RF BASICS

Low Power Wireless
Texas Instruments
Agenda

• Definitions

• RF Systems

• Modulation Formats

• System Range
• **dBm** – power referred to 1 mW,

\[ P_{dBm} = 10 \log(P/1\text{mW}) \]

• **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
Agenda

• Definitions

• RF Systems

• Modulation Formats

• System Range
• **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
Agenda

- Definitions
- RF Systems
  - Modulation Formats
- System Range
Modulation and Demodulation

Radio Transmitter

Source: Lili Qiu
• **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
• 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
• 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 many 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
Agenda

• Definitions

• RF Systems

• Modulation Formats

• System Range
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
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• 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
• 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

- **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 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
• 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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