ECE 621

RF IC Design - why this course?

Wireless market is exploding
- cellular
- cordless
- pagers
- wireless LANs
- wireless home networking

∴ need to understand the principles for design of the basic building blocks. Requires knowledge of
- ICs
- RF design (high frequency behavior)
- communication theory
- transceiver architectures

Recall

AM, FM radios and TV broadcast systems are also RF but at lower frequencies compared to present day applications

The key objective is transmission of information

Transmission of information

Information represents
- speech
- video
- data

and is transmitted in the form of electrical signals. These signals are usually limited to a specified bandwidth (because of the source or filters). Most of these signals occupy frequency bands extending to low Hz

⇒ cannot transmit these signals simultaneously over a single communication channel

⇒ multiplexing either in frequency or time

Amplitude modulation (AM), frequency modulation (FM) are different ways of multiplexing in the frequency domain

i.e., each "message" is translated to a different position in the frequency spectrum

An auxiliary signal the carrier is used for frequency multiplexing. The modified carrier is called a modulated signal

The process of recovering the original message is called demodulation

Nomenclature of frequencies

3kHz - 30 kHz	VLF	(very low frequency)
30-300 kHz	LF	
300 - 3000 kHz	MF	(medium)
3 - 30 MHz	HF	
30 - 300 MHz	VHF	
300 - 3000MHz	UHF	(ultra)
3 - 30 GHz	SHF	(super)
30 - 300 GHz	EHF	(extremely)

What about voice? .3kHz - 3 kHz VF (voice frequencies)

Example Commercial broadcast FM 88 MHz - 108 MHz

20 MHz band divided into 100, 200 kHz wide channels starting at 88.1 MHz (88.3 MHz, 88.5 MHz, ...)

Max freq. deviation = 75 kHz, Max modulation freq = 15 kHz

Bluetooth – wireless connection of PCs, smart phones, etc. (short range connectivity). The first major step to truly personal networking

Normal range	10 m	(0 dBm)	i.e. 1 mW
Optional "	100 m	20 dBm	i.e. 100 mW

Frequency band 2.4 GHz

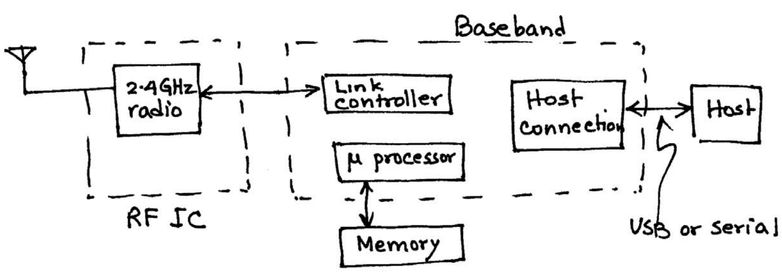
This is a license-free band open to any radio system. The band is called ISM (Industrial-Scientific Medical band. 2.4 GHz – 2.4835 GHz

Observations

In 2000 it was expected that there would be ~ 100 M electronic devices that are Bluetooth enabled. In reality only 7-10 M.

Early projections for 2005 (1 B). Now 400 M for 2006

What does a Bluetooth chipset look like



Note

All digital devices that are to be connected will have to be equipped with a Bluetooth transceiver

2.4 GHz band used by several devices

- cordless phones
- wireless LAN
- μwave ovens
- ...

⇒ possible interference between different devices

Wireless LAN standards

Standard	Freq (GHz)	Modulation	Data rate (Mb/sec)
open-air	2.4	FHSS	1.6
Home RF	2.4	FHSS	1-2
Bluetooth	2.4	FH SS	1
802.11	2.4	FH/DSSS	1-2
802.11b	2.4	DSSS	11
802.11a	5	DMT/OFDM	6-54
802.11g	2.4	OFDM	54
DECT	1.9	GFSK	1.152
Hiper LAN	5	GMSK	24

FHSS – frequency hopping spread spectrum
DSSS – direct sequence spread spectrum
DMT – discrete multi-tone
OFDM – orthogonal frequency division multiplexing
GFSK – Gaussian Frequency-shift keying
GMSK – " Minimum- " "

Recently a new standard for wireless PAN – ZigBee

ZigBee for small, low power digital radios based on IEEE 802.15.4 standard for wireless PAN. Bluetooth is 802.15.1

Uses of ZigBee

- applications with low data rates and low power consumption
- individual devices run for a year or so with a single alkaline battery
- Killer application meter reading, industrial controls

In this course, our focus will be on narrow band circuits typical of many RF applications

Broad band circuits required for optical communications or the new Ultra Wide Band (UWB) standard

What is UWB?

Any radio technology having a spectrum that occupies a bandwidth greater than 25% of the center frequency.

e.g. $f_0 = 2$ GHz BW $\geq$ 500 MHz

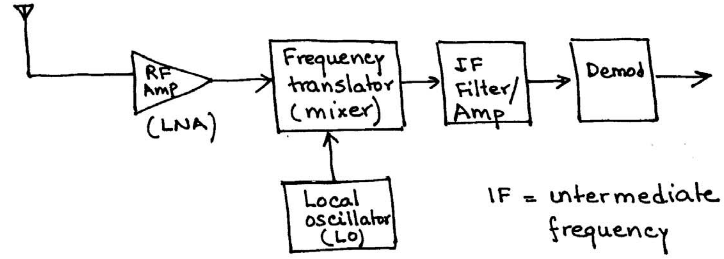
$f_0 = 4$ GHz BW $\geq$ 1 GHz

In the US, FCC has mandated that UWB transmissions can operate in 3.1 - 10.6 GHz with a limited transmit power of -41 dBm/MHz

Data rates 100 Mb/s - 480 Mb/sec

Also known as an impulse radio

A receiver architecture



IF = intermediate frequency

This architecture is called the super heterodyne receiver

The process of frequency translation by multiplication of a signal with an auxiliary signal is called mixing or heterodyning

Example

$$v_{RF} = A_{RF} \cos \omega_{RF} t$$
$$v_{LO} = A_{LO} \cos \omega_{LO} t$$

Multiply v_{RL} & v_{LO} $\Rightarrow$ $A_{RF} \cos \omega_{RF} t \; A_{LO} \cos \omega_{LO} t$

$$= \frac{A_{RF} A_{LO}}{2} \Big[\underbrace{\cos(\omega_{LO} - \omega_{RF}) t}_{\text{downconversion}} + \underbrace{\cos(\omega_{LO} + \omega_{RF}) t}_{\text{upconversion}} \Big]$$

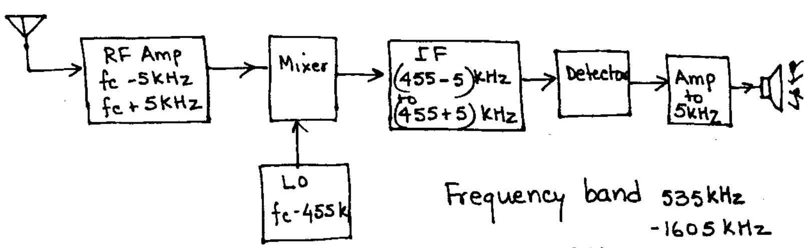
The IF frequency is $\omega_{LO} - \omega_{RF}$

Remarks

- A very successful architecture
- Local oscillator used for downconverting the RF to IF ($\omega_{IF} = \omega_{LO} - \omega_{RF}$)
- Note the IF is a fixed frequency

- Easier to design IF filters & amplifiers
  It is difficult to main constant BW in a tunable filter compared with a fixed one
  High gain can be provided in a fixed-frequency amplifier
  IF is at a lower frequency where gain is easier to achieve
- Major disadvantage: Spurious responses introduced due to mixing – the image frequency
  ⇒ need image-rejection filters
- For 900 MHz & 1.8 GHz bands typical IFs range from 70 MHz to 200 MHz
- Tuning is accomplished by changing the LO frequency. $\omega_{LO} - \omega_{RF} = \omega_{IF}$ converts signal at RF to IF.

Example (AM receiver)



Frequency band 535 kHz - 1605 kHz

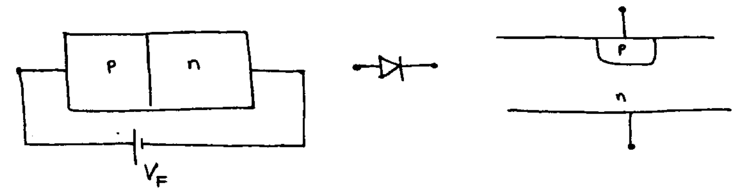
IF = 455 kHz

In this course we will consider the individual blocks
- LNA
- Mixer
- Oscillators

Since distortion and noise place a restriction on the dynamic range of the input signal we will also analyze distortion and noise in circuits

Models for IC Active devices

pn junction diode



For a forward voltage $V_F > 0$ current I is given by

$$I = I_s\left(e^{V/V_{th}} - 1\right)$$

where $V_{th} = \frac{kT}{q} \cong 26\text{ mV}$ at $300^\circ K$

and $I_s = f\left(A, n_i^2, \frac{1}{N_A}, \frac{1}{N_D}\right)$

(A: area; n_i^2: intrinsic carrier conc; $\frac{1}{N_A}, \frac{1}{N_D}$: doping conc.)

For a reverse voltage $V < 0$, the current is the leakage current

$$I \cong -I_s$$

For $V < -V_{BR}$ there is a breakdown of the junction and a large current can flow.