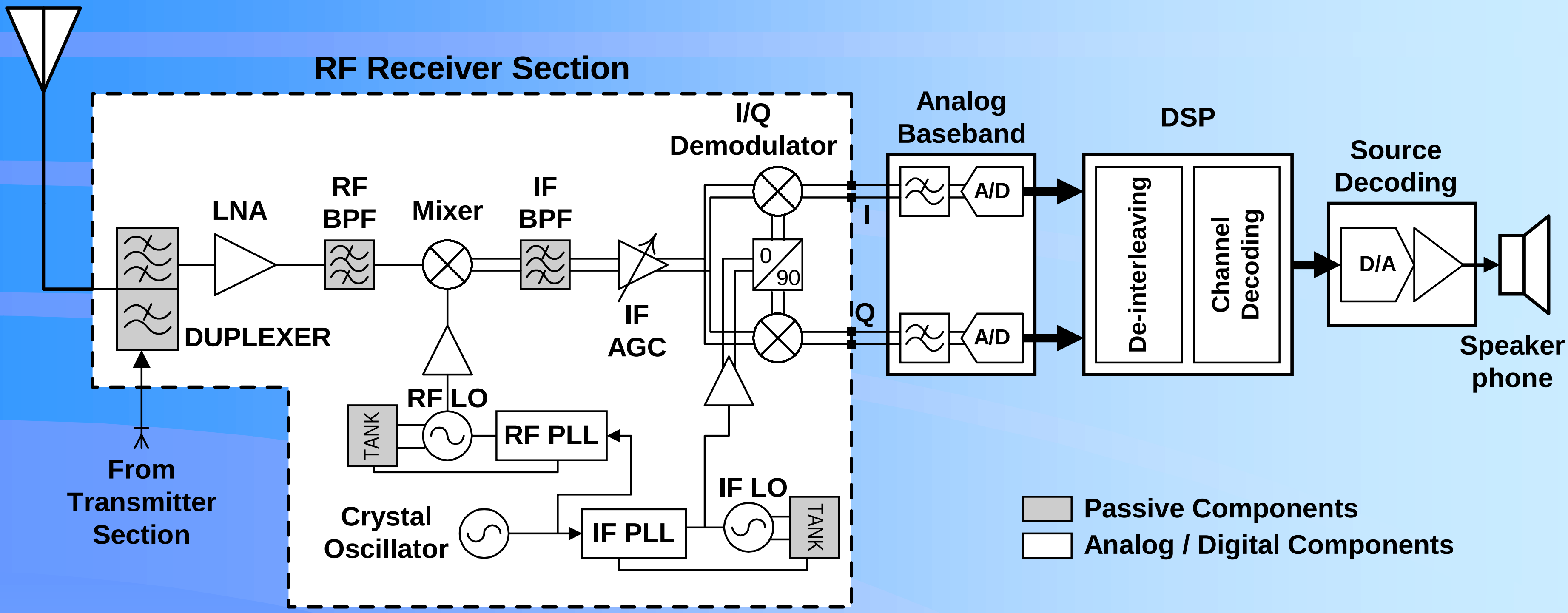
# Digital Demodulators

- The Quadrature demodulator is a universal demodulator used in the receiver section of most modern cellular systems to demodulate phase or frequency digitally modulated RF signals to their baseband quadrature components.
- After the demodulator, the *I* and *Q* outputs are normally filtered to remove any high frequency products before being fed into the analog baseband receiver section.
- As we can see from diagram below, a(t) and $\phi$(t) can be reconstructed from output signals I(t) and Q(t):

$$a(t) = 2 \cdot \sqrt{I(t)^2 + Q(t)^2}; \qquad \phi(t) = -\tan^{-1}\left(\frac{Q(t)}{I(t)}\right)$$

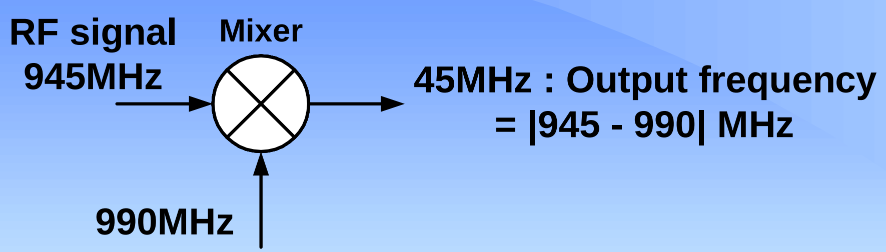


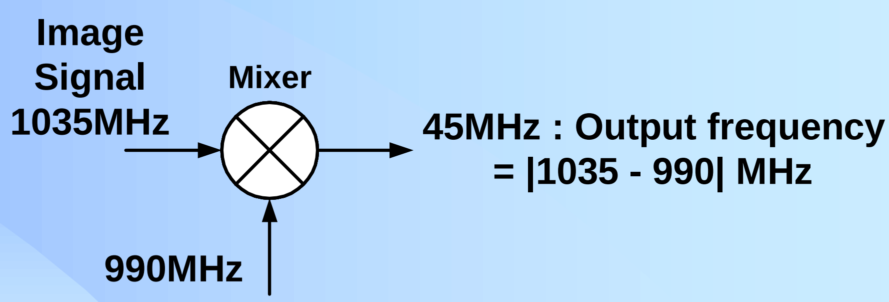
# Block Diagram of a Cellular Phone Receiver



# Cellular Phone Receiver RF Blocks Description

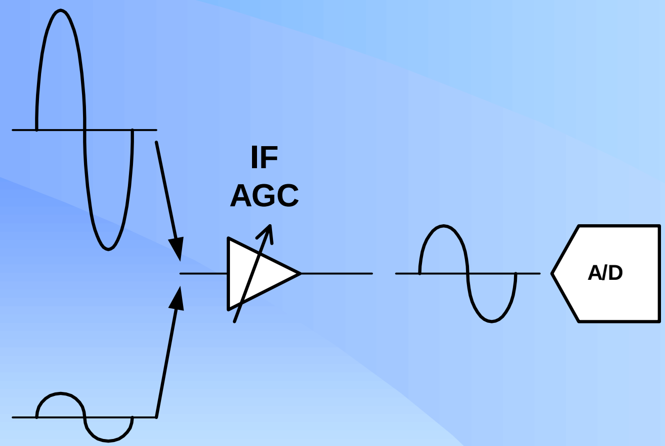
- **Duplexer:**
  This is where the receive RF signal and the transmit RF signal meet right before the antenna. The duplexer filter has different transfer functions from the antenna terminal to the receiver and transmitter. It needs to provide enough isolation between the transmit and the receive sections so that the high level transmit signal (~1W for GSM) does not overwhelm the sensitive receiver (~ 1µVrms). Commercial duplexers have the largest physical volume of all other components in the cellular phone RF section.
- **LNA:**
  The low noise amplifier is needed in order to amplify the very low level receive signals (~1µVrms) without adding noise to the signal which can reduce the receiver sensitivity. These amplifiers need to be also highly linear in order to handle weak signals in presence of large interfering signals.
- **RF (UHF) Bandpass Filter:**
  This filter is highly important since it eliminates large interferers outside the band of interest from reaching the mixer; these interferes can come from other wireless systems and networks. This filter spans normally the desired system bandwidth (925-960MHz for GSM). Furthermore, It rejects the Image Frequency interferer which can be drastic to the receiver:



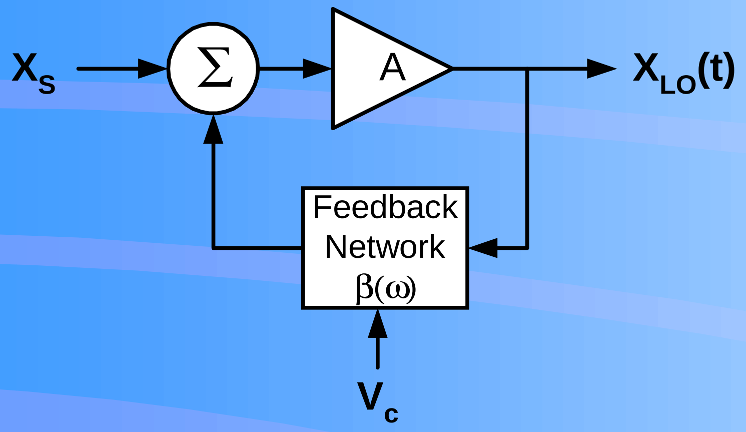
# Cellular Phone Receiver RF Blocks Description (Cont'd)

- **Mixer:**
  This is where the receive RF signal is down-converted to an intermediate frequency (IF) which is normally in the VHF band. This downconversion step is important since it brings down the RF signal to a lower frequency where it is easier to demodulate the signal to its baseband quadrature I and Q components.
- **IF (VHF) Bandpass filter:**
  This filter is highly important since its function is to select the desired receive channel before the demodulation step. This filter is normally narrowband and its bandwidth is equal to that of the receive RF signal (for GSM, BW = 200kHz). Its center frequency is anywhere between 30-300MHz. The filter should not distort the receive signal.
- **IF AGC (Automatic Gain Control):**
  This block is very important since it adapts the wide range of received signals (1µVrms-10mVrms) to a constant signal level at input of I/Q demodulator which is desired by sampling A/D converters in analog baseband section for optimum # of A/D bits per sample.



# Cellular Phone Receiver RF Blocks Description (Cont'd)

- **Local Oscillator (LO):**
  Oscillators are key components of all cellular phone systems. They are essentially dc-to-RF converters; they produce an RF signal output with only a dc signal input. It consists of an amplifier and a feedback network to provide positive feedback in the system.




$$X_{LO}(\omega) = \frac{A}{1 - A \cdot \beta(\omega)} \cdot X_S(\omega);$$

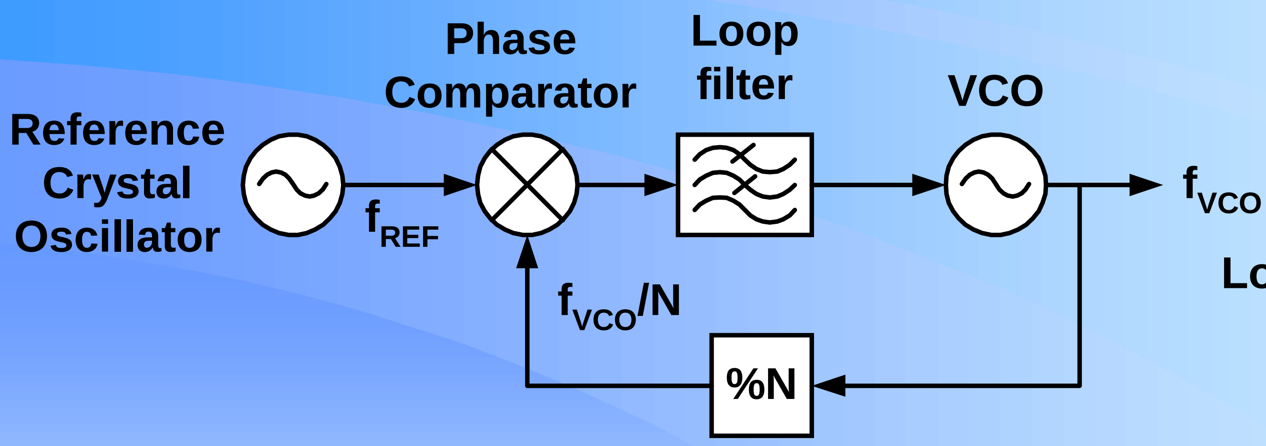
Oscillation occurs when $A \cdot \beta(\omega) = 1$

- The feedback network is frequency-sensitive and it includes some of type of resonance (LC), where $f_{Resonance} = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$. The resonator sets the operating frequency.

In addition, the variable reactance related to C (using a varactor) can be controlled by a dc voltage $V_c$, Hence, this type of oscillator is called Voltage Controlled Oscillator (VCO). By varying $V_c$, the cellular phone can tune to the different RF signal frequencies transmitted by the base station.

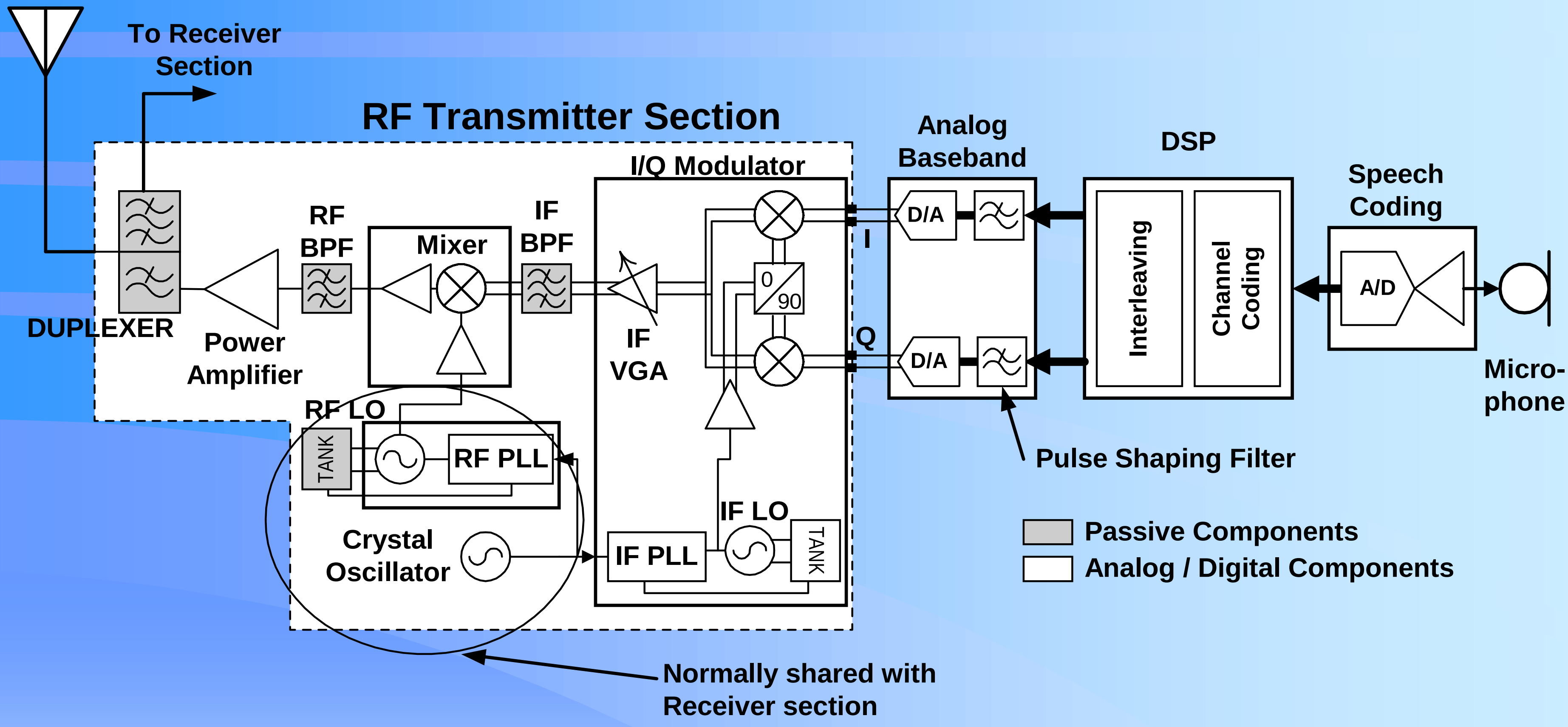
# Cellular Phone Receiver RF Blocks Description (Cont'd)

- **Phase Locked Loop (PLL):**
  Voltage controlled oscillators can not be used by themselves only in a cellular phone. This is because they do not have the appropriate frequency accuracy required by cellular systems. Their frequency inaccuracy is due to the fact that they are free running and their operating frequency can drift with temperature and dc noise applied to the feedback loop input.
  - A solution to the frequency accuracy problem is to lock the VCO to a very highly stable oscillator such a quartz crystal oscillator. This is achieved by including the VCO in a feedback loop with the crystal oscillator, so that its frequency accuracy and phase purity become very close to that of the reference crystal oscillator.




**Loop Condition:**
$f_{REF} = f_{VCO}/N$

# Block Diagram of a Cellular Phone Transmitter






Walid Y. Ali-Ahmad

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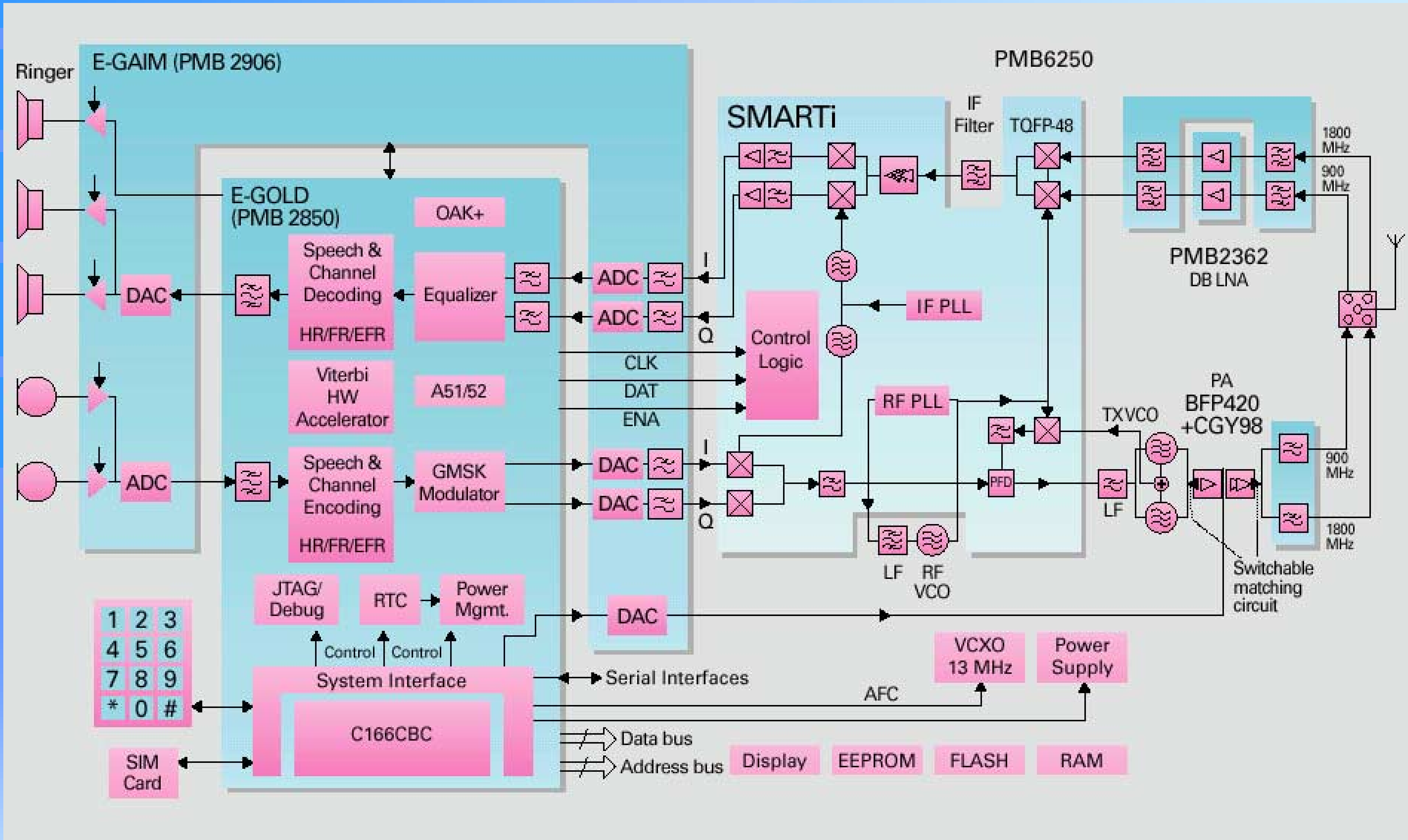
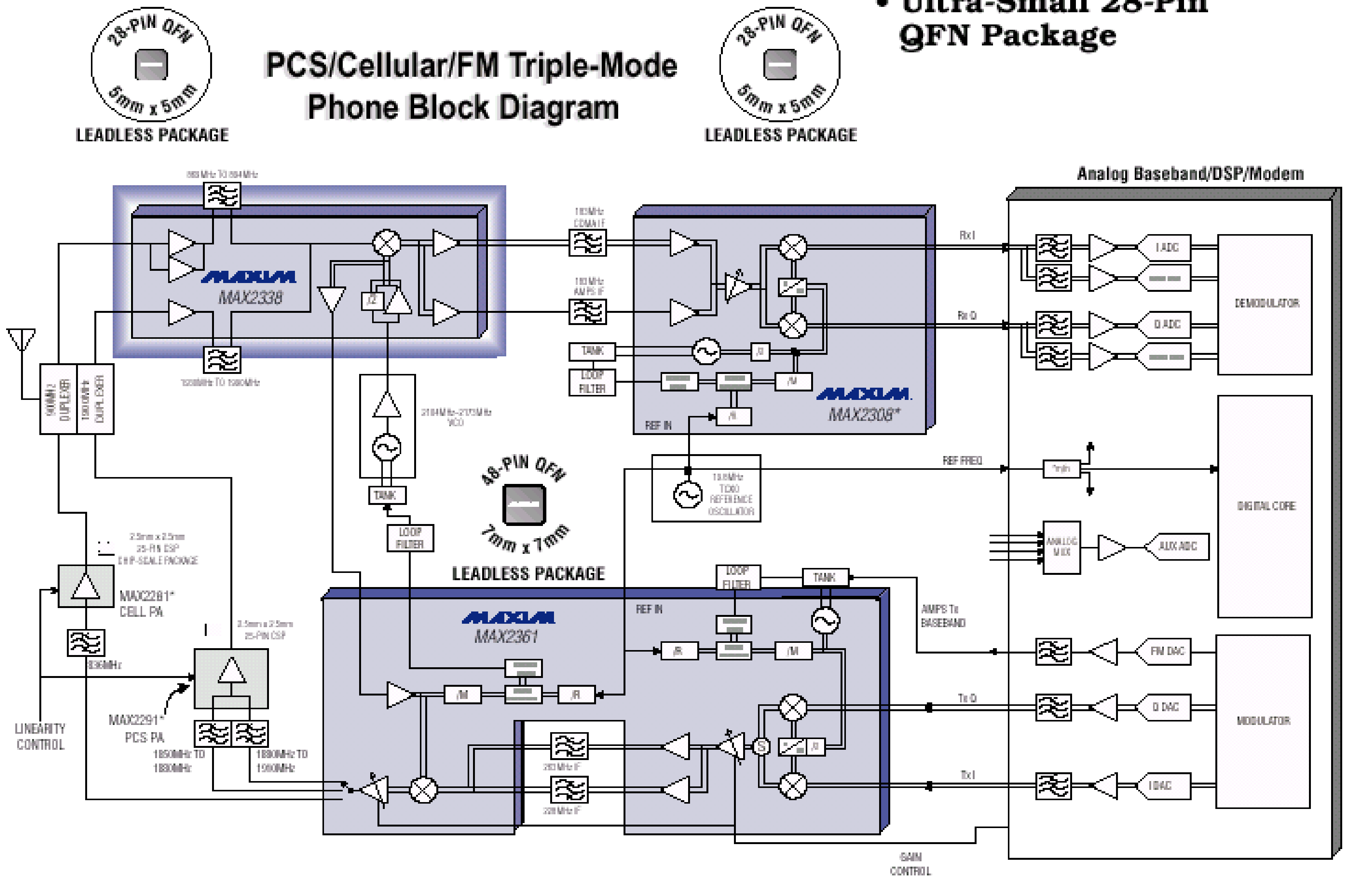
# Low-Power RF Integrated Circuits for a GSM Cell Phone Radio



# Low-Power RF Integrated Circuits for a CDMA Cell Phone Radio

- **Ultra-Small 28-Pin QFN Package**



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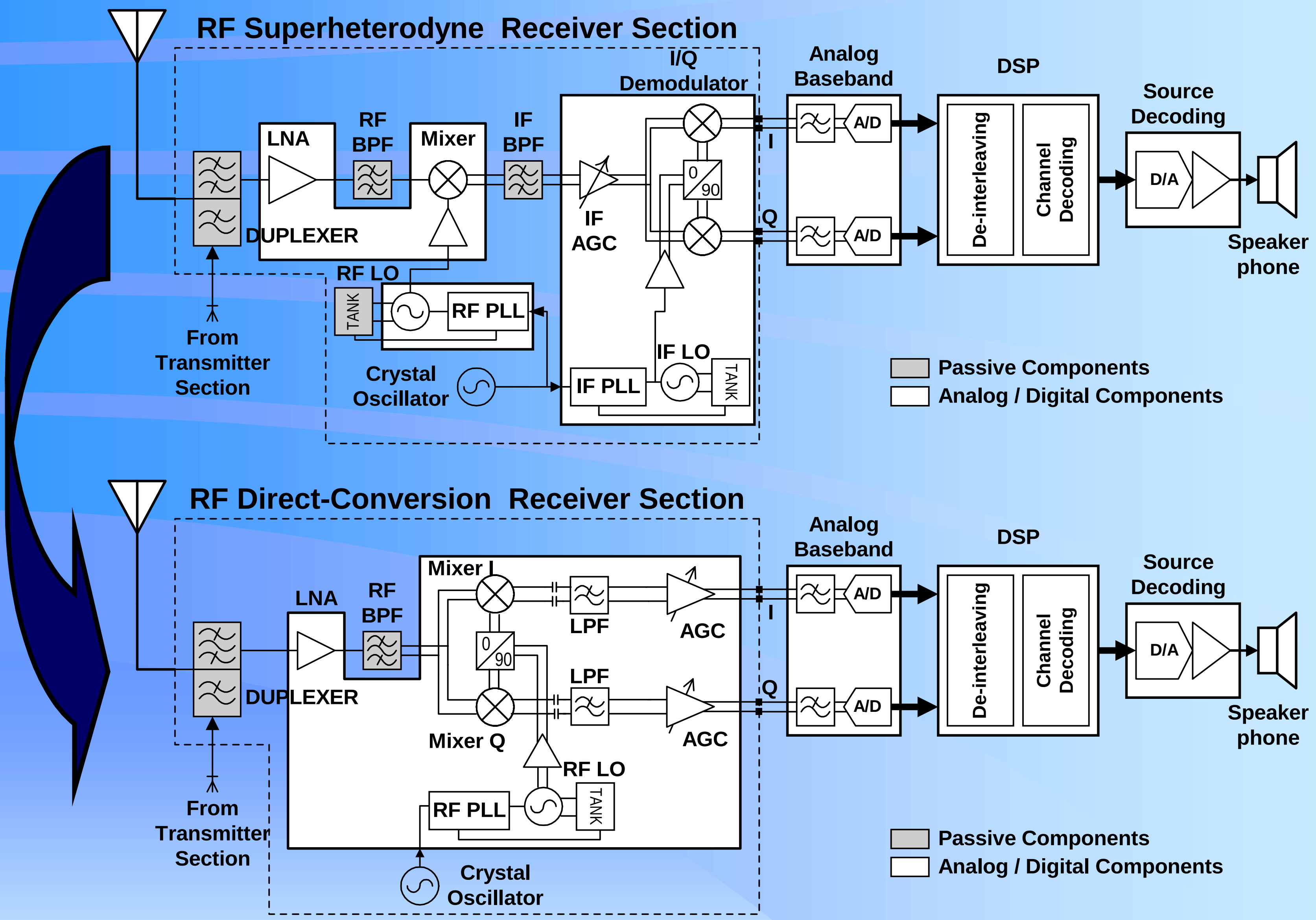
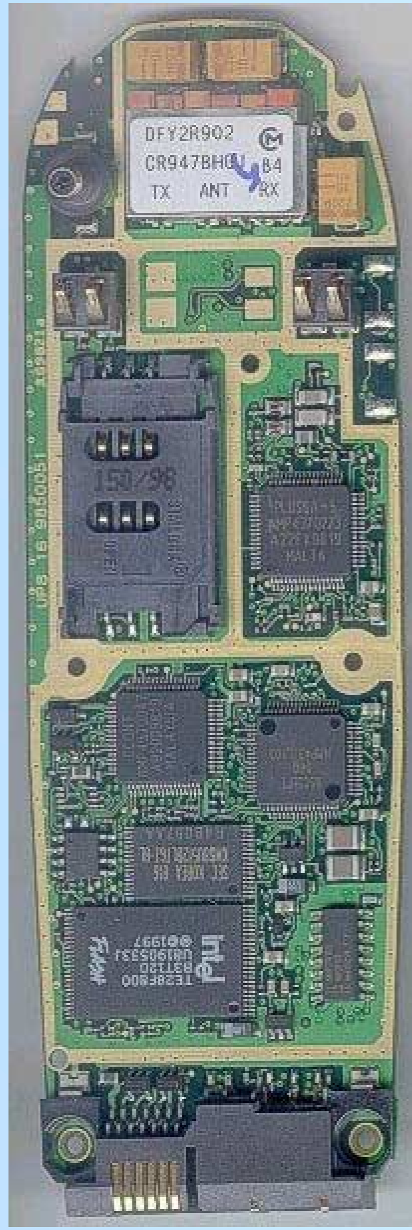
# Road to Integration: Heterodyne vs. Direct Conversion



# Inside a Cellular Phone (Nokia 5110)

# Inside a Cellular Phone (Nokia 3310)