RF Basics, RF for Non-RF Engineers

Dag Grini
Program Manager, Low Power Wireless
Texas Instruments
Agenda

• Basics
• Basic Building Blocks of an RF System
• RF Parameters and RF Measurement Equipment
• Support / getting started
Definitions

- dBm – relative to 1 mW
- dBc – relative to carrier
- 10mW = 10dBm, 0dBm = 1mW
- -110dBm = 1E-11mW = 0.00001nW
- For a 50 ohm load:
  - -110dBm is 0.7uV, i.e. not much!

- Rule of thumb:
  - Double the power = 3 dB increase
  - Half the power = 3 dB decrease
dBm to Watt

• About dBm and W

- Voltage Ratio\[ a_V = 20 \log \left( \frac{P_2}{P_1} \right) \] \[ [a_V] = \text{dB} \]
- Power Ratio\[ a_P = 10 \log \left( \frac{P_2}{P_1} \right) \] \[ [a_P] = \text{dB} \]
- Voltage Level\[ V' = 20 \log \left( \frac{V}{1 \mu V} \right) \] \[ [V'] = \text{dB} \mu \text{V} \]
- Power Level\[ P' = 10 \log \left( \frac{P}{1 \text{mW}} \right) \] \[ [P'] = \text{dB} \text{m} \]

e.g. 25mW max. allowed radiated power in the EU SRD band
>> \[ P' = 10 \log \left( \frac{25 \text{mW}}{1 \text{mW}} \right) = 10 \times 1.39794 \text{ dBm} >> 14 \text{ dBm} \]
Electromagnetic Spectrum

VHF = VERY HIGH FREQUENCY
UHF = ULTRA HIGH FREQUENCY
SHF = SUPER HIGH FREQUENCY
EHF = EXTREMELY HIGH FREQUENCY

ISM bands 315-915 MHz
ISM bands 2.4 GHz
ISM band 56-100 GHz

4G CELLULAR 56-100 GHz

30 km 0.3 km 3 m 3 cm

VLF LF MF HF VHF UHF SHF EHF

3.1-10.6 GHz

AM Broadcast FM Broadcast Radar Bands

Sonics Ultra-sonics Microwaves

10 kHz 1 MHz 100 MHz 10 GHz

ISM = Industrial, Scientific and Medical
UWB = Ultra Wide Band

Source: JSC.MIL
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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
ISM/SRD License-Free Frequency Bands

- 2.4GHz
- 315/915MHz USA
- 433/868MHz
- 315/426MHz
- 315/433MHz
- 433MHz
- 433/915MHz

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RF Communication Systems

• Simplex RF System
  - A radio technology that allows only one-way communication from a transmitter to a receiver
  - Examples: FM radio, Pagers, TV, One-way AMR systems
RF Communication Systems

• Half-duplex RF Systems
  ▪ Operation mode of a radio communication system in which each end can transmit and receive, but not simultaneously.
  ▪ **Note:** The communication is bidirectional over the same frequency, but unidirectional for the duration of a message. The devices need to be transceivers. Applies to most TDD and TDMA systems.
  ▪ Examples: Walkie-talkie, wireless keyboard mouse
RF Communication Systems

• Full-duplex RF Systems
  ▪ Radio systems in which each end can transmit and receive simultaneously
  ▪ Typically two frequencies are used to set up the communication channel. Each frequency is used solely for either transmitting or receiving. Applies to Frequency Division Duplex (FDD) systems.
  ▪ Example: Cellular phones, satellite communication
Agenda

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Wireless Communication Systems

Transmitter

- Low Frequency Information Signal (Intelligence)
- High Frequency Carrier

Modulator → Amplifier

Communication Channel

Receiver

Amplifier → Demodulator (detector) → Amplifier → Output transducer

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Modulation and Demodulation

Radio Transmitter

digital data
101101001

digital modulation

analog baseband signal

radio carrier

analog modulation

Radio Receiver

analog baseband signal

radio carrier

synchronization decision

digital data
101101001

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):
  - Pros: simple
  - Cons: susceptible to noise
  - 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), e.g. used in Bluetooth, 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
Basic Building Blocks of an RF System

• RF-IC
  - Transmitter
  - Receiver
  - 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
Transmitter

• Modern transmitters typically use fractional-N synthesizers

• For angle modulation like FSK, MSK, O-QPSK, the synthesizer frequency is adjusted

• For amplitude modulation like OOK and ASK, the amplifier level is adjusted

FSK modulation

- Frequency deviation
  - Frequency separation = 2 x df

\[ Fc - df \quad \text{DIO}=\text{low} \quad fc \quad Fc + df \quad \text{DIO}=\text{high} \]
Receiver Architecture

- **Super heterodyne receiver** – e.g. CC1000
  - Converts the incoming signal to an Intermediate Frequency (IF) signal and performs:
    1. **Carrier frequency tuning** – selects desired signal
    2. **Filtering** – separates signal from other modulated signals picked up
    3. **Amplification** – compensates for transmission losses in the signal path
Receiver Architecture

- **Image rejection receiver** – e.g. CC1020
  - The image frequency is an undesired input frequency that is capable of producing the same intermediate frequency (IF) as the desired input frequency produces.
Crystals

- Provides reference frequency for Local Oscillator (LO) and the carrier frequency

- Various types:
  - Low Power crystals (32.768 kHz)
    - Used with sleep modes on e.g. System-on-Chips
  - Crystals
    - Thru hole
    - Tuning fork
    - SMD
  - Temperature Controlled Crystal Oscillators (TCXO)
    - Temperature stability – some narrowband applications
  - Voltage Controlled Crystal Oscillators (VCXO)
  - Oven Controlled Crystal Oscillators (OCXO)
    - Extremely stable
Balun & Matching

Differential signal out of the chip

Balun

Filter & Match

Antenna (50 Ohm)

Single ended signal

Balun and matching towards antenna

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Antennas

Commonly used antennas:

• **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
Antennas

- The antenna is VERY important if long range is important

- A quarter wave antenna is an easy and good solution, but it is not small (433 MHz: 16.4 cm, 868 MHz: 8.2 cm)
  - You can “curl up” such an antenna and make a helical antenna. This is often a good solution since it utilizes unused volume for a product.

- If you need long range and have limited space, then talk to an antenna expert!
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
Adding an External PA

CC2420EM PA DESIGN

• Signal from TXRX_Switch pin level shifted and buffered
  ▪ Level in TX: 1.8 V, level for RX and all other modes: 0V
• CMOS and GaAs FET switches assures low RX current consumption
• Simpler control without external LNA
  ▪ No extra signal is needed from MCU to turn off LNA in low power modes

<table>
<thead>
<tr>
<th></th>
<th>CC2420EM</th>
<th>CC2420EM w/PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TX current</td>
<td>17.4 mA</td>
<td>30.8 mA</td>
</tr>
<tr>
<td>RX current</td>
<td>19.7 mA</td>
<td>19.7 mA</td>
</tr>
<tr>
<td>Output power</td>
<td>0 dBm</td>
<td>9.5 dBm</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>-94 dBm</td>
<td>-93.1 dBm</td>
</tr>
<tr>
<td>Line of Sight Range</td>
<td>230 meter</td>
<td>580 meter</td>
</tr>
</tbody>
</table>
Radio Range – Free Space Propagation

• How much loss can we have between TX and RX?

• 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, \( G_r \) is the receiver antenna gain
- Lambda is the wavelength
- \( D \) is the distance between transmitter and receiver, or the range
Radio Range – ”real life”

• How much loss can we really have TX to RX?

• 120 dB link budget at 433 MHz gives approximately 2000 meters (Chipcon rule of thumb)

• Based on the empirical results above and Friis’ equation estimates on real range can be made:

• Rule of Thumb:
  ▪ 6 dB improvement ~ twice the distance
  ▪ Double the frequency ~ half the range
    – 433 MHz longer range than 868 MHz
Radio Range – Important Factors

• Factors
  ▪ Antenna (gain, sensitivity to body effects etc.)
  ▪ Sensitivity
  ▪ Output power
  ▪ Radio pollution (selectivity, blocking, IP3)
  ▪ Environment (Line of sight, obstructions, reflections, multipath fading)
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Phase Noise

Down Conversion (receivers):

- Ideal oscillator
- Actual oscillator with phase noise

Down-converted bands consist of two overlapping spectra, with the wanted signal suffering from significant noise due to the tail of the interferer.

Interferer end up within the IF bandwidth and cannot be filtered out.
Phase Noise

Transmitters:

Nearby transmitter

Ideal oscillator

Difficult to detect weak signal at $\omega_2$.
The wanted signal is corrupted by the phase noise tail of the transmitter

• Phase noise is a key parameter for transceivers
• CC1020: -90 dBc/Hz @ 12.5 kHz (narrowband)
Narrowband Transmitter

- How good is the transmitter at making efficient use of the RF spectrum?

- **OBW = Occupied Band Width**
  - Defined as BW with 99.5% of the total average power (ARIB)
  - For 12.5 kHz channel spacing OBW < 8.5 kHz (ARIB)
  - Measured using built-in function of spectrum analyzer
Narrowband Transmitter

• **ACP = Adjacent Channel Power**
  - 25 kHz channel spacing, 17 kHz BW
  - 12.5 kHz channel spacing, 8.5 kHz BW
  - Measured using built-in function of spectrum analyzer

Narrowband characteristics:
• Bandwidth efficient modulation (e.g. GFSK)
• Low data rate
• Low deviation

CC1020: ACP = -51 dBc

• Low phase noise ➡️ key parameter for low ACP

• ETSI: Absolute ACP requirement (dBm), ARIB: Relative (dBc)
Receiver, Co-channel Rejection

• How good is the receiver at handling interferers at same frequency?
• Co-channel rejection, CC1020/CC1021: -11dB
• Test method: Modulated interferer
  ▪ Wanted signal 3 dB above sensitivity limit
Receiver Selectivity

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

- CC1020: 32dB @ 12.5 kHz
- Test method
  - Wanted 3dB above sensitivity level
  - Interferer injected in the adjacent channel
Receiver Selectivity

- Selectivity, measured for channels “further out” (alternate channel selectivity)
- Same test method as ACR/ACS
- Low phase noise and narrow IF bandwidth → good ACR/ACS
## Receiver Selectivity

<table>
<thead>
<tr>
<th>Standard, Ch. Spacing</th>
<th>Adjacent Channel Rejection</th>
<th>Selectivity, other channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARIB, 12.5 kHz</td>
<td>30 dB (± 12.5kHz)</td>
<td>40 dB for all other channel</td>
</tr>
<tr>
<td>ARIB, 25 kHz</td>
<td>40 dB (± 25kHz)</td>
<td>40 dB for all other channel</td>
</tr>
<tr>
<td>ETSI class 1, 25 kHz</td>
<td>60 dB (± 25 kHz)</td>
<td>84 dB (± 1 MHz)</td>
</tr>
<tr>
<td>Bluetooth, 1 MHz</td>
<td>0 dB (± 1 MHz)</td>
<td>30 dB (± 2 MHz)</td>
</tr>
<tr>
<td>CC2400, 1 MHz (250kbit/s)</td>
<td>12 dB (± 1 MHz)</td>
<td>48 dB (± 2 MHz)</td>
</tr>
<tr>
<td>CC2400, 1 MHz (1Mbit/s)</td>
<td>0 dB (± 1 MHz)</td>
<td>20 dB (± 2 MHz)</td>
</tr>
<tr>
<td>Zigbee (802.15.4), 5 MHz</td>
<td>0 dB (± 5 MHz)</td>
<td>30 dB for all other channels</td>
</tr>
<tr>
<td>CC2420, 5MHz</td>
<td>39/46 (+ - 5 MHz)</td>
<td>53/57 (+ - 10 MHz)</td>
</tr>
</tbody>
</table>

• **CC1020 is ARIB compliant (12.5 and 25 kHz channels)**
Receiver, Blocking/desensitization

- **Blocking/desensitization** is a measure of how good a receiver is to reject an interferer “far away” (out of band) from the wanted signal.
- Measured the same way as selectivity, but the interfering signal is usually not modulated.
- **CC1020 performance:**
  - 1 MHz 60 dB
  - 2 MHz 70 dB
  - 10 MHz 78 dB
- Blocking can be further improved with a SAW filter.
Image Rejection

- Image Rejection

- **CC1000**
  - No image rejection

- **CC1020**
  - Image rejection
Receiver Sensitivity

• How to achieve good RF sensitivity?
  
• Introduce high gain in front of the receiver
  • External LNA needed
  • Poor linearity (IP3)
  • Poor blocking/selectivity
  • “Removes” the losses in the SAW filter

• Lower noise bandwidth (narrowband)
  • Blocking/linearity not changed
  • Good selectivity
  • Good frequency control needed
RF Measurement Equipment

- Vector Network Analyzers
  - Component Characterisation – insertion loss
  - S-parameters - matching
- Spectrum Analyzers
  - Output Power, harmonics, spurious emission
  - Phase Noise
  - ACP
  - OBW
  - Modulation - deviation
- Signal Generators
  - Sensitivity (BER option needed)
  - Selectivity/blocking
  - Two-tone measurements – IP3
- Power Meters
  - Output Power – calibration
- Oscilloscopes
  - Digital signal analysis
- Function and Arbitrary Waveform Generators
2.4 GHz ISM-band devices

- Due to the world-wide availability of the 2.4GHz ISM band it is getting more crowded day by day.
- Devices such as Wi-Fi, Bluetooth, ZigBee, cordless phones, microwave ovens, wireless game pads, toys, PC peripherals, wireless audio devices and many more occupy the 2.4 GHz frequency band.

Source: Eliezer & Michael, TI
Spread Spectrum Systems

• Data sent using spread spectrum is intentionally spread over a wide frequency range

• Appears as noise, so it is difficult to detect and jam

• Resistant to noise and interference thus increasing the probability that the signal will be received correctly

• Unlikely to interfere with other signals even if they are transmitted on the same frequency

• 2 types of Spread Spectrum common in ISM bands:
  ▪ Direct Sequence Spread Spectrum (DSSS)
  ▪ Frequency Hopping Spread Spectrum (FHSS)
General Model of a Spread Spectrum System

- Input Data
- Channel Encoder
- Modulator
- Communication Channel
- Demodulator
- Channel Decoder
- Output Data

- Spreading Code
- Pseudorandom Noise
Direct Sequence Spread Spectrum

- Each bit represented by multiple bits using spreading code
- Spreading code spreads signal across wider frequency band
- Good resistance against interferers
DSSS – BPSK Example

(a) \( d(t) \)  
Source: William Stalling

(b) \( s_d(t) \)

(c) \( c(t) \)  
spreading code

(d) \( s(t) \)

(a) Spectrum of data signal

(b) Spectrum of pseudonoise signal

(c) Spectrum of combined signal
**DSSS Spreading Mechanism**

IEEE 802.15.4 (CC2420): 2 Mchips/s → 250 kbps data rate

- 4 bits (nibble) are coded into 32 chips using a look-up table

  - RX correlation example:

<table>
<thead>
<tr>
<th>Nibble value</th>
<th>Comparison (XOR) with all possible chip sequences</th>
<th>Correlation value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 1 0 1 1 1 0</td>
<td>18</td>
</tr>
<tr>
<td>1</td>
<td>1 1 1 0 1 1 0 0 1 1 1 0 0 0 1 1 1 0 1 0 1 0 0 1 0 1 0 0 1 0 0 1 0</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 0 1 1 0 1 0 1 0 0 0 1 0</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>0 0 1 0 0 0 1 0 1 1 1 0 0 1 1 1 0 0 1 1 0 0 0 0 0 0 1 1 0 1 0 1 0 1</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>0 1 0 1 0 1 0 0 0 0 1 0 1 1 1 0 1 1 1 0 0 0 0 0 1 1 0 0 0 0 1 1 1 1</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>0 0 1 1 0 1 0 1 0 1 0 0 0 1 0 0 1 0 1 1 1 0 1 1 0 1 0 1 0 0 1 1 1 0</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>1 1 1 0 0 0 0 0 1 1 1 0 1 0 1 1 0 0 0 1 1 0 0 1 0 1 1 1 0 0 1 1 0 0</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>1 0 0 1 1 0 0 1 0 0 0 0 1 1 1 0 1 1 0 1 0 0 1 0 0 0 0 1 1 0 1 1 1 0 1</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>1 0 0 1 1 0 0 0 1 1 1 0 1 0 1 1 0 0 0 1 1 0 1 1 1 0 0 1 1 1 0 1 1 1 1</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>1 0 1 1 1 0 0 0 1 1 1 0 0 1 0 0 0 0 1 1 1 0 1 1 1 1 1 0 1 1 1 0 0 1 1</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>0 1 1 1 1 0 1 1 1 1 0 0 0 1 1 0 0 1 0 1 1 0 0 1 0 1 1 0 0 0 0 1 1 1 1 1</td>
<td>14</td>
</tr>
<tr>
<td>11</td>
<td>0 1 1 1 0 1 1 1 1 1 1 1 0 0 0 1 1 0 0 1 0 1 1 0 0 1 0 1 1 0 0 0 1 1 1 0 0</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>0 0 0 0 0 1 1 1 1 0 1 1 1 1 0 1 1 1 0 0 1 1 0 0 1 1 1 1 0 1 1 0 1 1 1 0</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 0 0 0 1 1 0 0 1 1 1 0 0 1 1</td>
<td>12</td>
</tr>
<tr>
<td>14</td>
<td>1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 0 1 1 1 1 0 1 1 0 1 0 0 1 1 1 1 0 0</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>1 1 0 0 0 1 0 1 1 1 0 0 0 0 0 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1</td>
<td>18</td>
</tr>
</tbody>
</table>
DSSS – Co-existence Performance

- CC2420 - In-band interference
- Power of interferer only 1 dB lower than CC2420 transmitter, NO packet errors
- Narrowband interferer shown as peak in the centre on top of the CC2420 spread spectrum
- A typical FSK receiver requires the desired signal to be 11 dB above interferer
Frequency Hopping Spread Spectrum (FHSS)

- Signal broadcast over a seemingly random series of frequencies
- Receiver hops between frequencies in sync with transmitter
- Jamming on one frequency affects only a few bits

Source: Eliezer & Michael, TI
2.4 GHz Devices – Static Frequency Hopping

- Utilise a predetermined set of frequencies with either a repeating hop pattern or a pseudorandom hop pattern, e.g. Bluetooth (versions 1.0 and 1.1)

Source: Eliezer & Michael, TI
2.4 GHz – Adaptive Frequency Hopping

- Scan the entire frequency band at start-up and restrict usage to frequencies with the lowest energy content. RadioDesk and Bluetooth 1.2 and 2.0 are using AFH.

- Substitute frequencies experiencing interference on the fly.

Source: Eliezer & Michael, TI

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Power

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b/g</td>
<td></td>
</tr>
<tr>
<td>Microwave oven</td>
<td></td>
</tr>
<tr>
<td>Cordless</td>
<td></td>
</tr>
</tbody>
</table>

Technology for Innovators™
Frequency Agility

- Frequency agility can be considered an extremely slow hopping frequency hopping system.
- In a frequency agile system the frequency is first changed when the link performance is degraded, i.e. when the Packet Error Rate (PER) exceeds a predetermined threshold.
Agenda

• Basics
• Basic Building Blocks of an RF System
• RF Parameters and RF Measurement Equipment
• Support / getting started
Getting Started

• Define and specify the product
  ▪ Following a standard or going proprietary?
  ▪ Power consumption
  ▪ Range and regulatory requirements – frequency of operation
  ▪ Data rate
  ▪ RF protocol
  ▪ SW content
  ▪ Analyse test tool and instrumentation needs
  ▪ Cost

• Compare different vendors – choose RF-IC & tools
  ▪ Purchase and evaluate EVMs and required tools
  ▪ What SW examples, application notes and documentation are available?

• Develop, co-operate or outsource?
  ▪ Sufficient resources available?
  ▪ Do you have the necessary competence in-house?
  ▪ Compliance testing?
Support

• Search for the relevant information
  ▪ Documentation – e.g. data sheets, user guides and application notes
  ▪ Knowledge bases
  ▪ SW examples

• Contact your local distributor or TI directly:
  ▪ Internet:
    ▪ TI Low Power Wireless home page:
      – http://www.ti.com/lpw
    ▪ TI MSP430 home page:
      – http://www.ti.com/msp430
    ▪ TI Semiconductor Product Information Center Home Page:
      – http://support.ti.com
    ▪ TI Semiconductor KnowledgeBase Home Page:
      – http://support.ti.com/sc/knowledgebase
Summary

• RF Basics
  ▪ Available frequency bands
  ▪ RF communication systems
  ▪ Modulation and demodulation
  ▪ Basic building blocks of an RF system – components
  ▪ Extending range
  ▪ Key RF parameters
  ▪ RF measurement equipment
  ▪ Spread spectrum systems – DSSS / FHSS / Frequency Agility
  ▪ Getting started
  ▪ Support
Thank you for your attention!

Questions?
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