RF BASICS

Low Power Wireless

Texas Instruments

Agenda

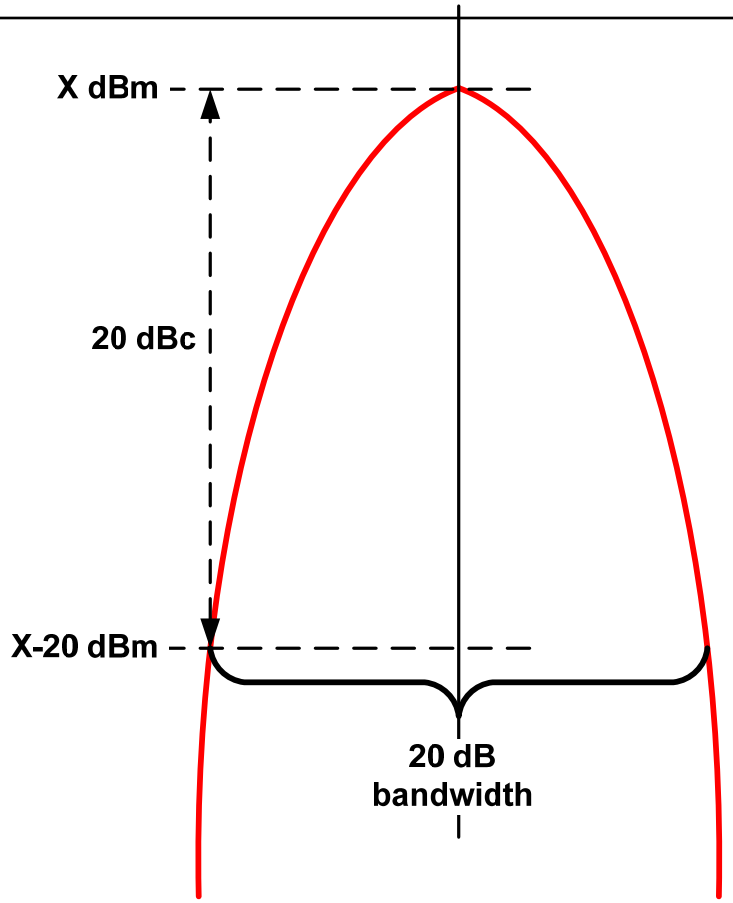
- Defintions
- RF Systems
- Modulation Formats
- System Range

Definitions

- dBm – power referred to 1 mW,

$$P_{dBm}=10\log(P/1mW)$$

- dBc – power referred to carrier

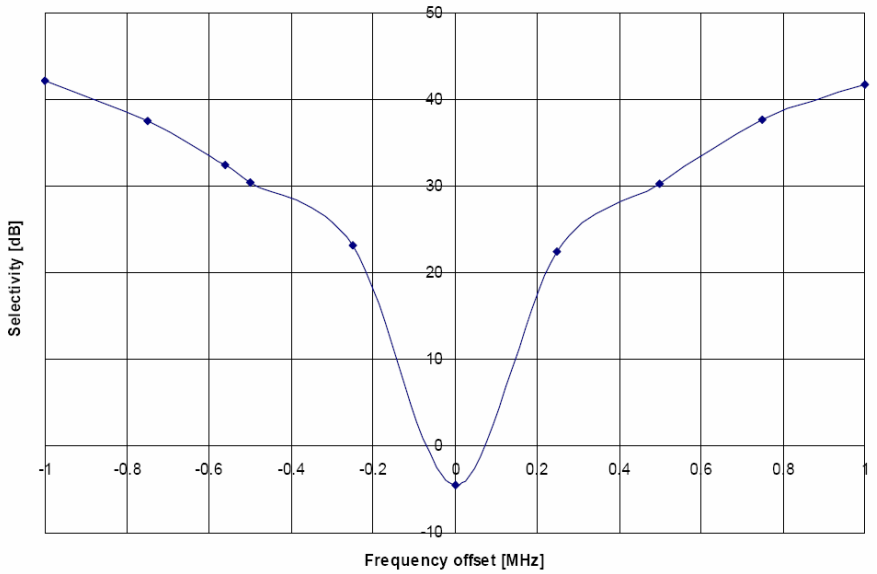


- Rule of thumb:

  6dB increase in link budget => twice the range

Definitions (2)

- **PER**
  Packet Error Rate, % of packets not successfully received
- **Sensitivity**
  Lowest input power with acceptable link quality, typically 1% PER
- **Deviation/separation**
  Frequency offset between a logic ‘0’ and ‘1’ using FSK modulation
- **Blocking/selectivity**
  How well a chip works in an environment with interference



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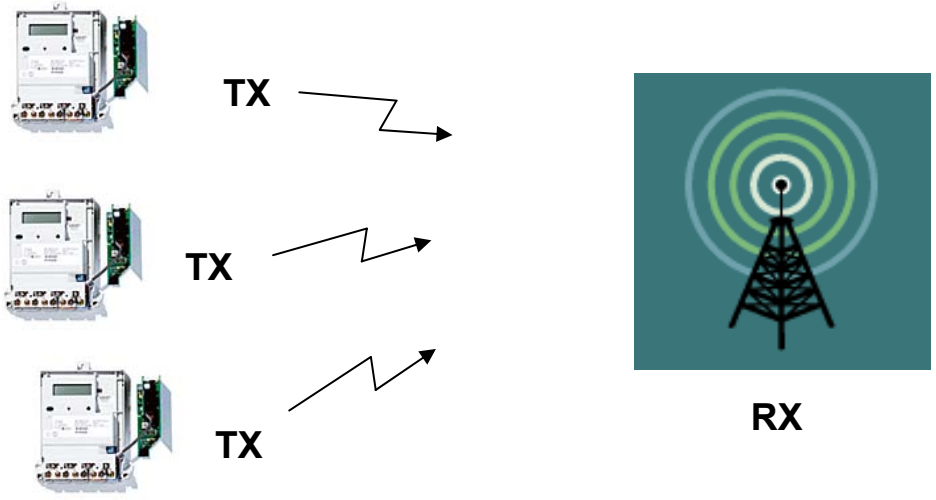
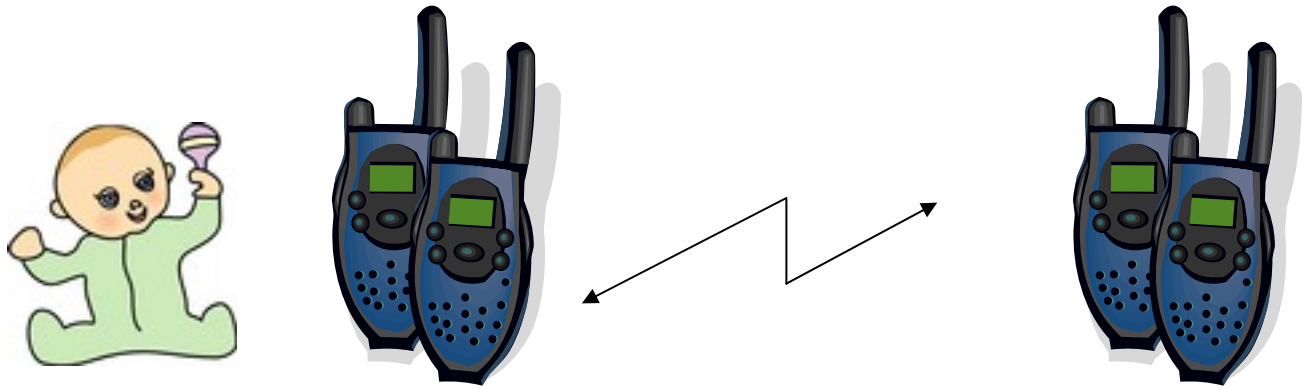
RF Communication Systems

- **One-way RF System**
  - A radio technology that only allows one-way communication from a transmitter to a receiver
  - Typical transmitter chips: CC1150 and CC2550
  - Characteristics: low cost and PCB size, simple protocol, limited protocol functionality
  - Examples: One-way sensor systems, One-way garage door opener



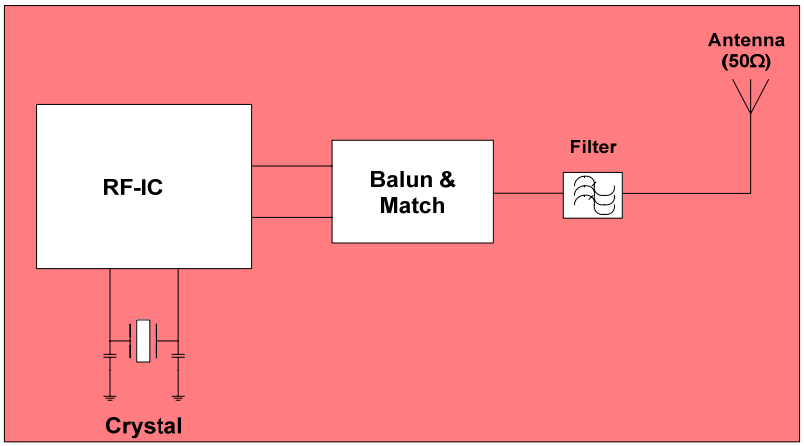
RF Communication Systems

- Two-way RF Systems
  - A radio technology that allows two-way communication between end devices
  - Chips: CC1100, CC2500, CC2420, CC2430
  - Characteristics : Flexible system, robust protocol, low/medium cost
  - Examples: Baby call, Walkie-talkie, wireless keyboard mouse



Basic Building Blocks of an RF System

- **RF-IC**
  - Transmitter
  - Transceiver
  - System-on-Chip (SoC); typically transceiver with integrated microcontroller
- **Crystal**
  - Reference frequency for the LO and the carrier frequency
- **Balun**
  - Balanced to unbalanced
  - Converts a differential signal to a single-ended signal or vice versa
- **Matching**
- **Filter**
  - Used if needed to pass regulatory requirements / improve selectivity
- **Antenna**



RF-ICs, examples

- **Transmitter**
  - CC1050, CC1070, CC1150, and CC2550
- **Transceiver**
  - CC1000, CC1020, CC1100, CC2500, CC2400, and CC2420
- **System-on-Chip (SoC)**
  - Transceiver with a built-in micro controller
  - CC1010, CC1110, CC2510, CC2430

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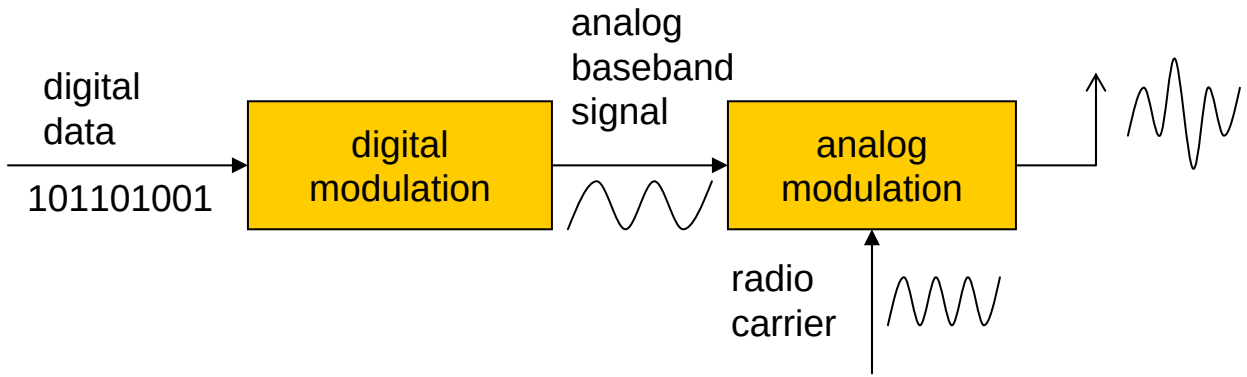
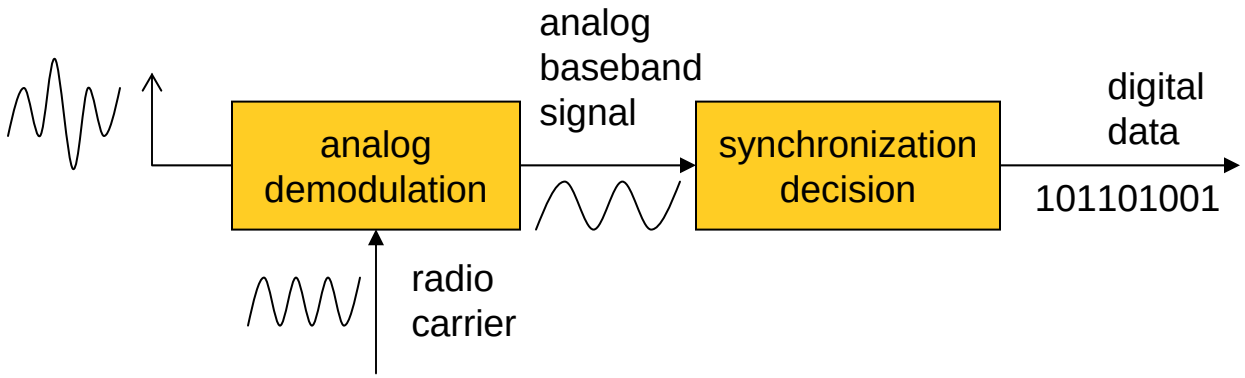
Modulation and Demodulation



Radio Transmitter



Radio Receiver

Source: Lili Qiu

Modulation Methods

- **Starting point:** we have a low frequency signal and want to send it at a high frequency

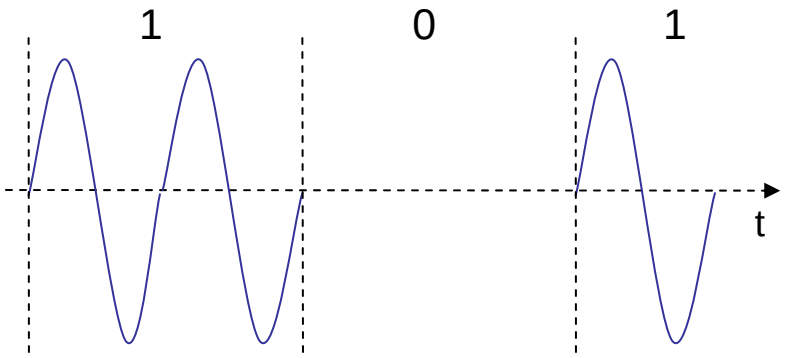
- **Modulation:** The process of superimposing a low frequency signal onto a high frequency signal

- 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

Digital Modulation

- Modulation of digital signals is known as Shift Keying

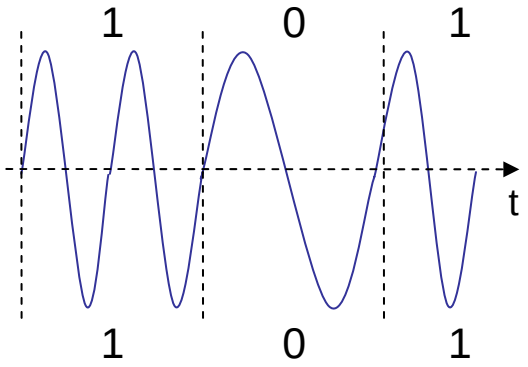
- **Amplitude Shift Keying (ASK/OOK):**
  - Pros: simple, duty cycling (FCC), lower transmit current
  - Cons: susceptible to noise, wide spectrum
  - Example: Many legacy wireless systems, e.g. AMR

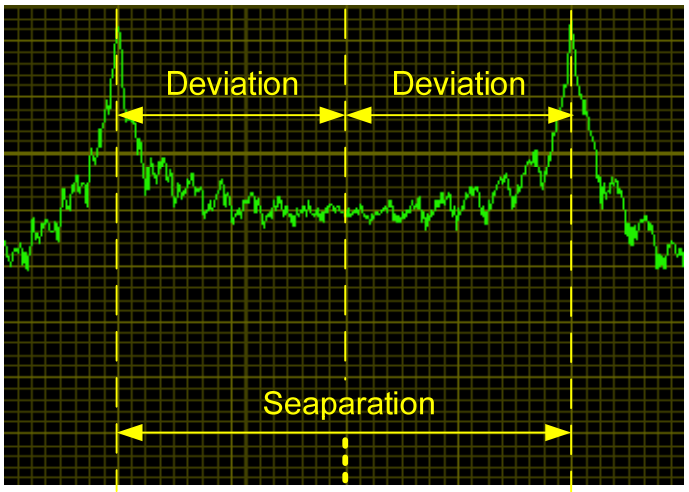


Source: Lili Qiu

Digital Modulation

- **Frequency Shift Keying (FSK):**
  - Pros: less susceptible to noise
  - Cons: theoretically requires larger bandwidth/bit than ASK
  - Popular in modern systems
  - Gaussian FSK (GFSK) has better spectral density than 2-FSK modulation, i.e. more bandwidth efficient

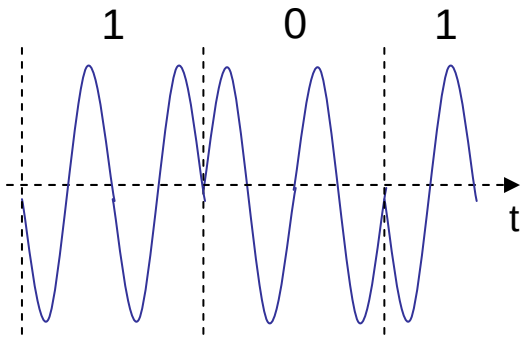




Source: Lili Qiu

Digital Modulation

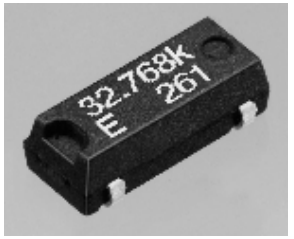
- **Phase Shift Keying (PSK):**
  - Pros:
    - Less susceptible to noise
    - Bandwidth efficient
  - Cons:
    - Require synchronization in frequency and phase ➔ complicates receivers and transmitter
  - Example: IEEE 802.15.4 / ZigBee

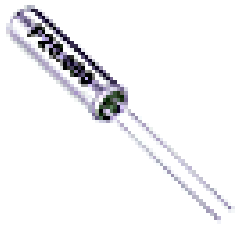


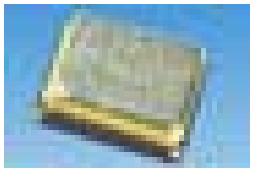
Source: Lili Qiu

Crystals

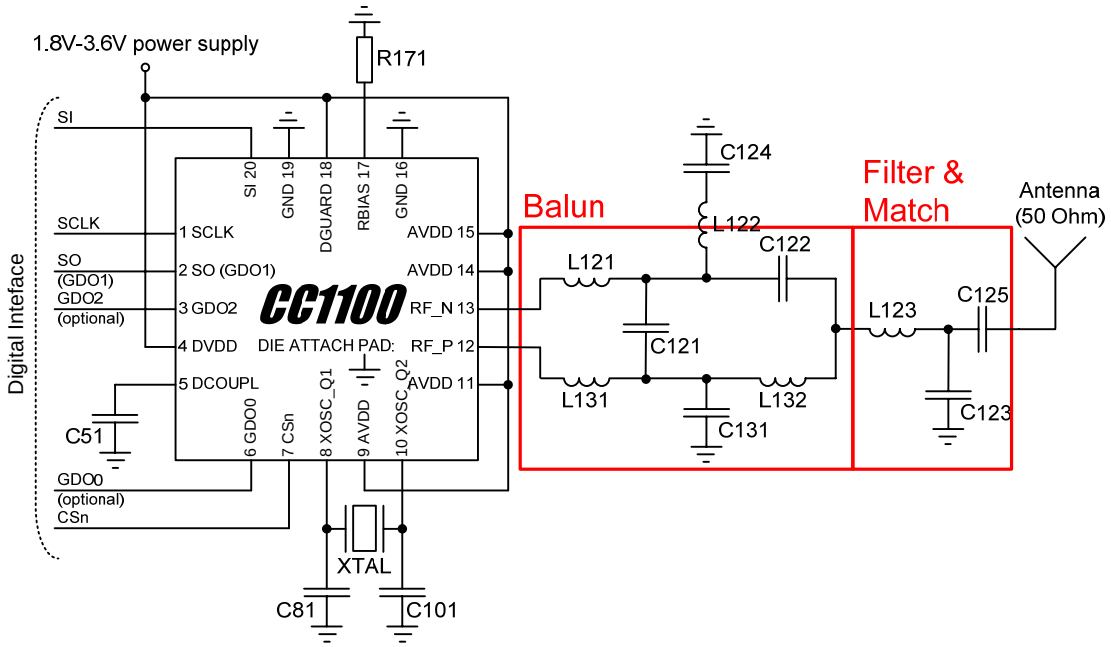
- Provides reference frequency for Local Oscillator (LO) and the carrier frequency
- Important characteristics:
  - Price, often a price vs. performance trade-off
  - Size
  - Tolerance[ppm], both initial spread, ageing and over temperature







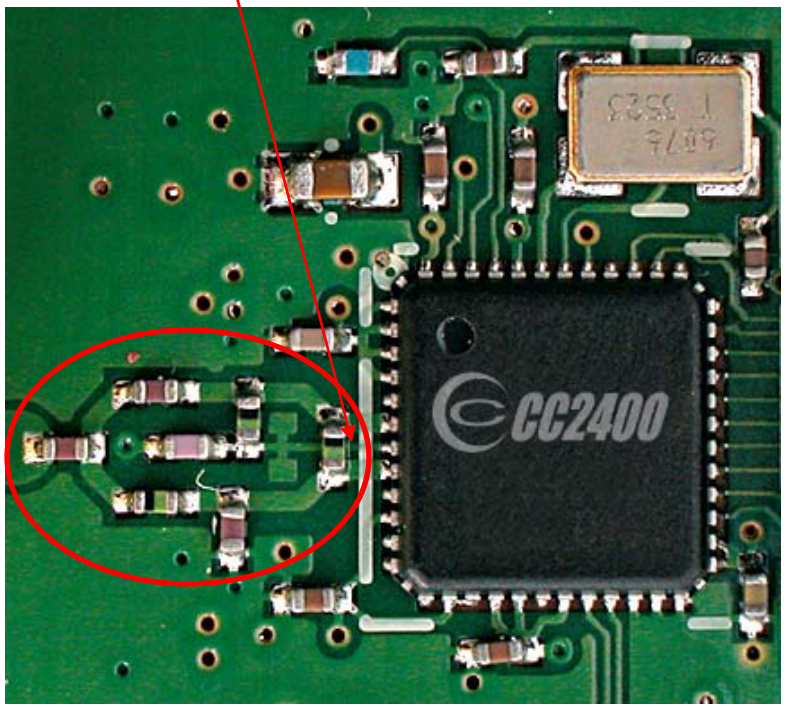
Balun & Matching



Differential signal out of the chip

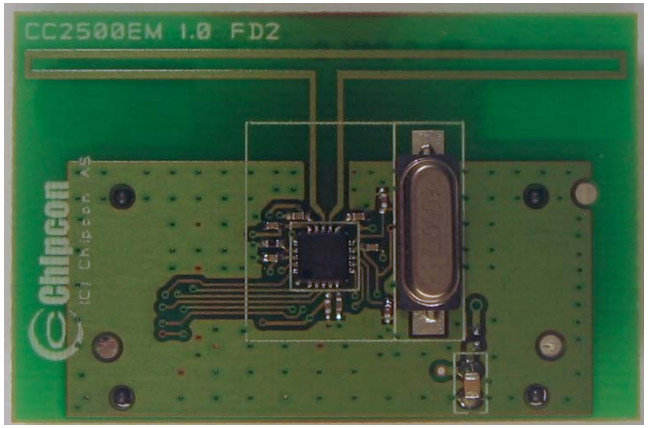
Single ended signal

Balun and matching towards antenna



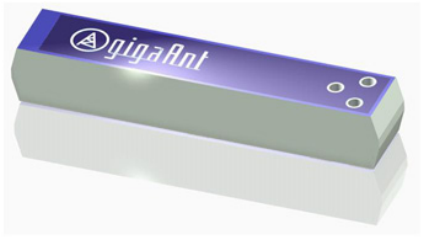
Antennas, commonly used

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



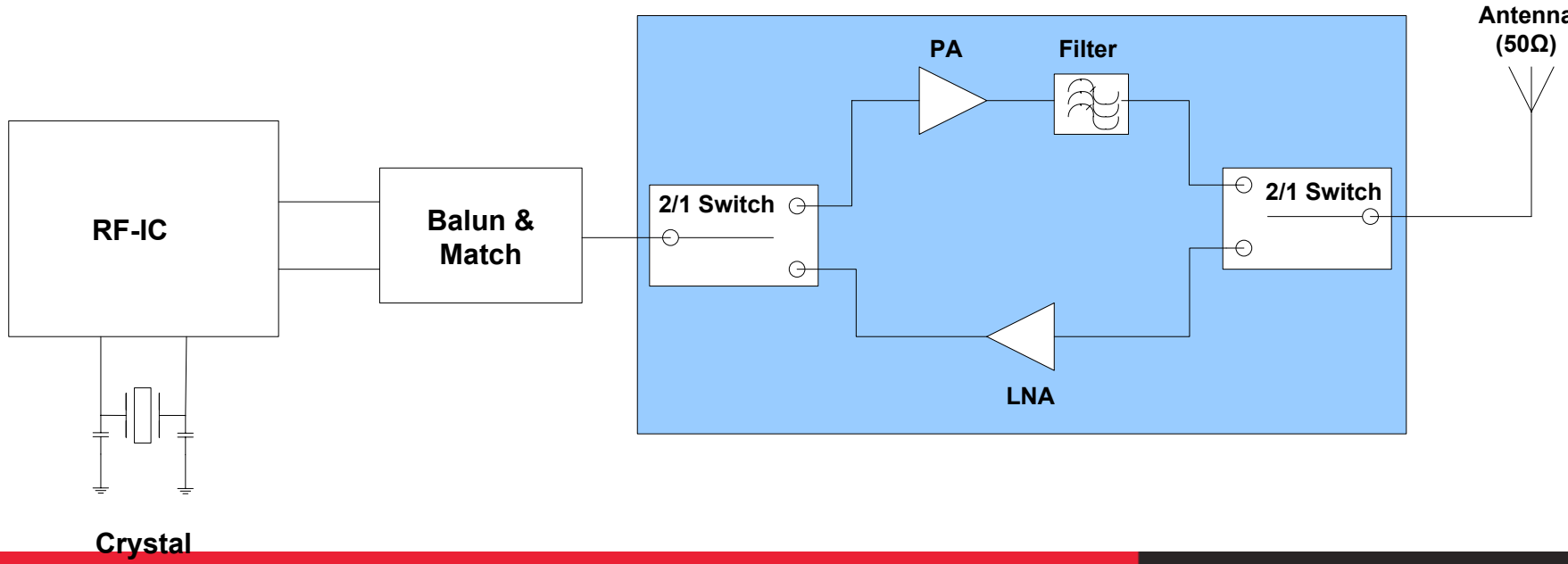
- **Whip antennas**
  - Expensive (unless piece of wire)
  - Good performance
  - Hard to fit in may applications

- **Chip antennas**
  - Expensive
  - OK performance
  - Small size



Extending the Range of an RF System

1. Increase the Output power
   - Add an external Power Amplifier (PA)
2. Increase the sensitivity
   - Add an external Low Noise Amplifier (LNA)
3. Increase both output power and sensitivity
   - Add PA and LNA
4. Use high gain antennas
   - Regulatory requirements need to be followed



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Radio Range – Important Factors

- Antenna
- Sensitivity
- Output power
- Radio pollution (selectivity, blocking, IP3)
- Environment (Line of sight, obstructions, reflections, multipath fading)

RF Measurement Equipment

- Vector Network Analyzers
- Spectrum Analyzers
- Signal Generators
- Power Meters
- Oscilloscopes
- Function and Arbitrary Waveform Generators

Questions?

Worldwide License-Free Frequency Allocations

Low Power Wireless

Texas Instruments

Agenda

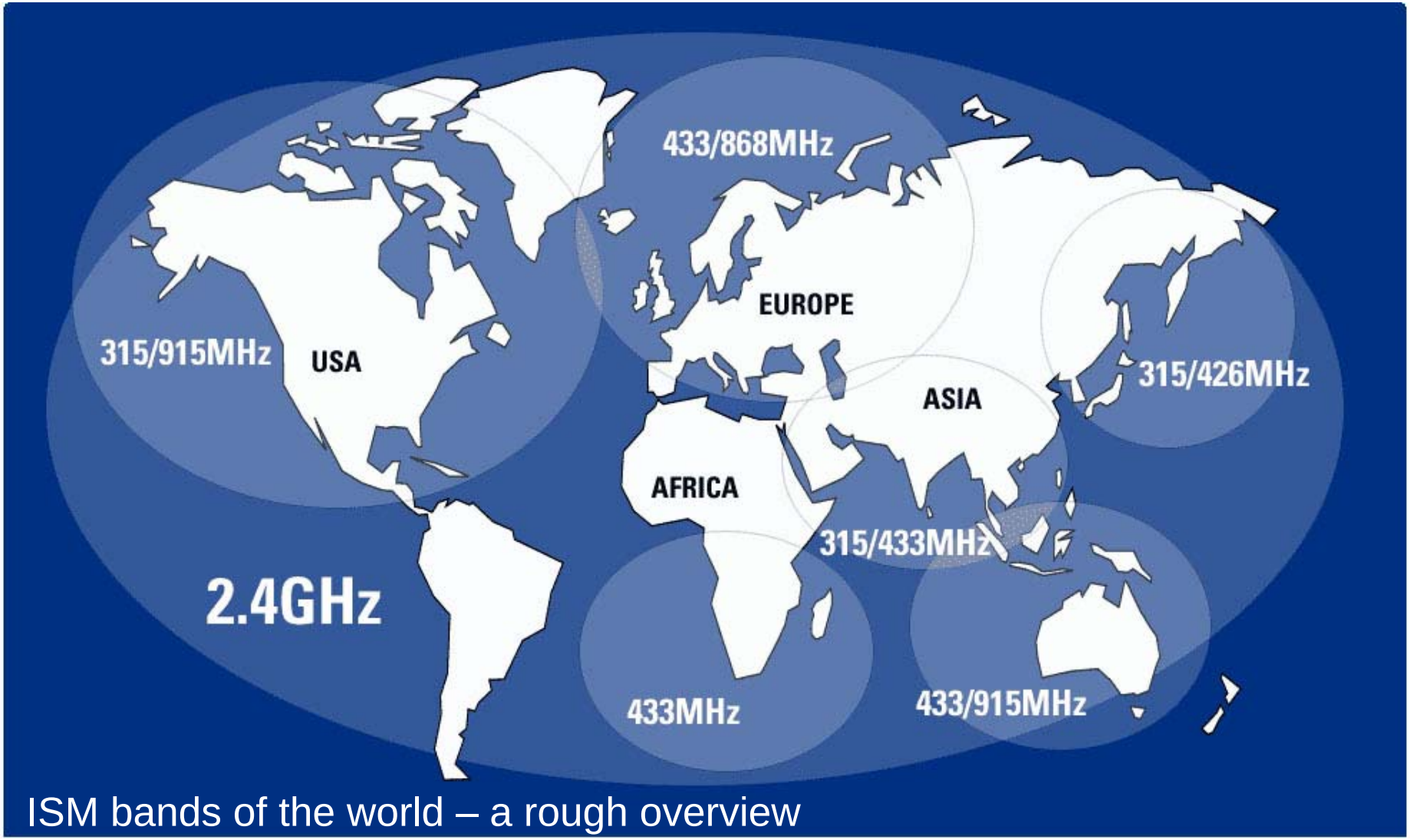
- **The ISM/SRD License-Free Frequency Bands**
  - Global 2.4 GHz band and regional Sub-1GHz bands
- **The global 2.4 GHz ISM band**
  - USA
  - Europe
  - Japan/Korea
- **Sub-1GHz ISM bands**
  - USA
  - Europe
  - Japan/Korea

The License-Free Frequency Bands

- Two frequency bands
  - 2.4 GHz
  - Sub 1 GHz
- Two frequently used abbreviations
  - ISM Industrial, Scientific and Medical
  - SRD Short Range Device

- National restrictions can be limiting
  - Confirm with national authorities

The ISM/SRD License-Free Frequency Bands



ISM bands of the world – a rough overview

Agenda

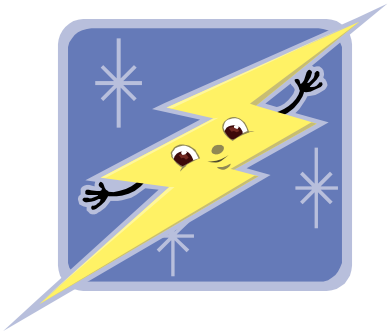
- **The ISM/SRD License-Free Frequency Bands**
  - Global 2.4 GHz band and regional Sub-1 GHz bands
- **The global 2.4 GHz ISM band**
  - USA
  - Europe
  - Japan/Korea
- **Sub 1GHz ISM bands**
  - USA
  - Europe
  - Japan/Korea

The global 2.4 GHz ISM band

- The 2400–2483.5 MHz band
  - Pros
    - Same solution world wide
    - Large bandwidth
    - 100% duty cycle allowed
  - Cons
    - Shorter range
    - Crowded

The global 2.4 GHz ISM band

- **2.4 GHz in USA (Canada)**



  - FCC CFR 47, Part 15.
    - **FCC certification required**
  - Sharing of the bandwidth: ”if you do not occupy one channel all the time, we will allow you to transmit with higher output power”
    - FCC CFR 47 part 15.247 cover wideband modulation
      - up to 1W/30 dBm output power with FHSS or DSSS
    - FCC CFR 47 part 15.249 cover single channel systems
      - ~0.75mW/-1.25 dBm output power

The global 2.4 GHz ISM band

- **2.4 GHz in Europe**
  - CEPT ERC/REC 70-03, ETSI EN 300 328 and EN 300 440
    - **”Self certification” is possible**
  - Equipment classes
    - EN 300 328 cover wideband modulation systems
      - **Output power of 100mW with FHSS and DSSS**
      - **Spectral Power Density limitations**
    - EN 300 440 cover non-specific SRDs
      - **Output power of 10mW**
  - Similar as FCC: ”By spreading the transmitted power you are allowed a higher output power”

The global 2.4 GHz ISM band

- **2.4 GHz in Japan (Korea)**
  - ARIB STD T-66 Japan
    - **Certification required**
    - Modulation is DSSS, FHSS or other digital modulation
    - Output power of 10mW in a 1MHz bandwidth

Agenda

- **The ISM/SRD License-Free Frequency Bands**
  - Global 2.4 GHz band and regional Sub-1 GHz bands
- **The global 2.4 GHz ISM band**
  - Regional Differences
- **Sub 1-GHz ISM bands**
  - USA
  - Europe
  - Japan/Korea

Sub 1-GHz ISM bands

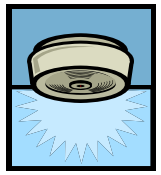
- Regional limitations
  - **Pros**
    - Better range
    - Less crowded
  - **Cons**
    - Custom solutions
    - Limitations in “performance”
    - Duty cycle restrictions

Sub-1GHz ISM bands

- **Sub-1GHz ISM bands in USA (Canada)**
  - Covered by FCC CFR 47, part 15
  - 902 - 928 MHz
    - FCC CFR 47 part 15.247 cover wideband modulation
      - Up to 1W/30 dBm output power with FHSS or DSSS
      - CC1100 250kbps/FSK/10 dBm is OK, DN006
    - FCC CFR 47 part 15.249 cover single channel systems
      - ~0.75mW/-1.25 dBm output power
  - FCC part 15.231 Periodic operation above 70 MHz
    - Restricted to control signals: alarm, door openers, remote switches
    - Operation not allowed in restricted bands, 15.205.

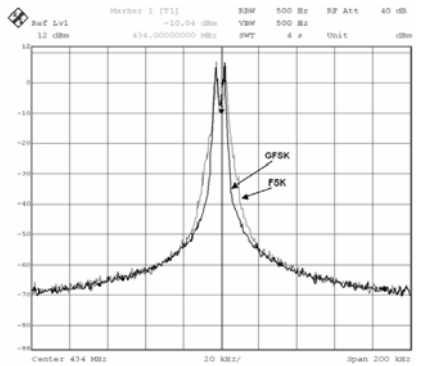
Sub-1GHz ISM bands

- **Sub-1GHz ISM bands in Europe**
  - 433.05-434.79 MHz and 863-870 MHz covered by CEPT ERC/REC 70-03, ETSI EN 300 220



    - Old version of EN 300 220 is valid until 31.12.2007

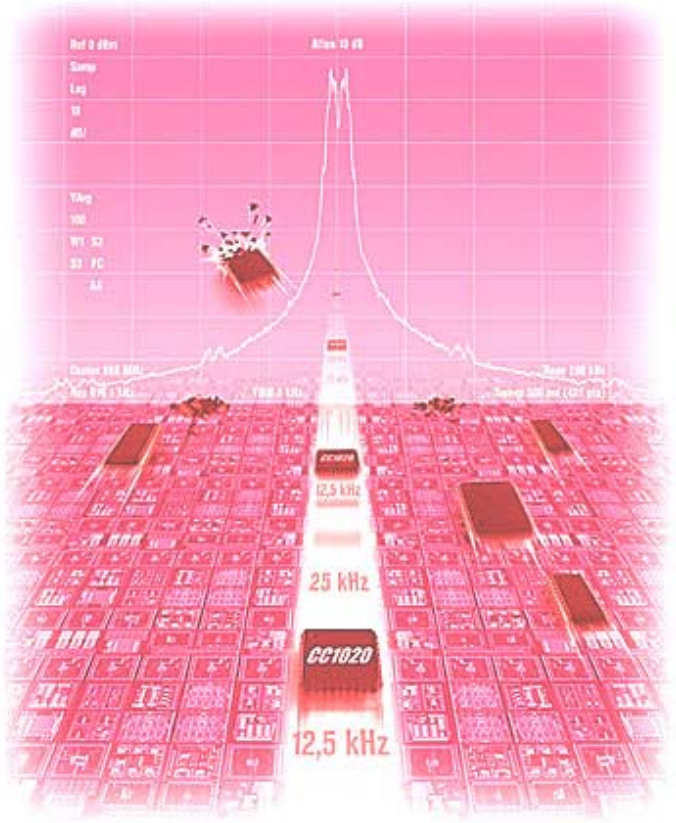
    - Narrow channels (25kHz channel spacing)



    - LBT (Listen Before Talk) regulations

Sub-1GHz ISM bands

- **Sub 1GHz ISM bands in Japan** (Korea)
  - Limited availability
  - ARIB STD-T67 covers 426-430 MHz band
  - 12.5 and 25kHz channel spacing requirements



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