Introduction to Software Defined Radio (SDR) - A Hands-on Course

Class 2: RF and Radio Basics

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Presented by:

DesignNews CEC CONTINUING EDUCATION CENTER Blue Ridge Advanced Design and Automation Asheville, North Carolina Digi-Key ELECTRONICS ROHDE&SCHWARZ

This Week's Agenda

9/25 Intro to SDR

9/26 RF and Radio Basics

9/27 Exploring SDR with the RTL-SDR, Part 1

9/28 Exploring SDR with the RTL-SDR, Part 2

9/29 Commercial SDR Designs

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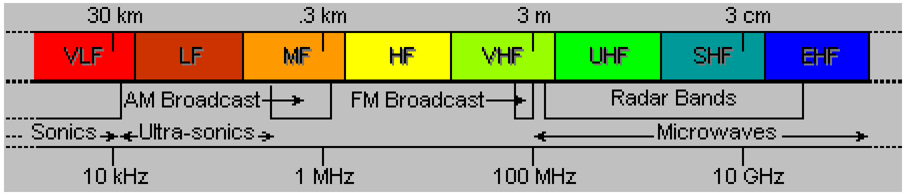
Radio Frequencies (RF)

- Somewhere between sound and light…



ITU Band	Frequency Range	Wavelength
VLF	3 Khz – 30 Khz	100 Km – 10 Km
LF	30 Khz – 300 Khz	1 m – 100 Km
MF	300Khz – 3 Mhz	10 m – 1 m
HF	3 Mhz – 30 Mhz	100 m – 10 m
VHF	30 Mhz – 300 Mhz	10 m – 1 m
UHF	300 Mhz – 3 Ghz	1 m – 10 cm
SHF	3 Ghz – 30 Ghz	10cm – 1cm
EHF	30 Ghz – 300 Ghz	1 cm – 1 mm

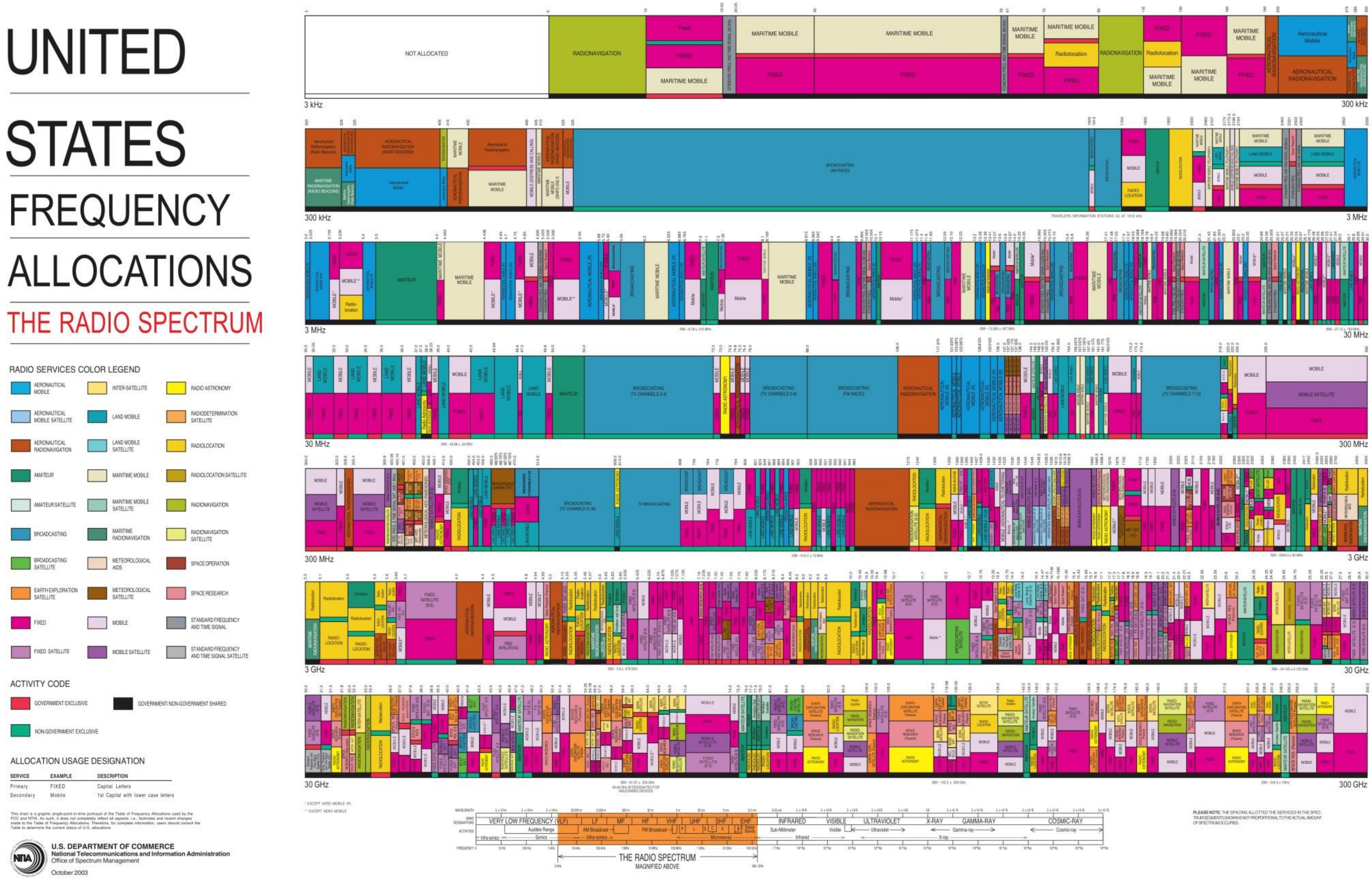
Wavelength

$$wavelength\ \lambda\ in\ meters = \frac{300{,}000}{Frequency\ in\ Hz}$$

Thus, for 2.4 Ghz

$$\lambda\ = \frac{300{,}000}{2{,}400{,}000} = 125\ mm$$

Question 1 – Is there an Extremely LOW Frequency band (ELF)? What was it ever used for?



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Asheville, North Carolina

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL AIDS
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

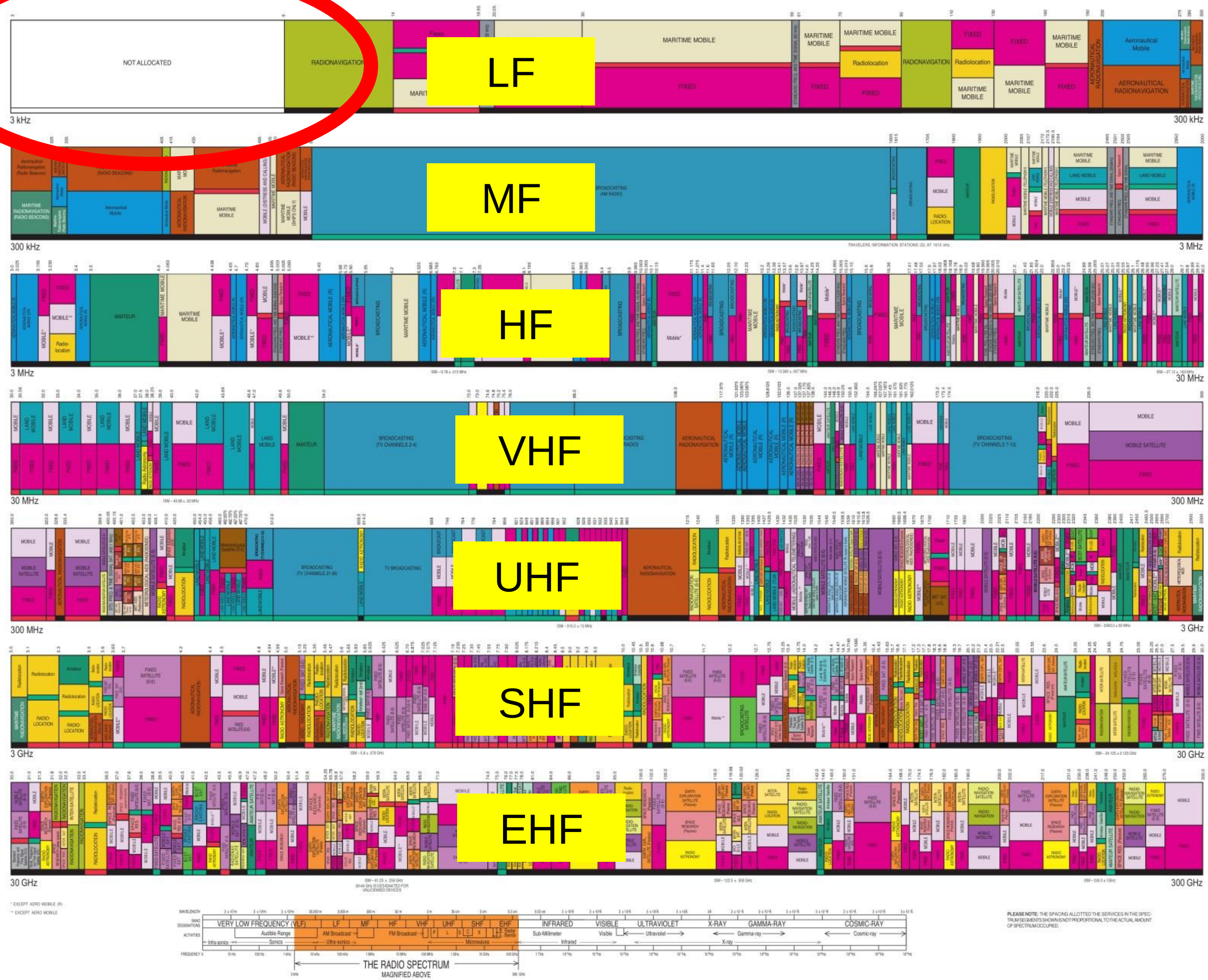
ACTIVITY CODE

- GOVERNMENT EXCLUSIVE
- GOVERNMENT/NON-GOVERNMENT SHARED
- NON-GOVERNMENT EXCLUSIVE

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
October 2003



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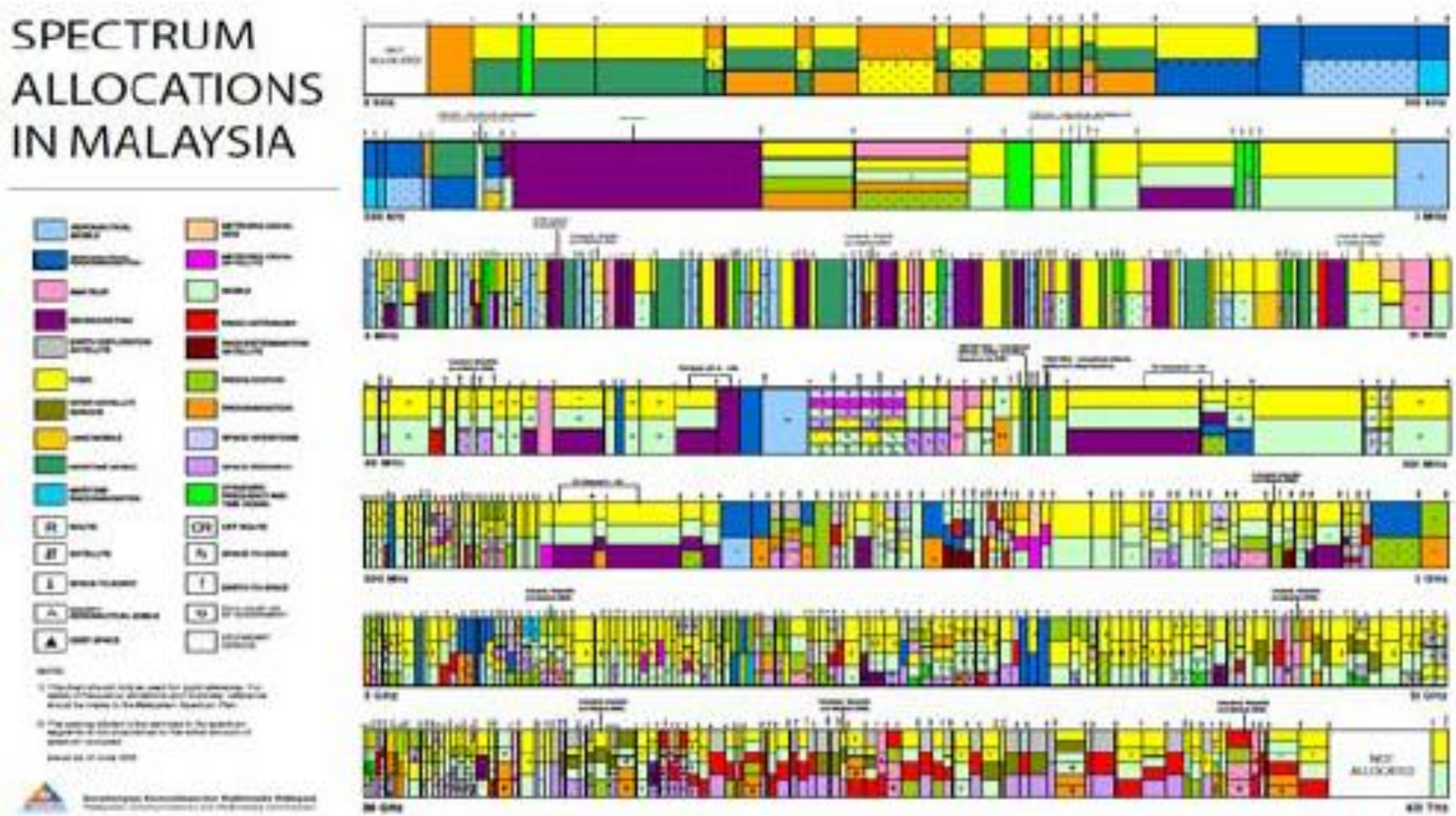

SPECTRUM
ALLOCATIONS
IN MALAYSIA

Frequency Spectrum Allocation

Unlicensed ISM/SRD bands:

- **USA/Canada:**

260 – 470 MHz (FCC Part 15.231; 15.205)

902 – 928 MHz (FCC Part 15.247; 15.249)

2400 – 2483.5 MHz (FCC Part 15.247; 15.249)

- **Europe:**

433.050 – 434.790 MHz (ETSI EN 300 220)

863.0 – 870.0 MHz (ETSI EN 300 220)

2400 – 2483.5 MHz (ETSI EN 300 440 or ETSI EN 300 328)

- **Japan:**

315 MHz (Ultra low power applications)

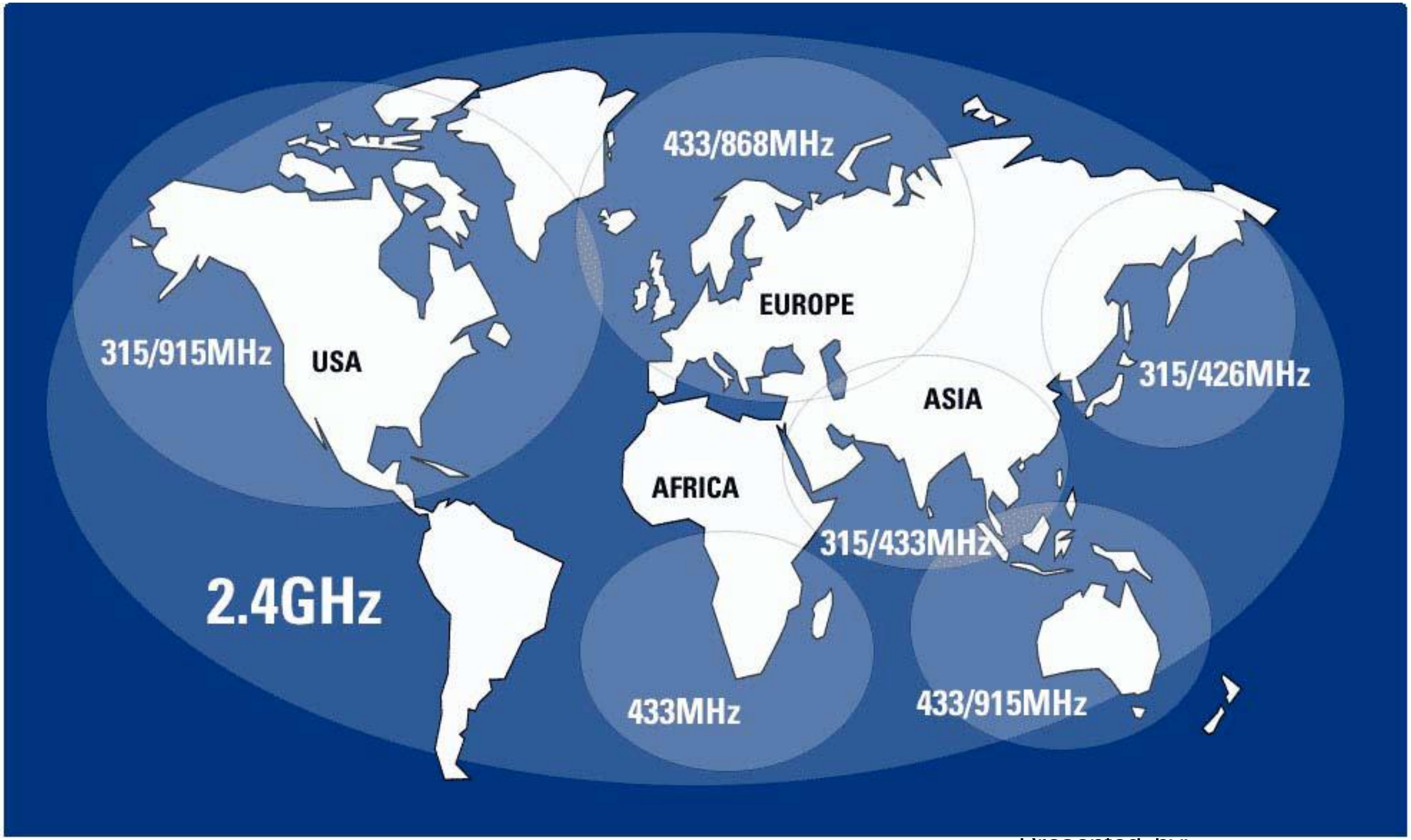
426-430, 449, 469 MHz (ARIB STD-T67)

2400 – 2483.5 MHz (ARIB STD-T66)

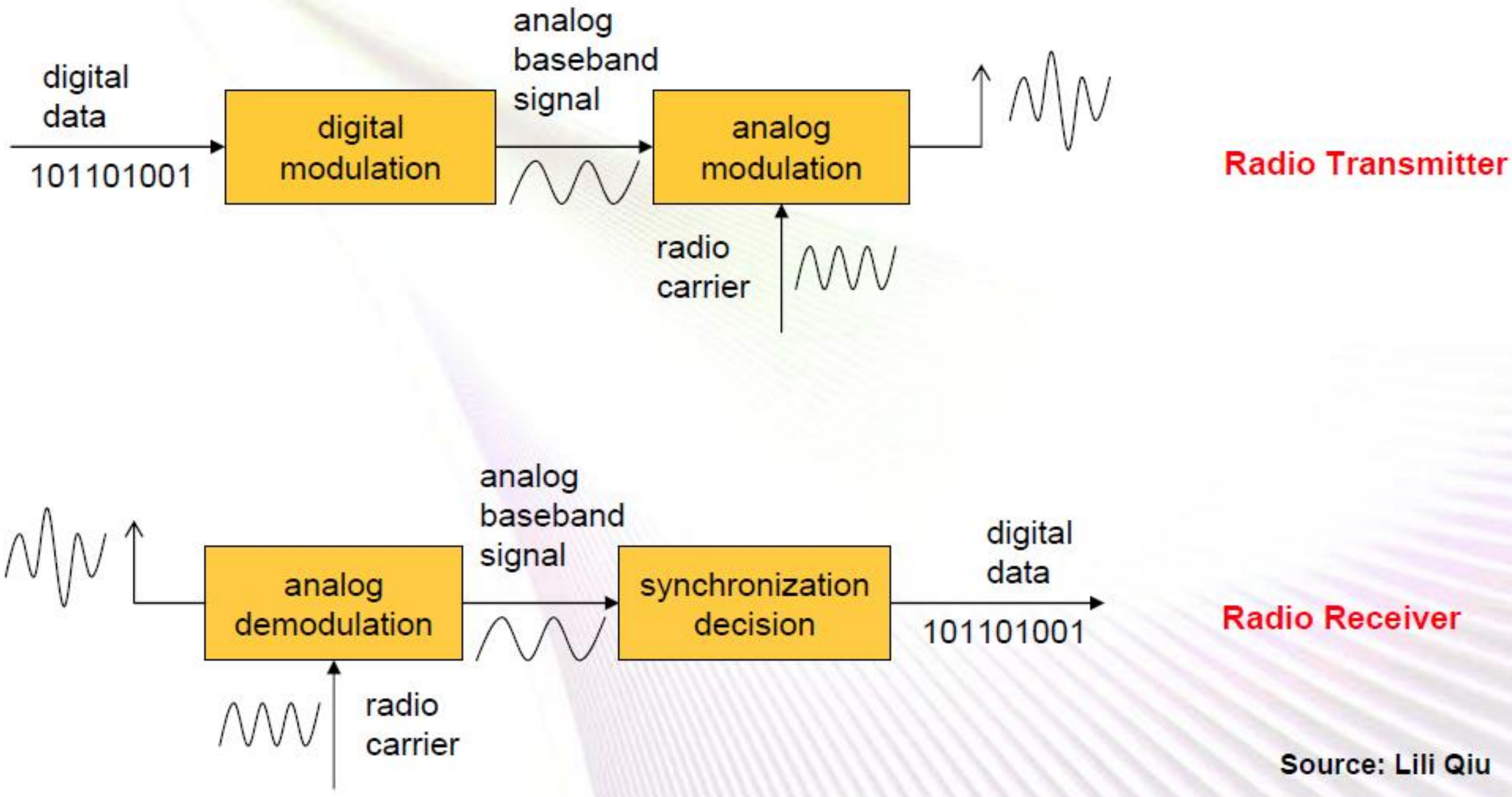
2471 – 2497 MHz (ARIB RCR STD-33)

ISM = Industrial, Scientific and Medical **SRD** = Short Range Devices

Worldwide ISM / SRD



Modulation and Demodulation



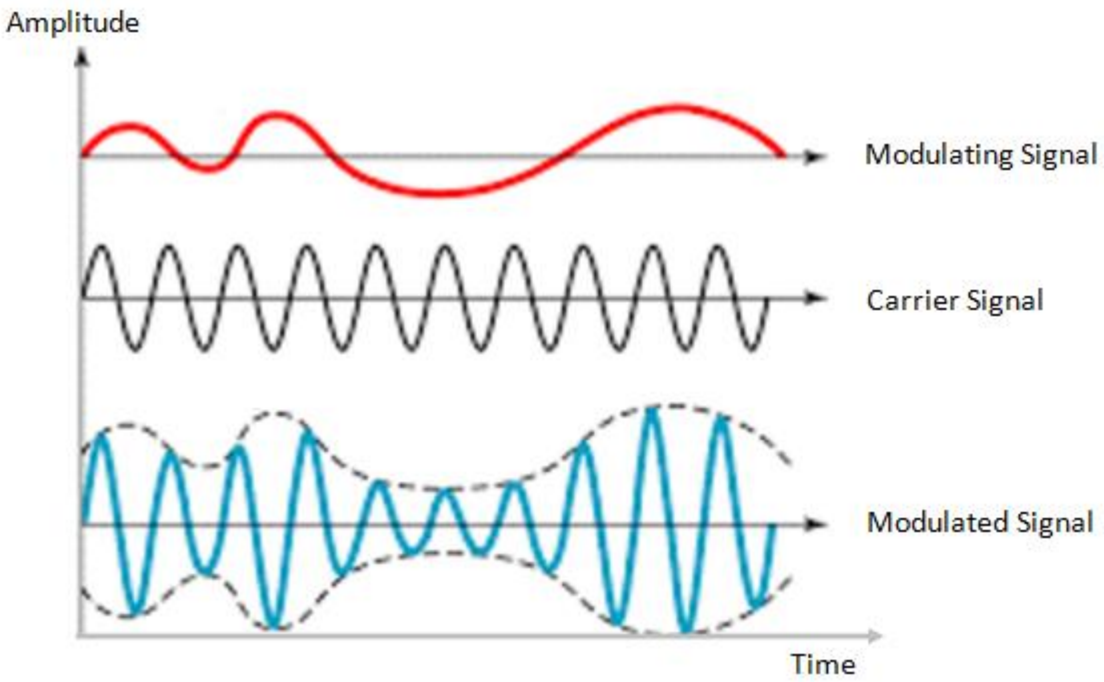
Source: Lili Qiu

Modulation: The process of superimposing a low frequency signal onto a high frequency signal

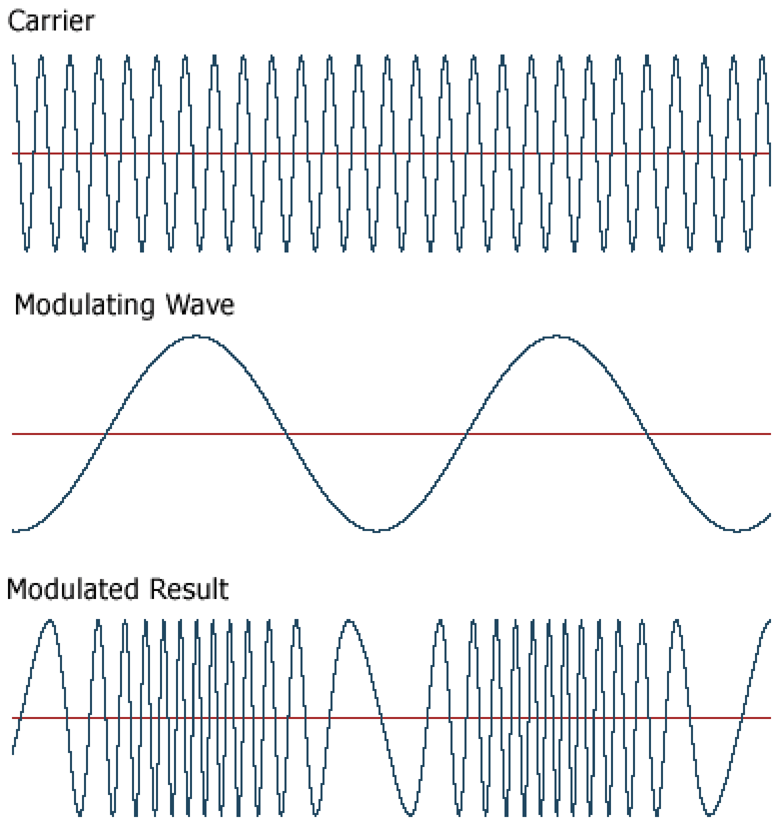
Three modulation schemes available:

1. **Amplitude Modulation (AM):** the amplitude of the carrier varies in accordance to the information signal
2. **Frequency Modulation (FM):** the frequency of the carrier varies in accordance to the information signal
3. **Phase Modulation (PM):** the phase of the carrier varies in accordance to the information signal

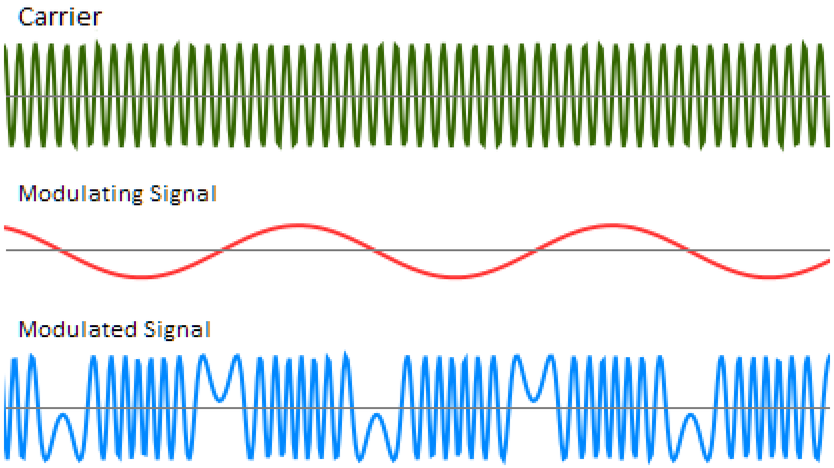
Amplitude Modulation



Frequency Modulation



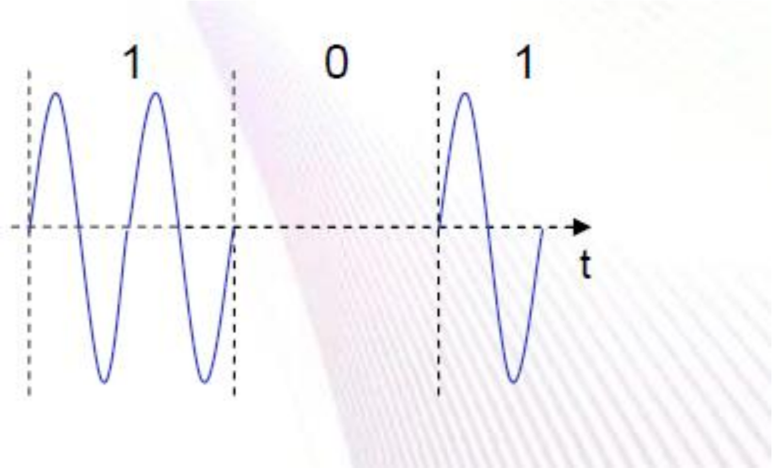
Phase Modulation



Phase Modulation

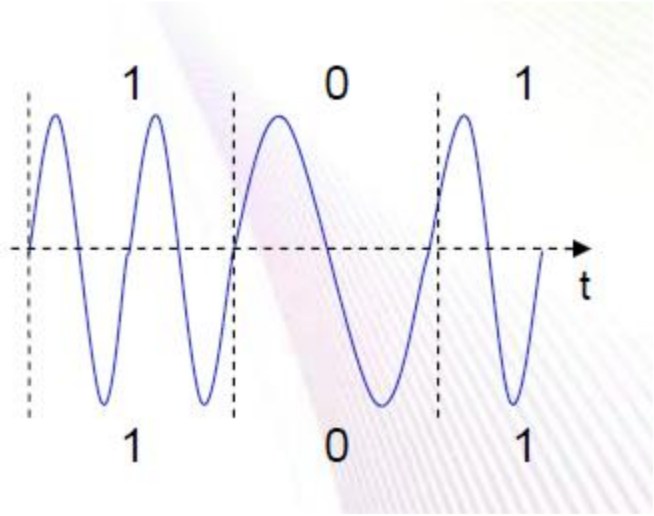
OK, what about digital?

- AM (on / off keying or CW)



Frequency Shift Keying (FSK)

- less susceptible to noise than AM
- theoretically requires larger bandwidth/bit than AM



Phase Shift Keying (PSK)

Pros:

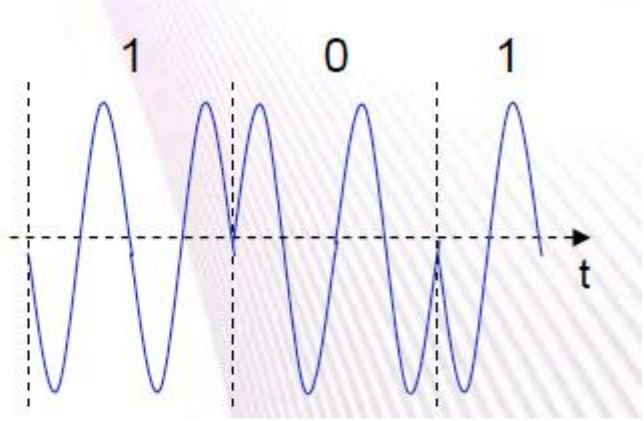
– Less susceptible to noise

– Bandwidth efficient

Cons:

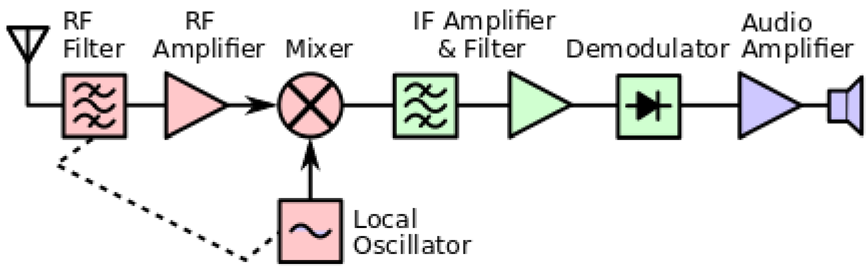
– Require synchronization in frequency and phase complicates receivers and transmitter

Example: IEEE 802.15.4



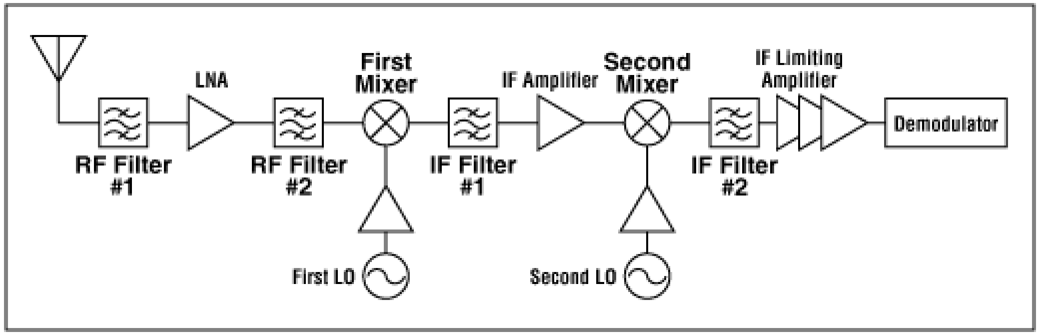
Superheterodyne Receiver

- Mixes a (typically higher) frequency than the desired RF
- Output of the mixer is the two mixed frequencies, the sum, and the difference
- We filter all but the difference into an intermediate frequency or IF



Dual Conversion

- In order to increase selectivity and cut out frequencies close to the desired frequency, a second IF stage was added



Question 2 – What are common first and second IF frequencies?

Free Space Propagation

Friis' transmission equation for free space propagation:

$$P_r = P_t + G_t + G_r + 20\log\left(\frac{\lambda}{4\pi}\right) - 20\log d \quad \text{or} \quad P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}$$

- P_t is the transmitted power, P_r is the received power
- G_t is the transmitter antenna gain, G_r is the receiver antenna gain
- λ is the wavelength
- d is the distance between transmitter and receiver, or the range

Frequency Vs Range

- If range is cut in half as frequency is doubled, why do we want higher RF frequencies?
  - As we double the frequency, the wavelength is halved. Thus we can get more gain in a smaller antenna (within reason)
  - As we go up in frequency, we can achieve greater bandwidth (BW is a lower % of center frequency)
  - Higher frequencies tend to be line of sight

Antennas

- The ‘ideal’ free-space antenna is a half-wave dipole, but it is directional
- A quarter-wave element with a ground is the best omnidirectional
- We can compress an antenna’s length by taking the long length and winding it as a helical (within reason)
- All of these simple antennas are very low bandwidth and have sensitive impedances
- We need to match this complex impedance to the transmission line, and the line to the radio

Impedance Matching

- Any given antenna has a certain complex impedance at any point of attachment (feed point) at any given frequency
- The antenna may have a balanced output or an unbalanced output (referenced to ground)
- Transmission lines are typically expressed as total impedance (say, 50 or 75Ω)
- Outside of the scope of this class, but matching circuits must be added to provide maximum efficiency (minimum loss)

Smith Chart

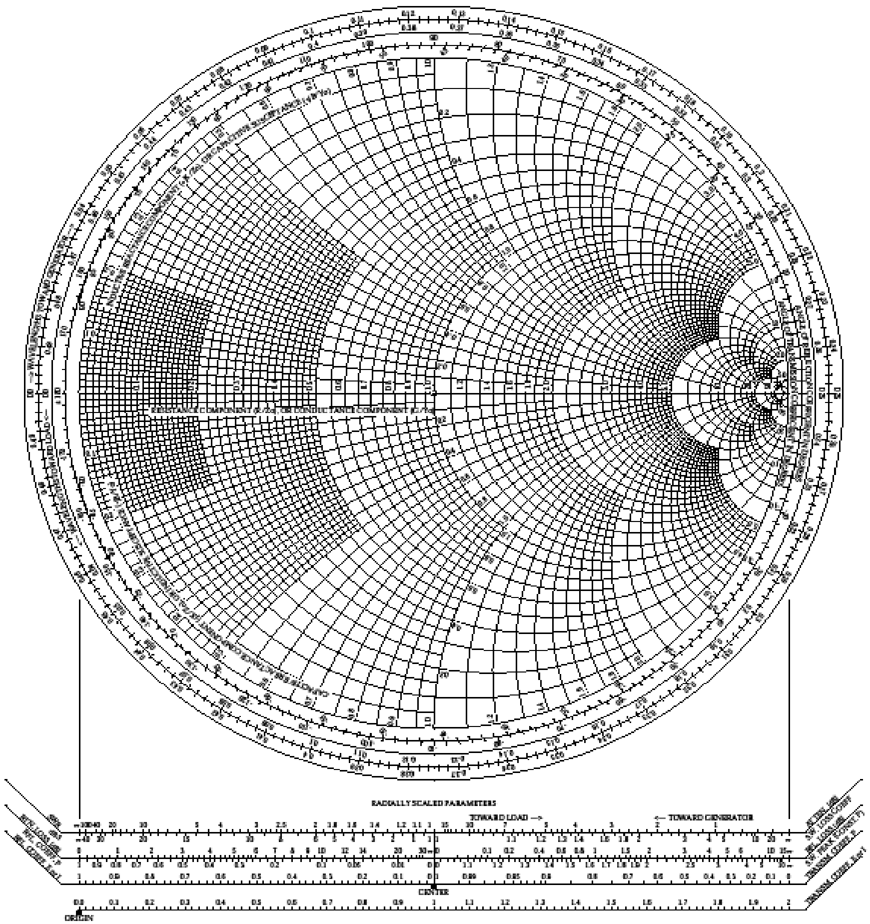
- Philip Smith of Bell Laboratories developed the "Smith Chart" back in the 1930"s to expedite the tedious and repetetive solution of certain rf design problems. These include:
  - Transmission line problems
  - RF amplifier design and analysis
  - L-C impedance matching networks
  - Plotting of antenna impedance
  - Etc.

Construction

- The Smith Chart is made up of a family of circles and a second family of arcs of circles.
- The circles are called “constant resistance circles”
- The arcs are “constant reactance circles”
- Impedances must be entered in rectangular form – broken down into a real and an imaginary component.
- The real part (resistance) determines the circle to use.
- The imaginary part (reactance) determines the arc to use.
- The intersection of an arc and a circle represents the plotted impedance.

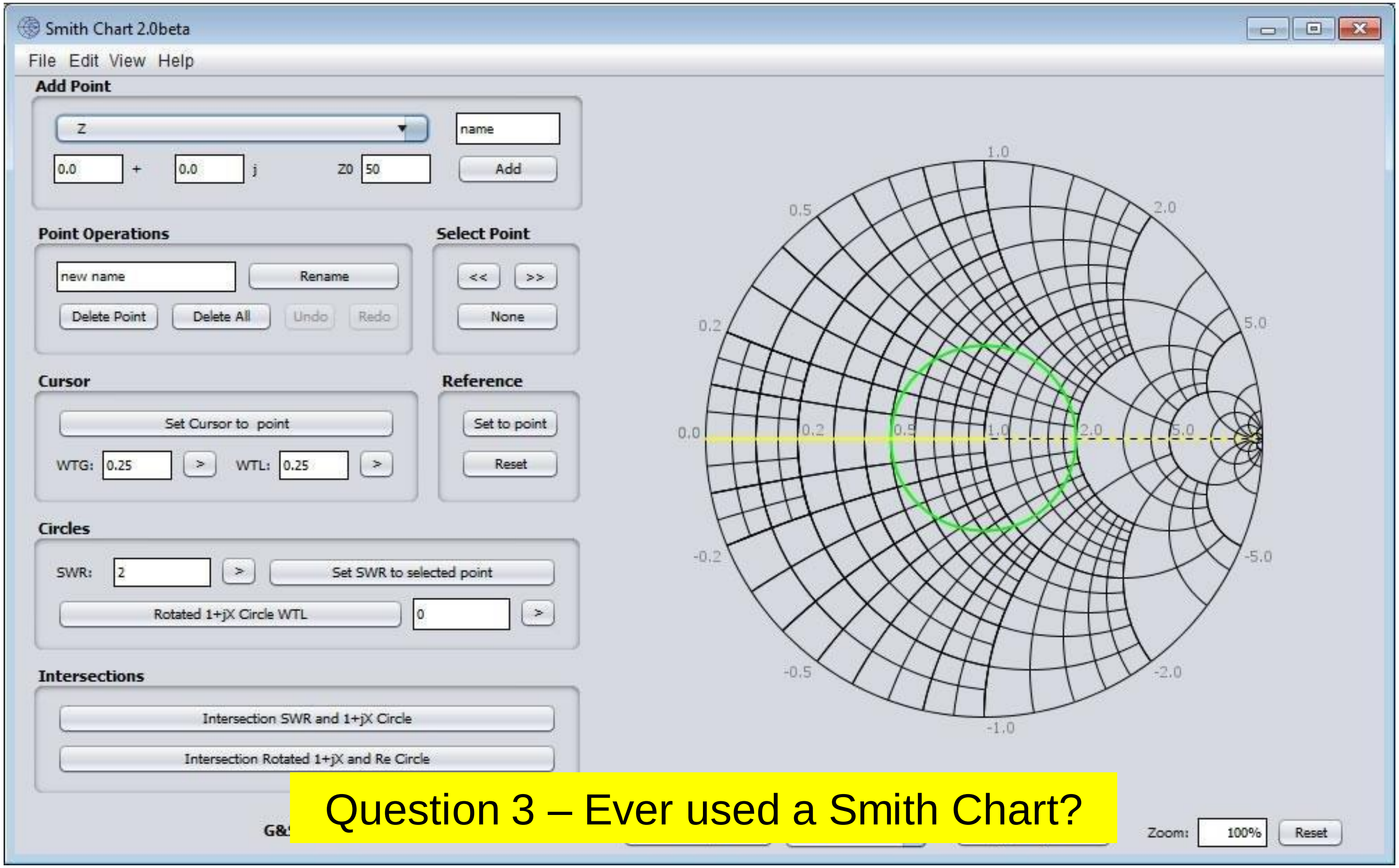
The Complete Smith Chart

Black Magic Design



Presented by:

https://sourceforge.net/projects/gnssmithchart/



Question 3 – Ever used a Smith Chart?

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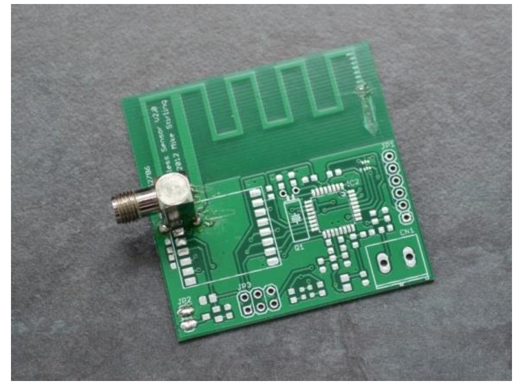
Commonly Used Antennas in 2.4Ghz



PCB antennas

- Little extra cost (PCB)
- Size demanding at low frequencies
- Good performance possible
- Complicated to make good designs

¼ wave whip antennas

- Expensive (unless piece of wire)
- Good performance
- Hard to fit in may applications

Chip antennas

- Expensive
- OK performance

Tunable Antennas

- We need ways of making one antenna have usable gain at multiple frequencies or even a very broad range of frequencies
- Active antennas give some success, much like an actively tuned version of the 'long wire' antenna

Selectivity

- **ACR = Adjacent Channel Rejection**
- **ACS = Adjacent Channel Selectivity**

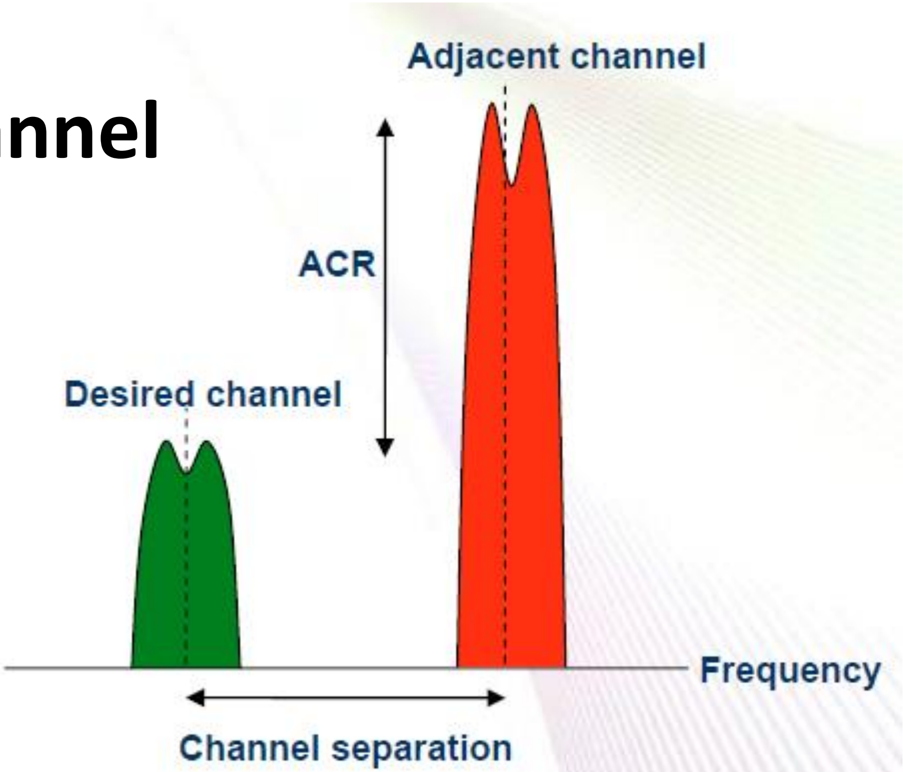
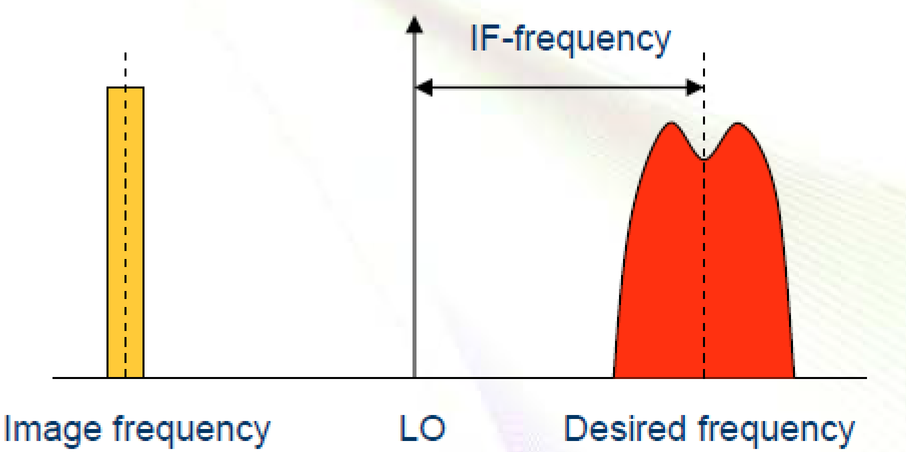


Image Rejection

- Remember that the first injection mixer outputs both the sum and difference of the local oscillator and the input – AND interharmonics. What happens if there is another signal
  +/- the IF frequency



Test Equipment

Vector Network Analyzers

Component Characterization – insertion loss

S-parameters - matching

Spectrum Analyzers

Output Power, harmonics, spurious emission

Phase Noise

Signal Generators

Sensitivity (BER option needed)

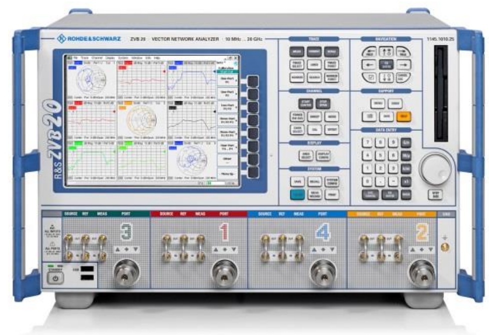
Selectivity/blocking

Two-tone measurements – IP3

Oscilloscopes

Digital signal analysis

Function and Arbitrary Waveform Generators



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Please stick around as I answer your questions!

- Please give me a moment to scroll back through the chat window to find your questions
- I will stay on chat as long as it takes to answer!
- I am available to answer simple questions or to consult (or offer in-house training for your company)
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