

# MSP430 Advanced Technical Conference 2006



## RF Basics, RF for Non-RF Engineers

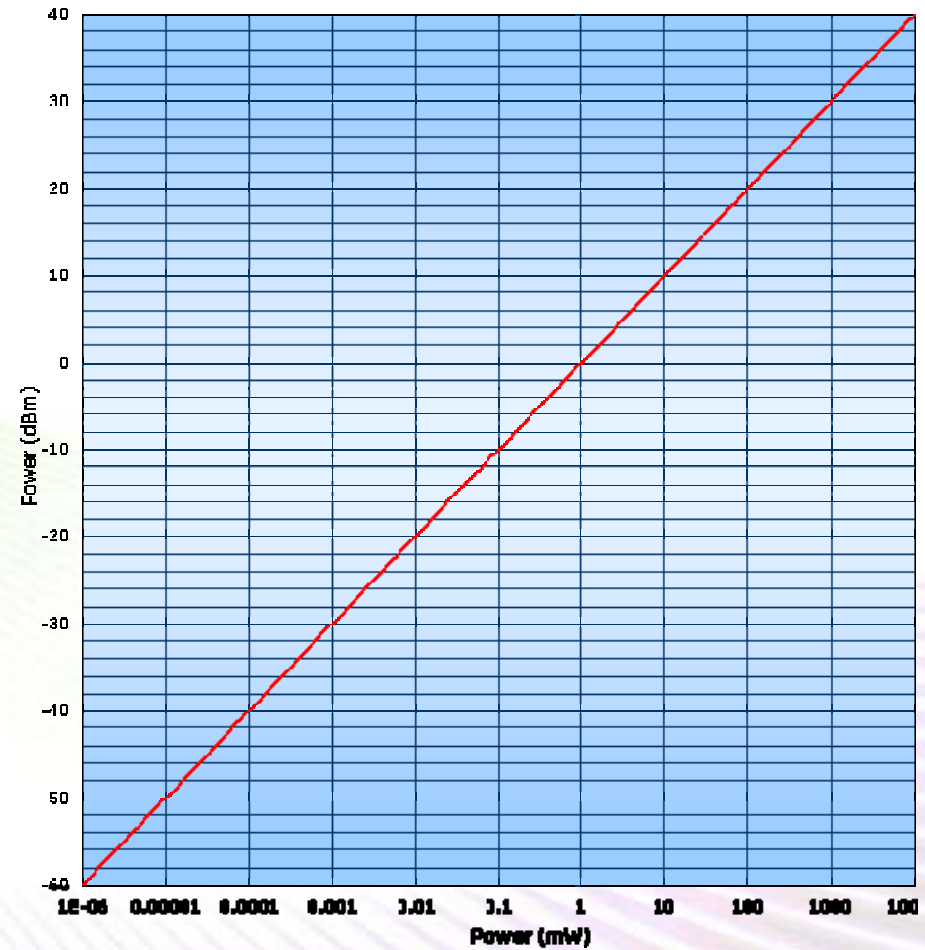
Dag Grini  
Program Manager, Low Power Wireless  
Texas Instruments

# 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



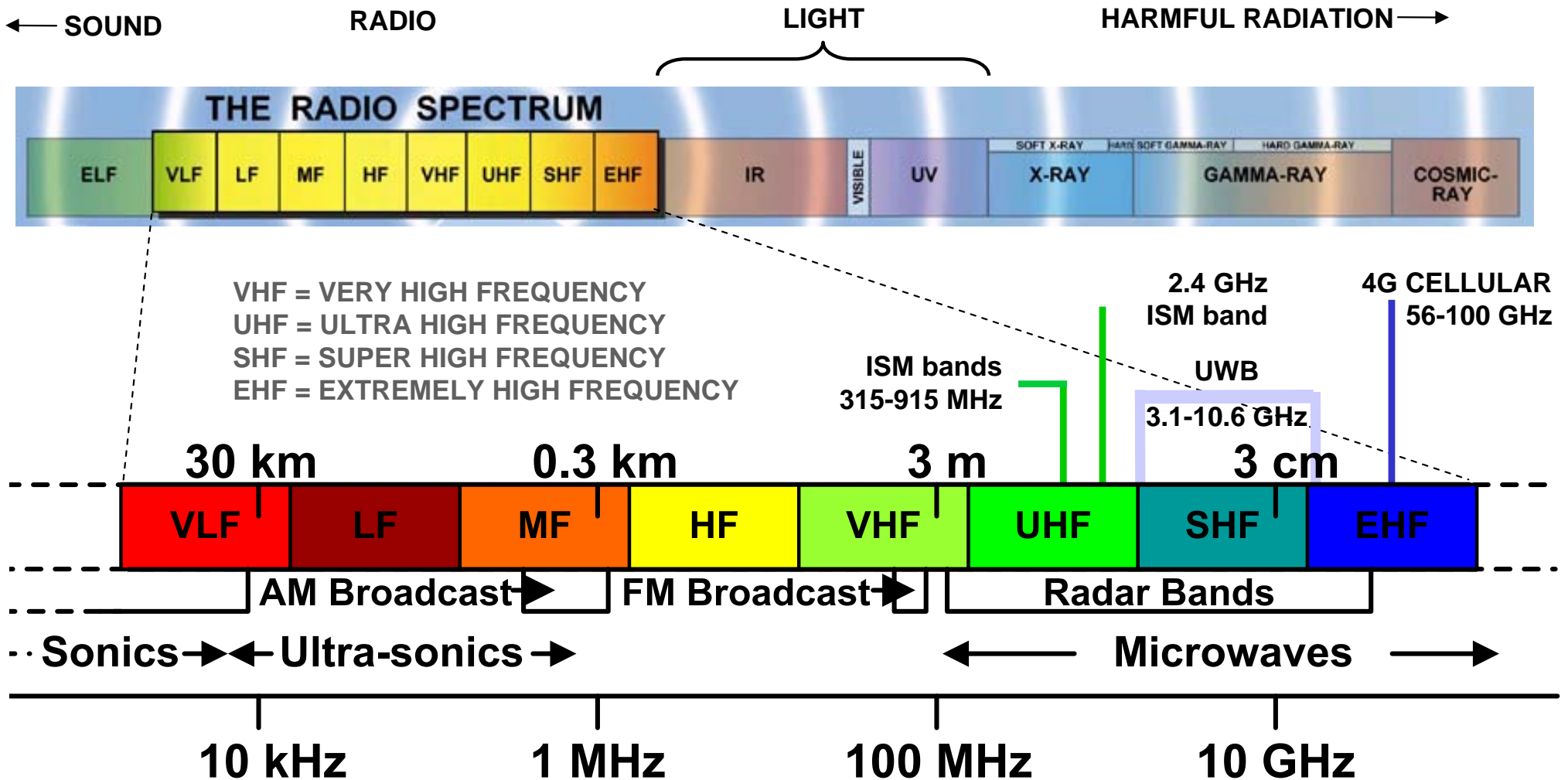
# dBm to Watt

- **About dBm and W**

- Voltage Ratio             $aV = 20 \log (P2/P1)$                              $[aV] = \text{dB}$
- Power Ratio              $aP = 10 \log (P2/P1)$                              $[aP] = \text{dB}$
- Voltage Level             $V' = 20 \log (V/1\mu V)$                              $[V'] = \text{dB}\mu V$
- Power Level              $P' = 10 \log (P/1\text{mW})$                              $[P'] = \text{dBm}$

e.g. 25mW max. allowed radiated power in the EU SRD band  
>>  $P' = 10 \log (25\text{mW}/1\text{mW}) = 10 * 1,39794 \text{ dBm} >> 14 \text{ dBm}$

# Electromagnetic Spectrum



**ISM** = Industrial, Scientific and Medical

**UWB** = Ultra Wide Band

Source: [JSC.MIL](http://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:**

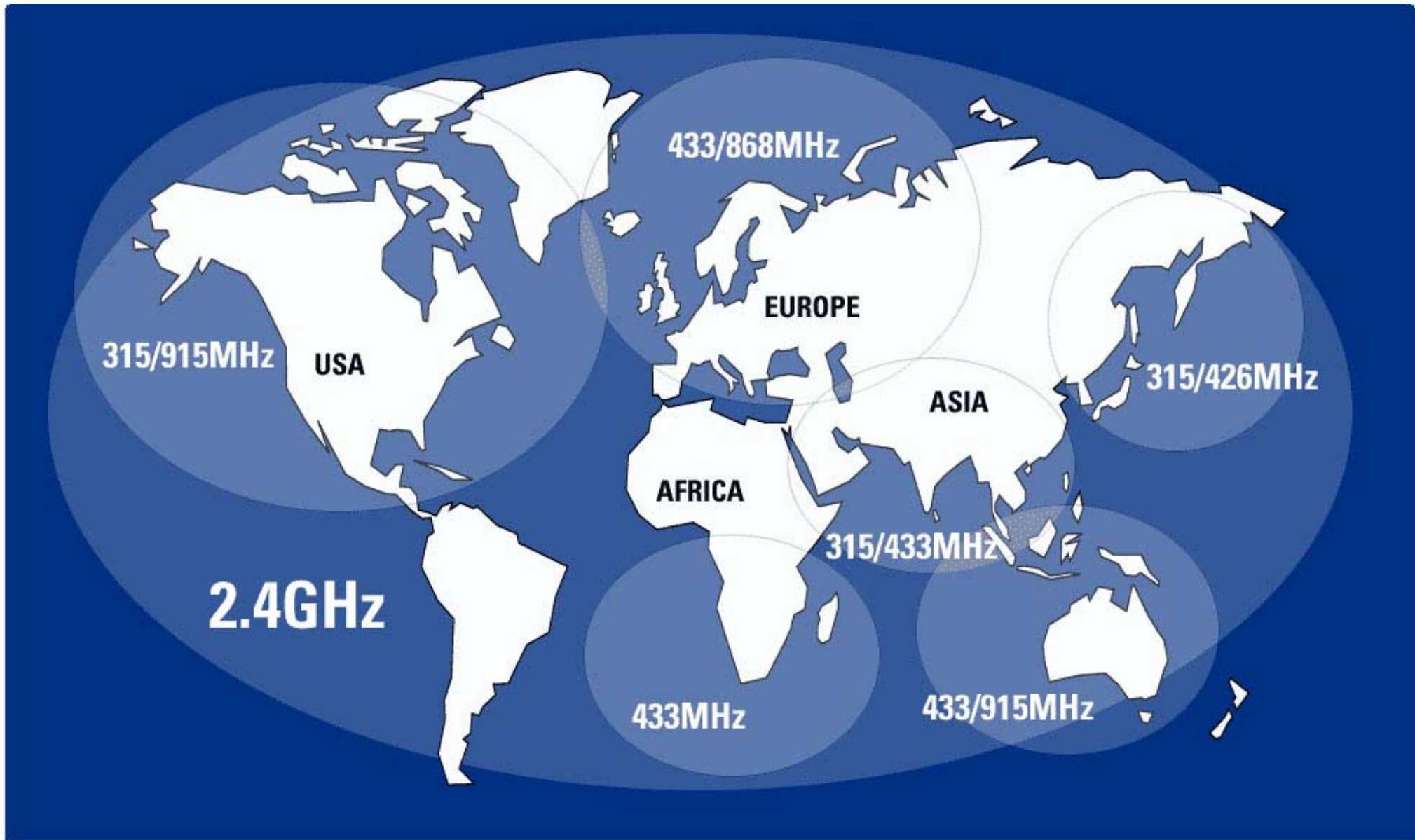
- 433.050 – 434.790 MHz (ETSI EN 300 220)
- 863.0 – 870.0 MHz (ETSI EN 300 220)
- 2400 – 2483.5 MHz (ETSI EN 300 440 or ETSI EN 300 328)

- **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

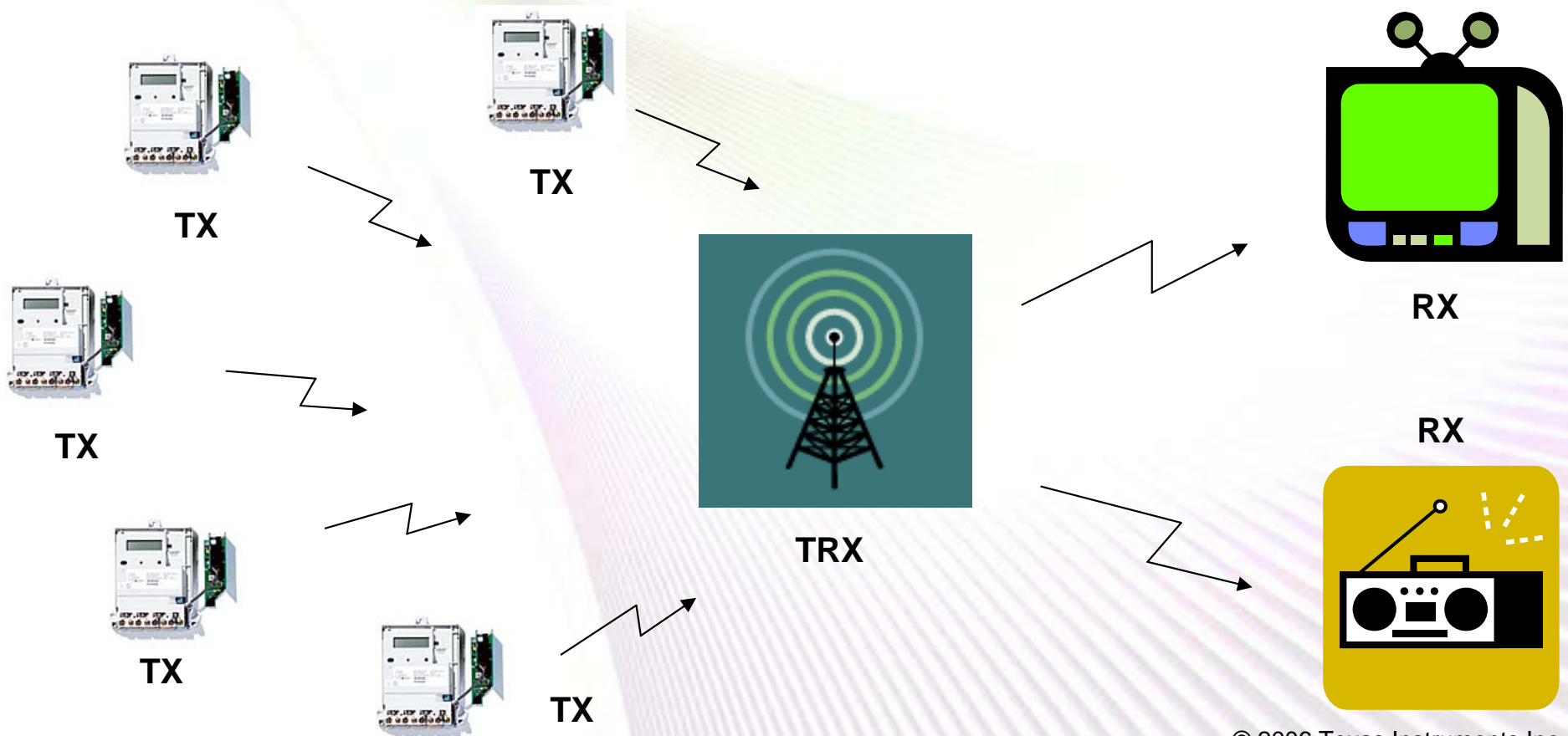


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# RF Communication Systems

- **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



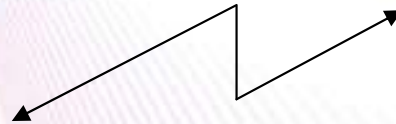
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# RF Communication Systems

- **Half-duplex RF Systems**

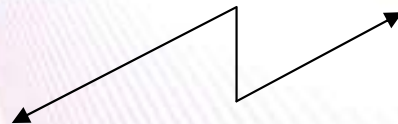
- Operation mode of a radio communication system in which each end can transmit and receive, but not simultaneously.
- **Note:** The communication is bidirectional over the same frequency, but unidirectional for the duration of a message. The devices need to be transceivers. Applies to most TDD and TDMA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



# RF Communication Systems

- **Full-duplex RF Systems**

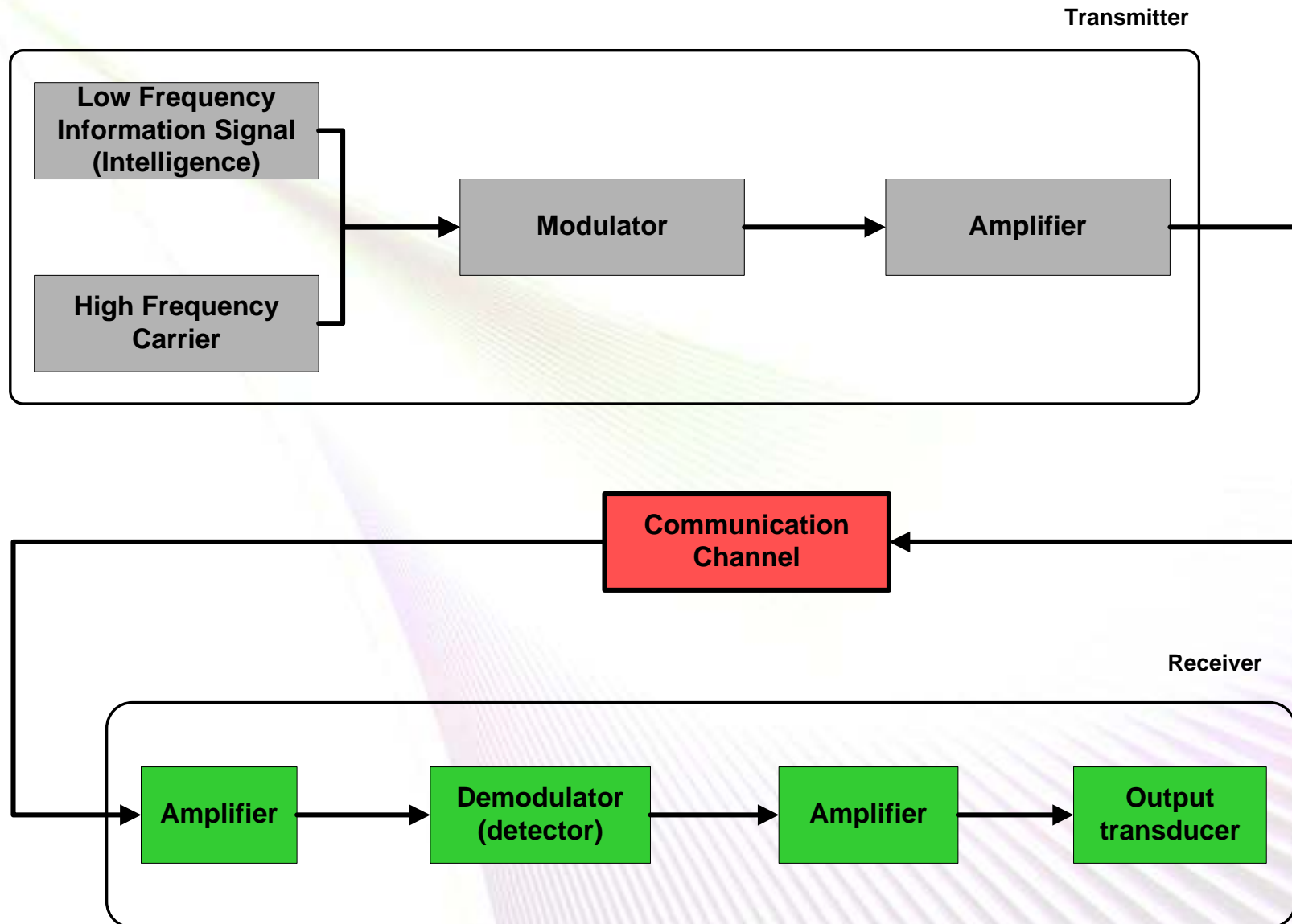
- Radio systems in which each end can transmit and receive simultaneously
- Typically two frequencies are used to set up the communication channel. Each frequency is used solely for either transmitting or receiving. Applies to Frequency Division Duplex (FDD) systems.
- Example: Cellular phones, satellite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



# Agenda

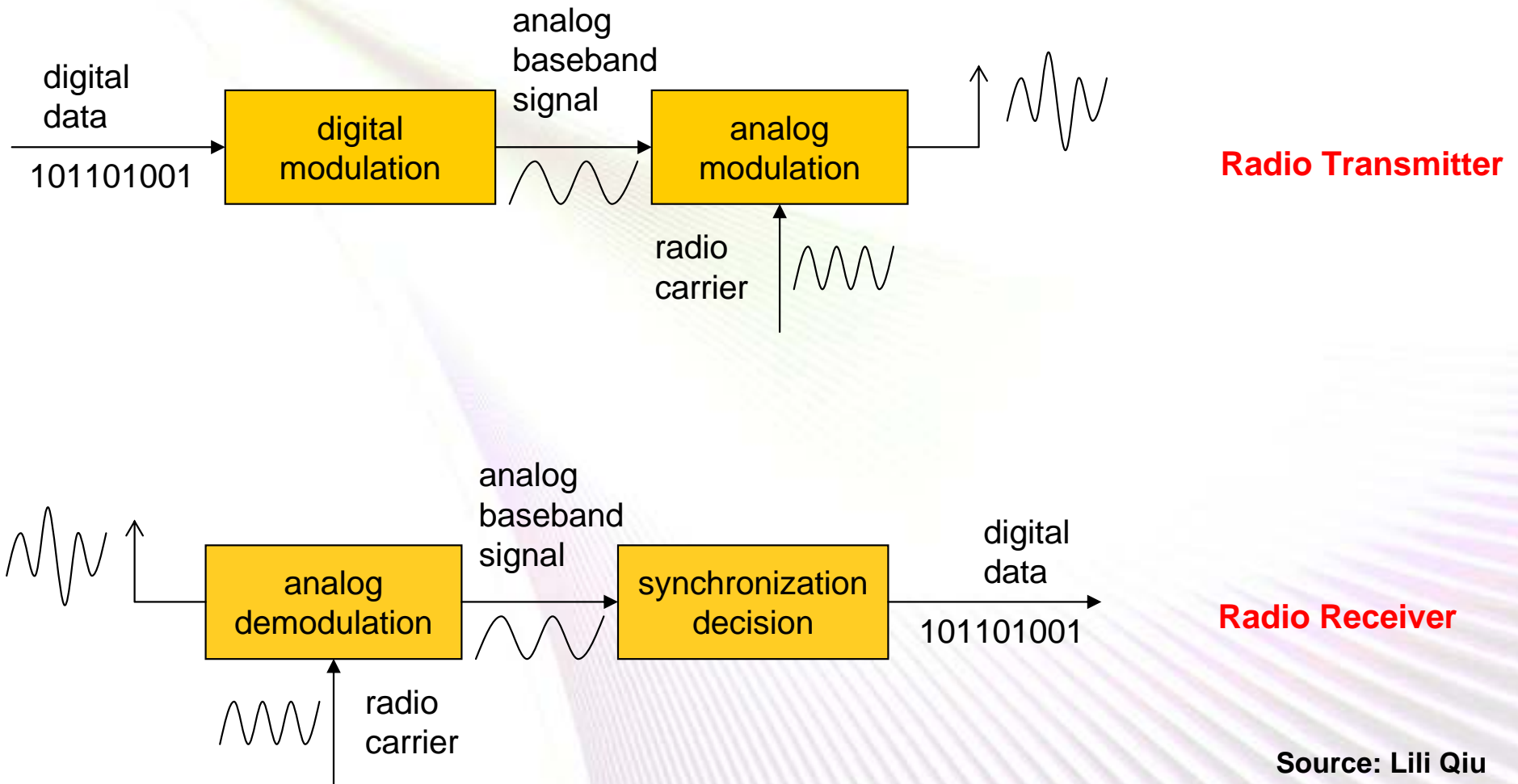
- Basics
- Basic Building Blocks of an RF System
- RF Parameters and RF Measurement Equipment
- Support / getting started

# Wireless Communication Systems



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# Modulation and Demodulation



Source: Lili Qiu

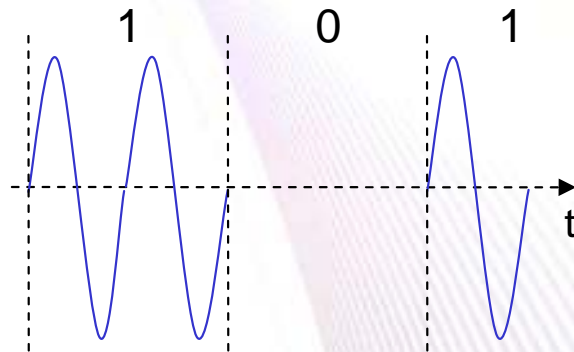
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# Modulation Methods

- **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



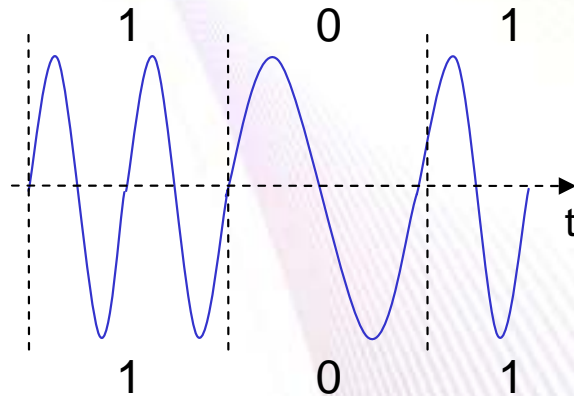
Source: Lili Qiu

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# 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

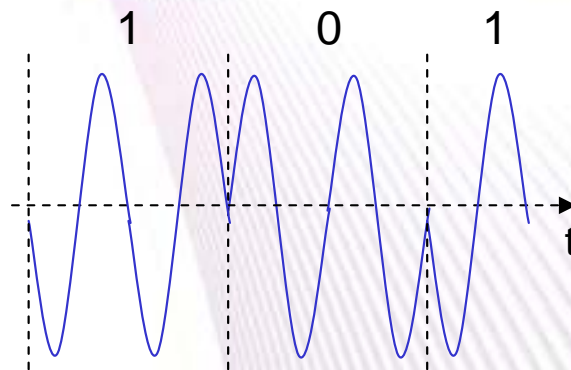
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# Digital Modulation

- **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

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# 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

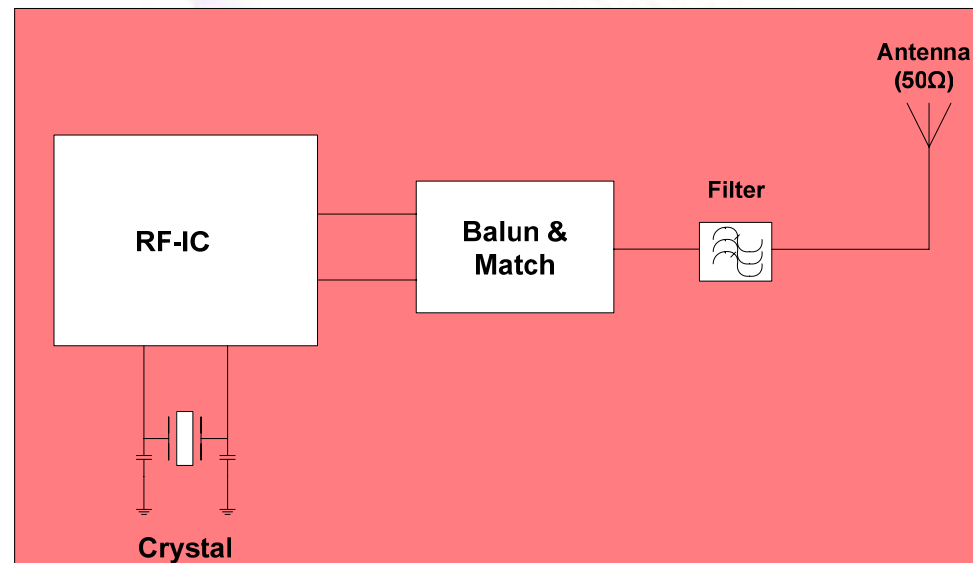
- **Balanced to unbalanced**
- Converts a differential signal to a single-ended signal or vice versa

- Matching

- Filter

- Used if needed to pass regulatory requirements / improve selectivity

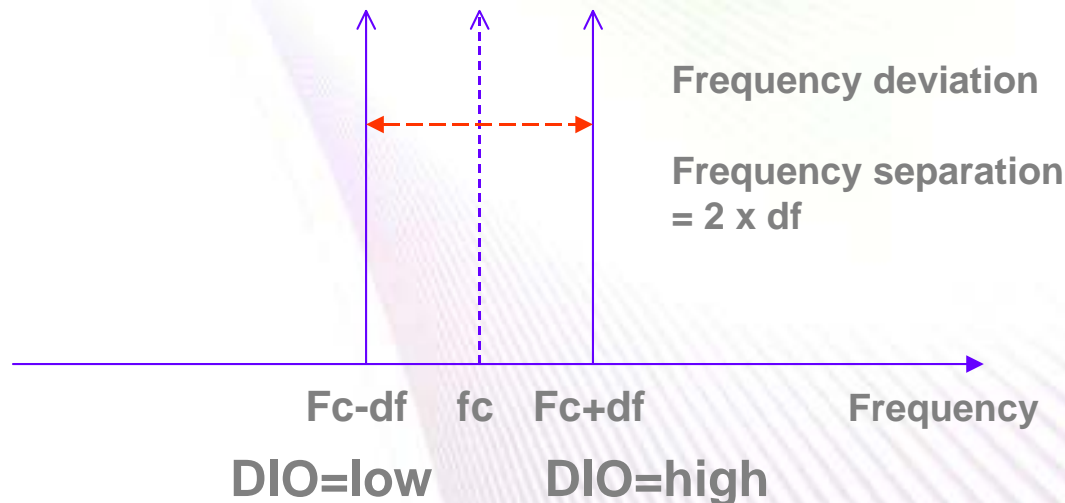
- Antenna



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# 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**

# Receiver Architecture

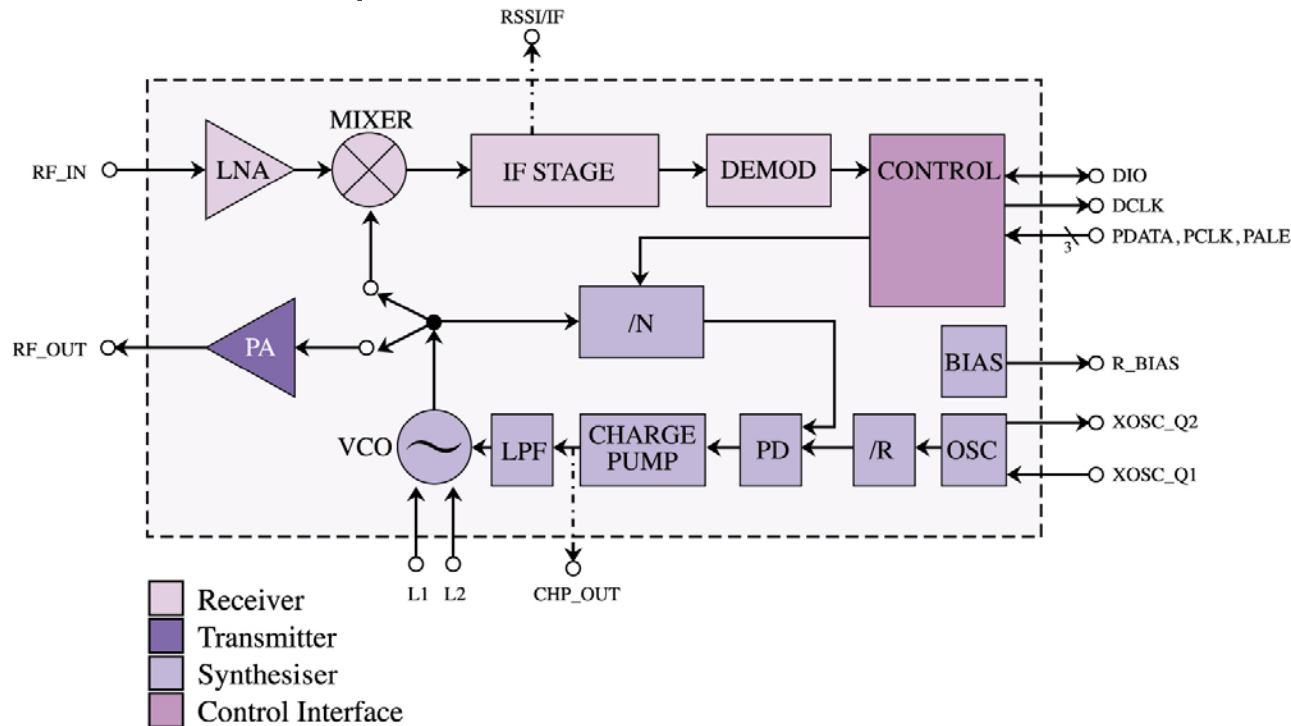
- **Super heterodyne receiver** – e.g. CC1000

- Converts the incoming signal to an **Intermediate Frequency (IF)** signal and performs:

1. **Carrier frequency tuning** – selects desired signal

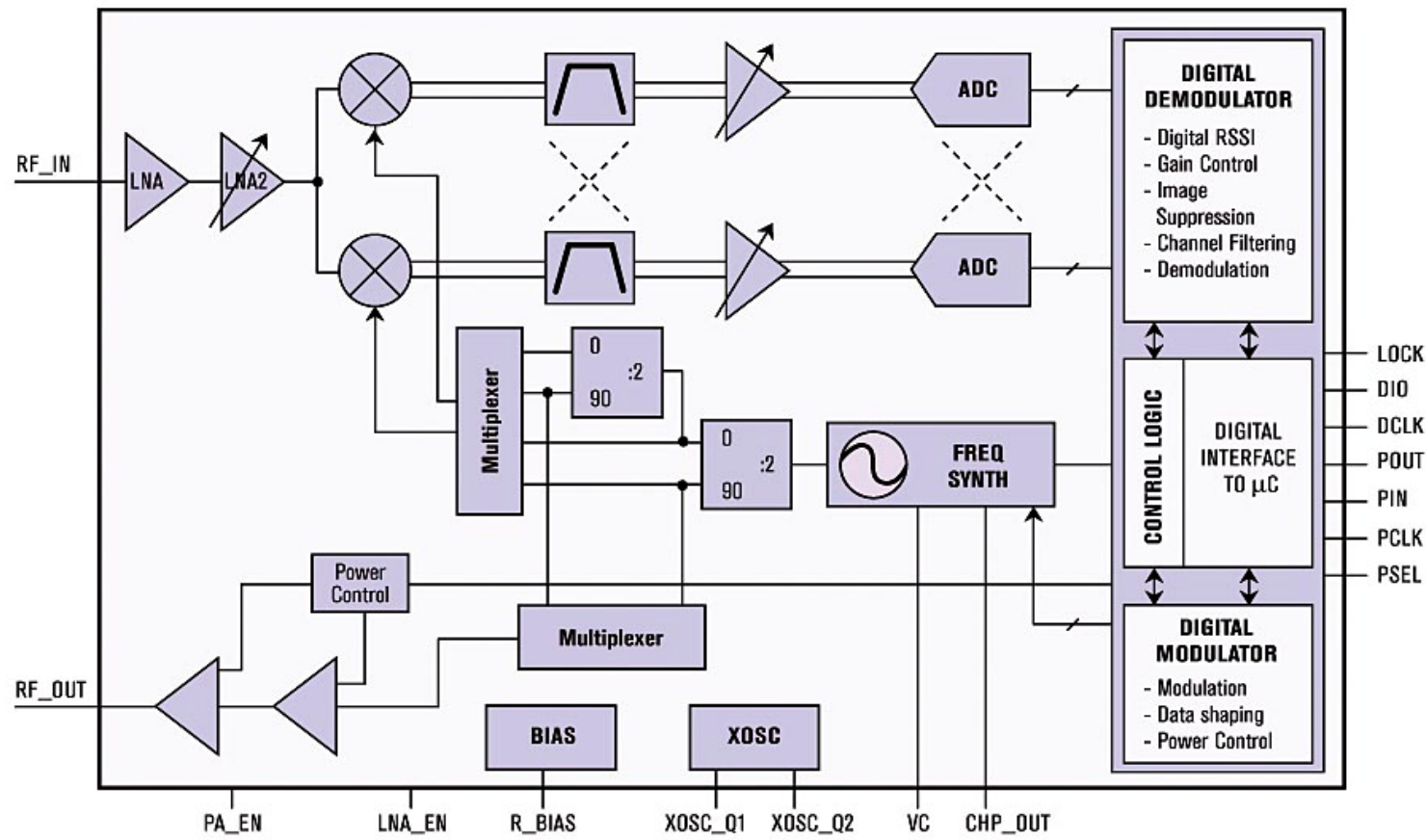
2. **Filtering** – separates signal from other modulated signals picked up

3. **Amplification** – compensates for transmission losses in the signal path



# Receiver Architecture

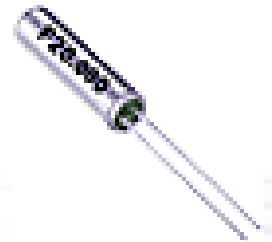
- **Image rejection receiver** – e.g. CC1020
  - The **image frequency** is an undesired input frequency that is capable of producing the same intermediate frequency (IF) as the desired input frequency produces



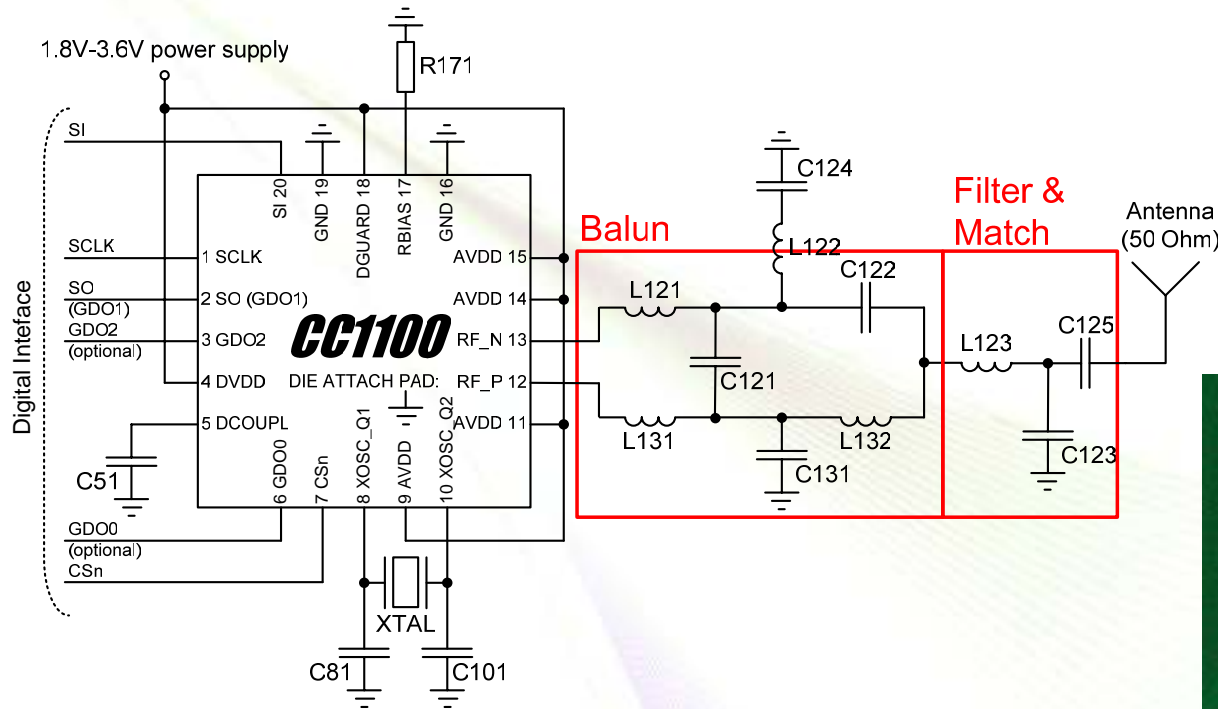
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# Crystals

- 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



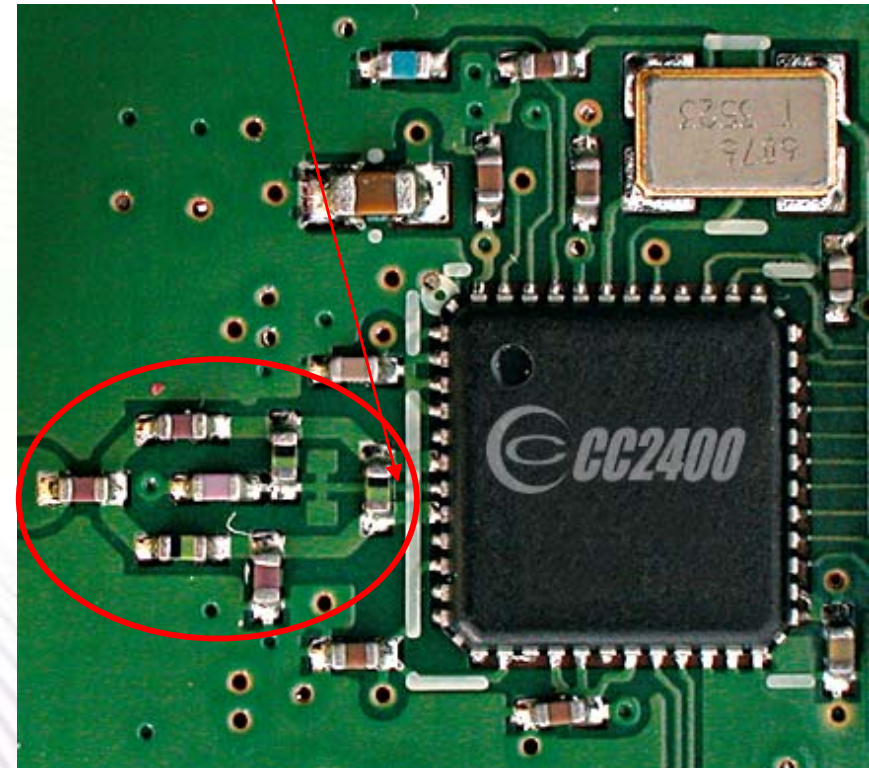
# Balun & Matching



Differential signal out of the chip

Single ended signal

Balun and matching towards antenna

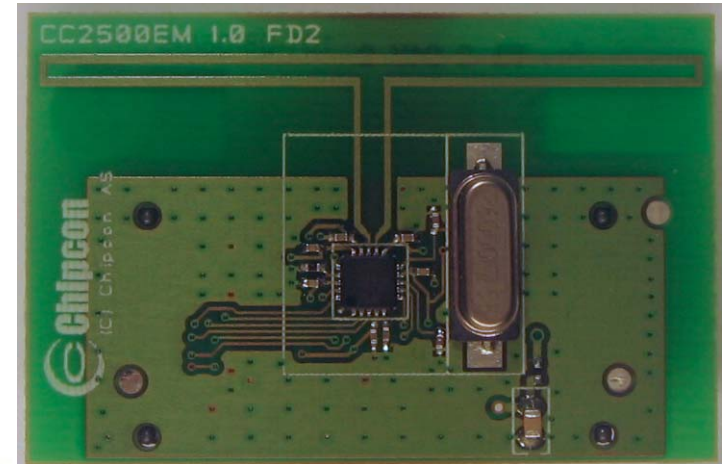


# Antennas

## 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



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# 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)

## 3. Increase both output power and sensitivity

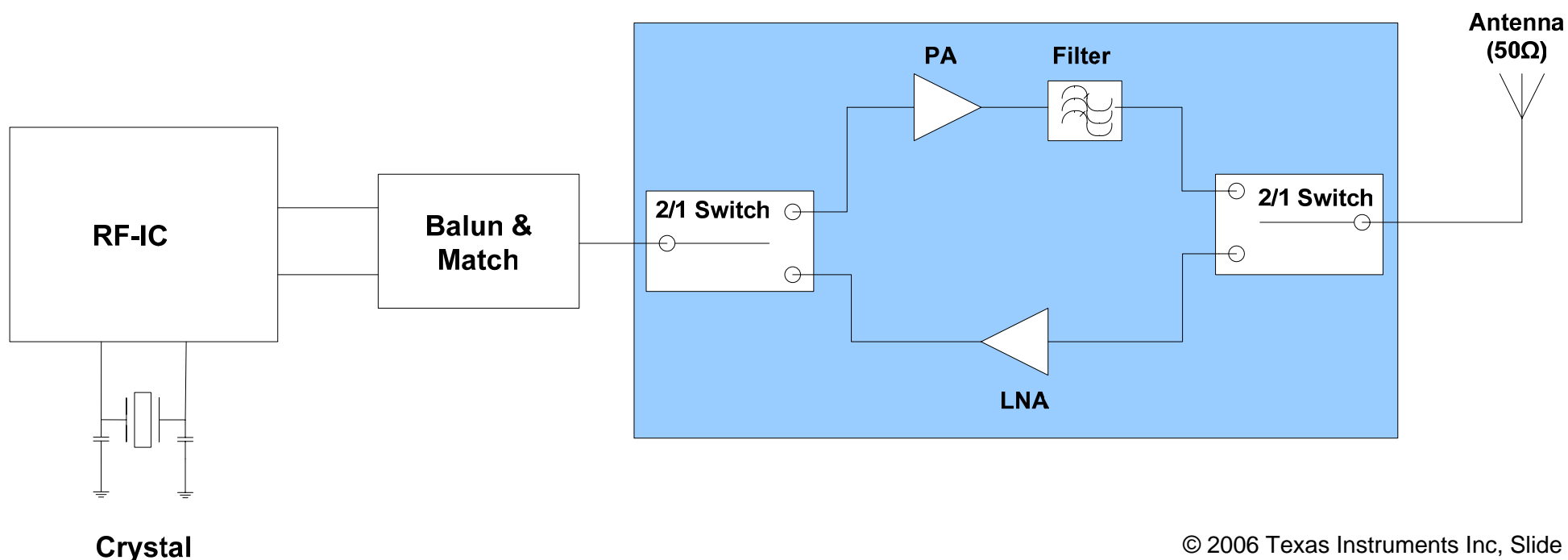
- Add PA and LNA

## 2. Increase the sensitivity

- Add an external Low Noise Amplifier (LNA)

## 4. Use high gain antennas

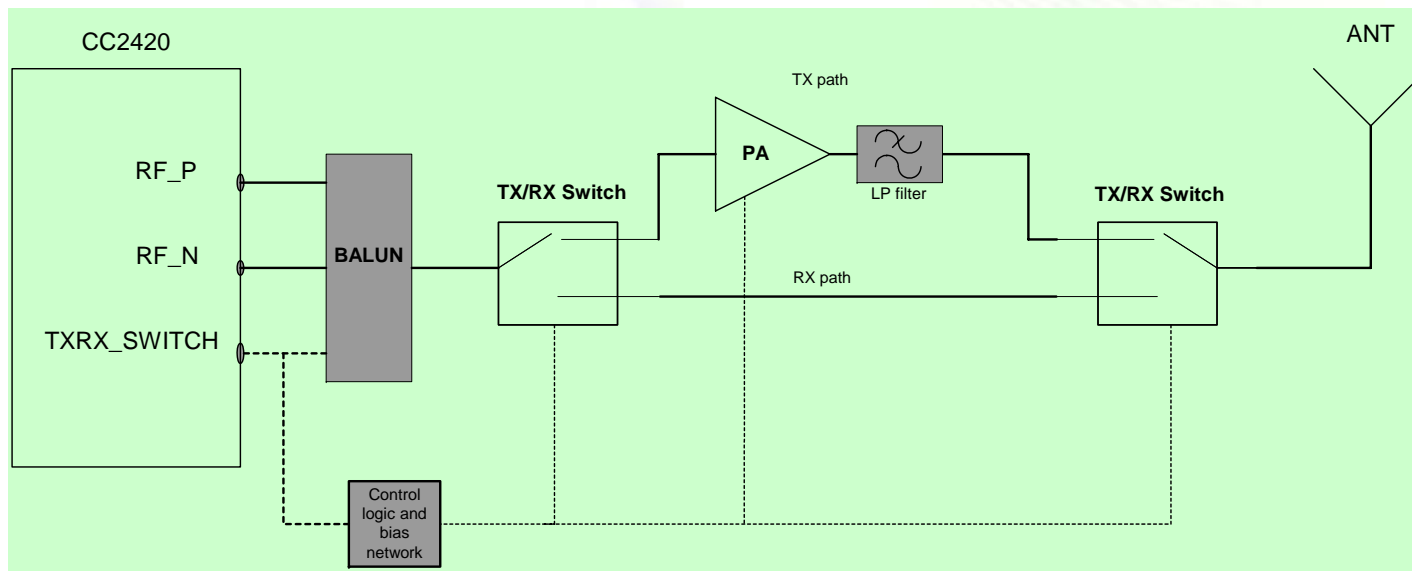
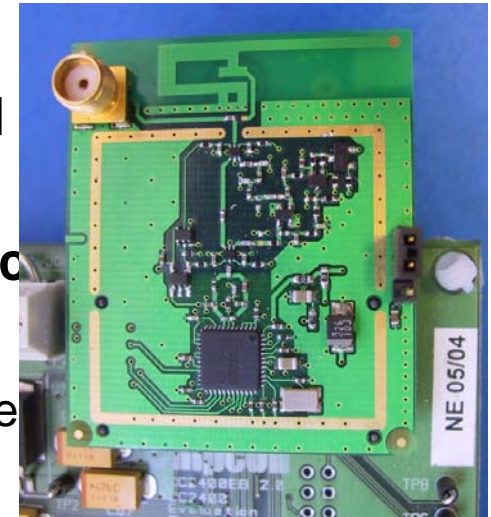
- Regulatory requirements need to be followed



# 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**
- **Simpler control without external LNA**
  - No extra signal is needed from MCU to turn off LNA in low power



	CC2420EM	CC2420EM w/PA
<b>TX current</b>	17.4 mA	30.8 mA
<b>RX current</b>	19.7 mA	19.7 mA
<b>Output power</b>	0 dBm	9.5 dBm
<b>Sensitivity</b>	-94 dBm	-93.1 dBm
<b>Line of Sight Range</b>	230 meter	580 meter

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# 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 emperical 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

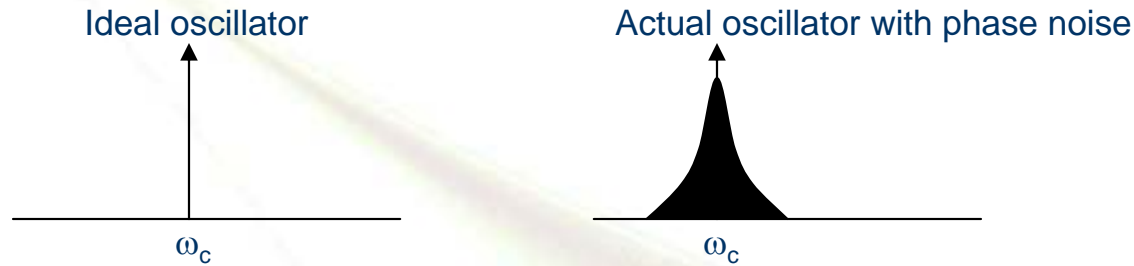
- **Factors**

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

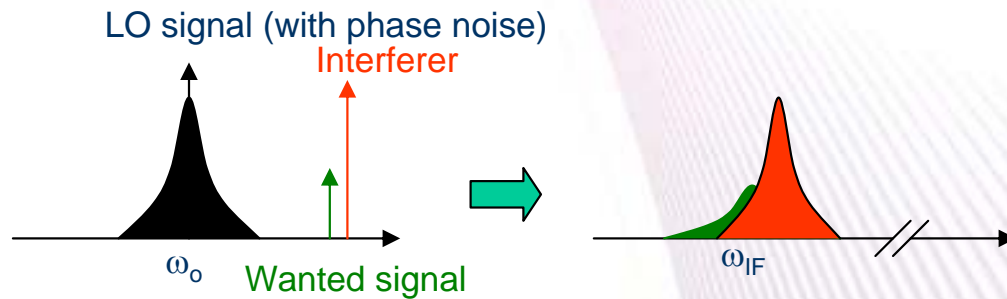
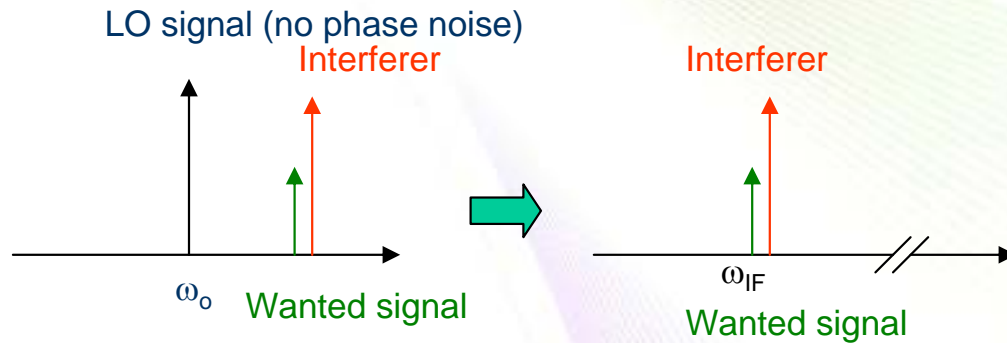
# Agenda

- Basics
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# Phase Noise



## Down Conversion (receivers):



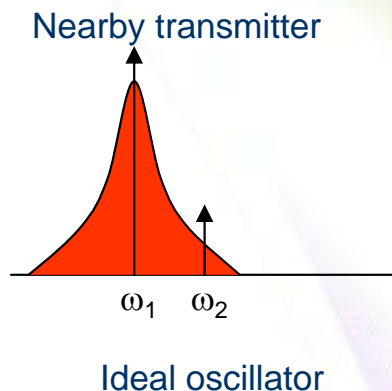
Down-converted bands consist of two overlapping spectra, with the wanted signal suffering from significant noise due to the tail of the interferer

Interferer end up within the IF bandwidth and **cannot** be filtered out



# Phase Noise

Transmitters:



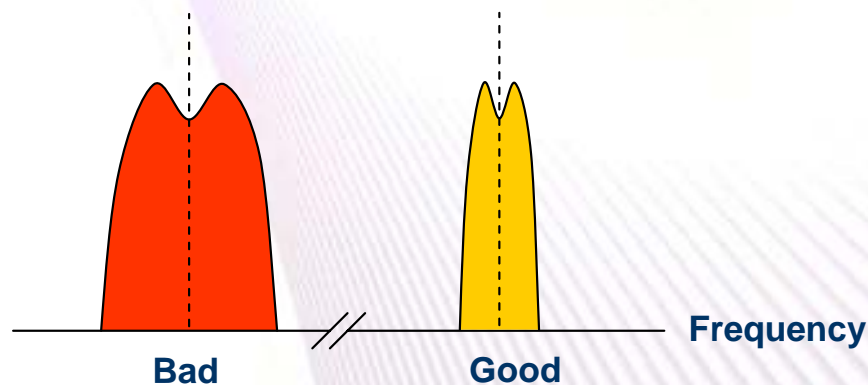
Difficult to detect weak signal at  $\omega_2$ .

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

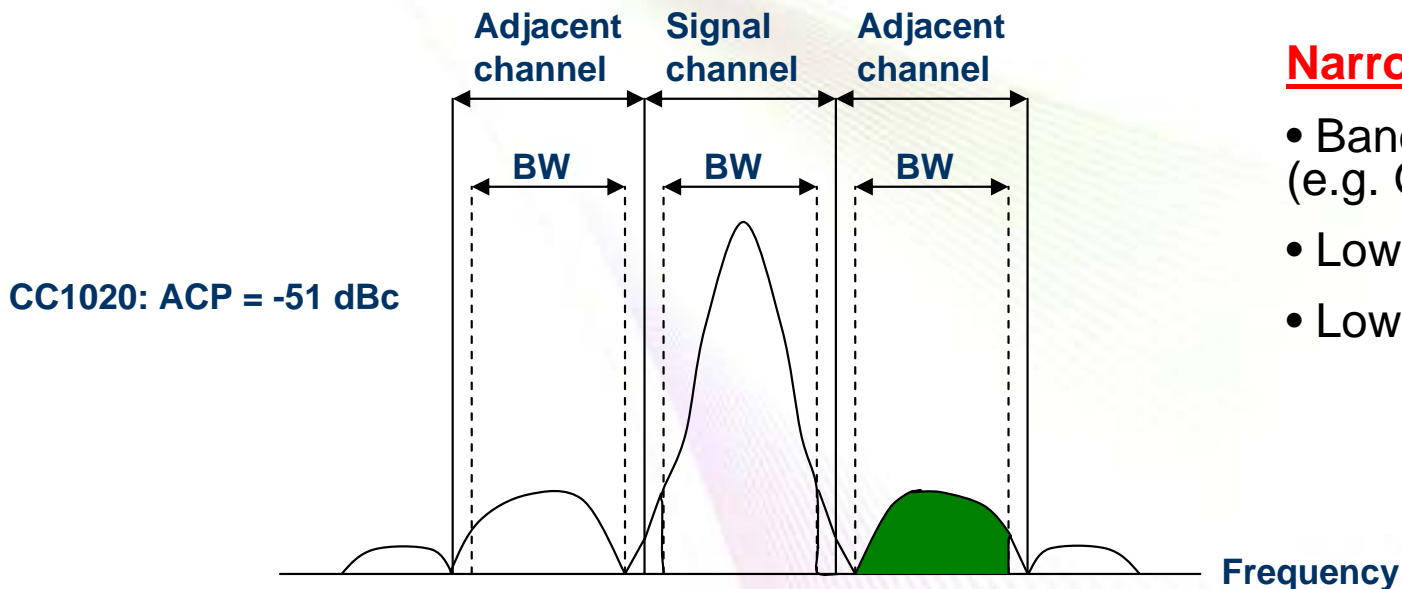
- How good is the transmitter at making efficient use of the RF spectrum?
- **OBW = Occupied Band Width**
  - Defined as BW with 99.5% of the total average power (ARIB)
  - For 12.5 kHz channel spacing OBW < 8.5 kHz (ARIB)
  - Measured using built-in function of spectrum analyzer



# 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



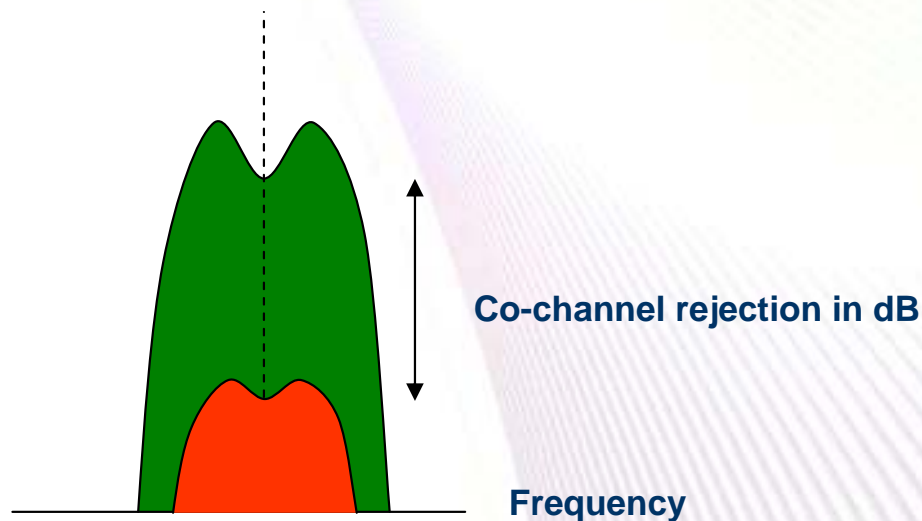
## Narrowband characteristics:

- Bandwidth efficient modulation (e.g. GFSK)
- Low data rate
- Low deviation

- **Low phase noise** ➔ **key parameter for low ACP**
- **ETSI: Absolute ACP requirement (dBm), ARIB: Relative (dBc)**

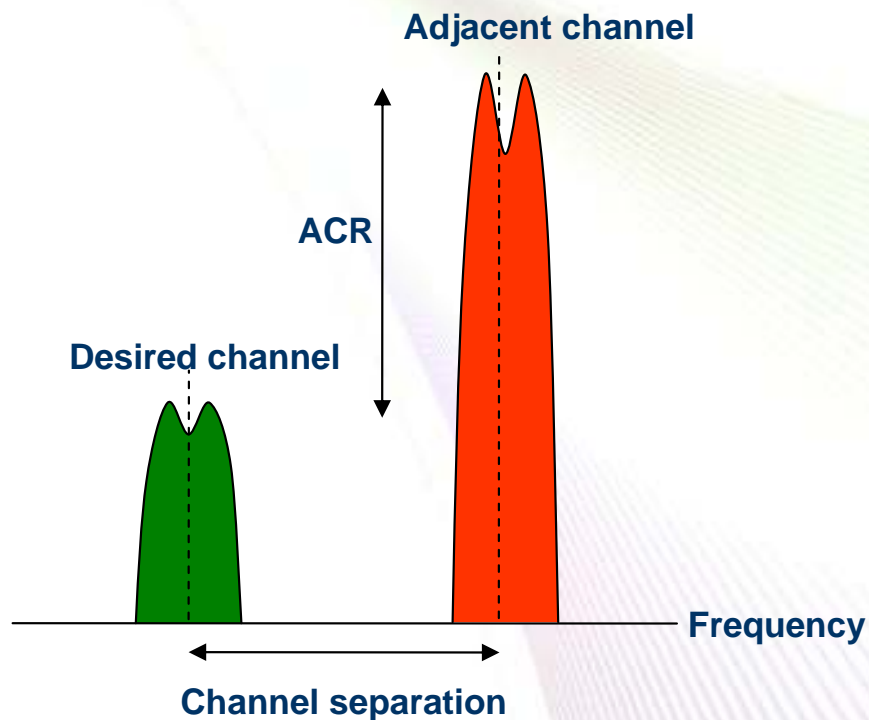
# Receiver, Co-channel Rejection

- 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

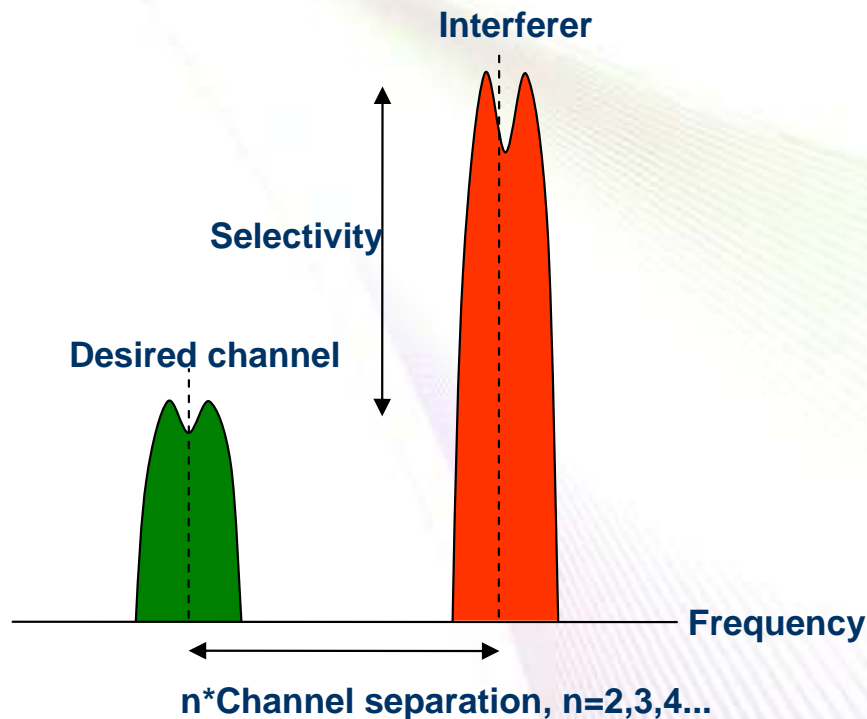
- ACR = Adjacent Channel Rejection or
- ACS = Adjacent Channel Selectivity



- **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

<b>Selectivity Requirement for different RF standards</b>			
<b>Standard, Ch. Spacing</b>	<b>Adjacent Channel Rejection</b>	<b>Selectivity, other channels</b>	
ARIB, 12.5 kHz	30 dB ( $\pm$ 12.5kHz)	40 dB for all other channel	
ARIB, 25 kHz	40 dB ( $\pm$ 25kHz)	40 dB for all other channel	
ETSI class 1, 25 kHz	60 dB ( $\pm$ 25 kHz)	84 dB ( $\pm$ 1 MHz)	
Bluetooth, 1 MHz	0 dB ( $\pm$ 1 MHz)	30 dB ( $\pm$ 2 MHz)	40 dB ( $\pm$ 3 MHz)
<b>CC2400, 1 MHz (250kbit/s)</b>	<b>12 dB (<math>\pm</math> 1 MHz)</b>	<b>48 dB (<math>\pm</math> 2 MHz)</b>	<b>50 dB (<math>\pm</math> 3 MHz)</b>
<b>CC2400, 1 MHz (1Mbit/s)</b>	<b>0 dB (<math>\pm</math> 1 MHz)</b>	<b>20 dB (<math>\pm</math> 2 MHz)</b>	<b>41dB (<math>\pm</math> 3 MHz)</b>
Zigbee (802.15.4), 5 MHz	0 dB ( $\pm$ 5 MHz)	30 dB for all other channels	
<b>CC2420, 5MHz</b>	<b>39/46 (+ - 5 MHz)</b>	<b>53/57 (+ - 10 MHz)</b>	

- **CC1020 is ARIB compliant (12.5 and 25 kHz channels)**

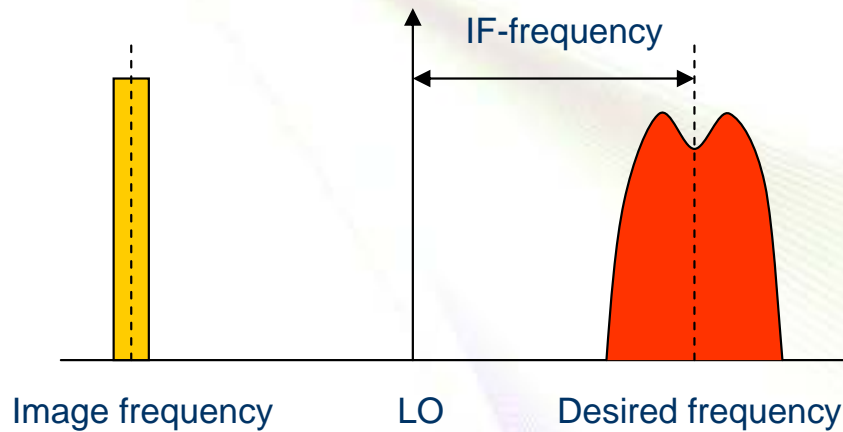
# Receiver, Blocking/desensitization

- **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**

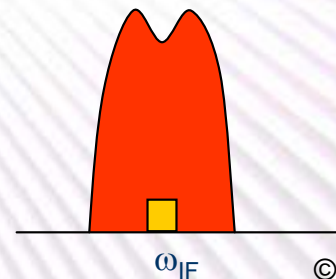
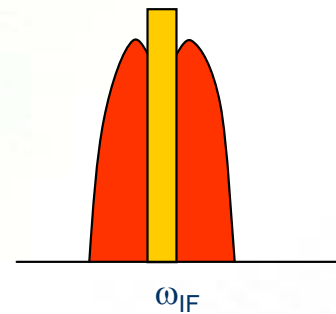


# Image Rejection

- Image Rejection



- **CC1000**
  - No image rejection
- **CC1020**
  - Image rejection

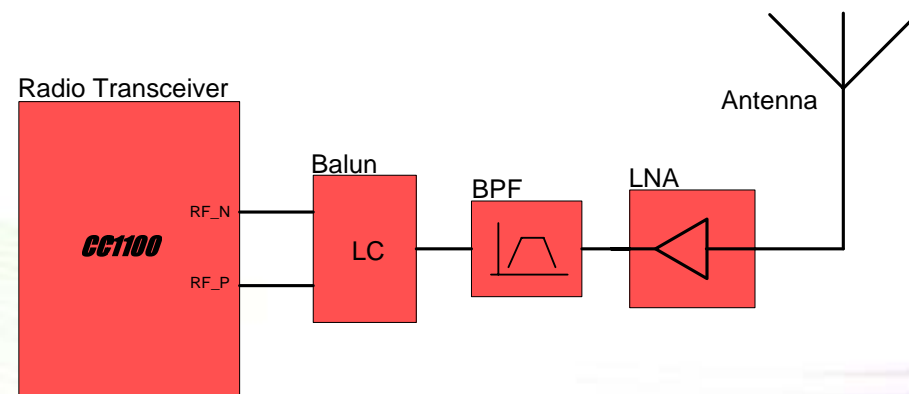


# Receiver Sensitivity

- How to achieve good RF sensitivity?

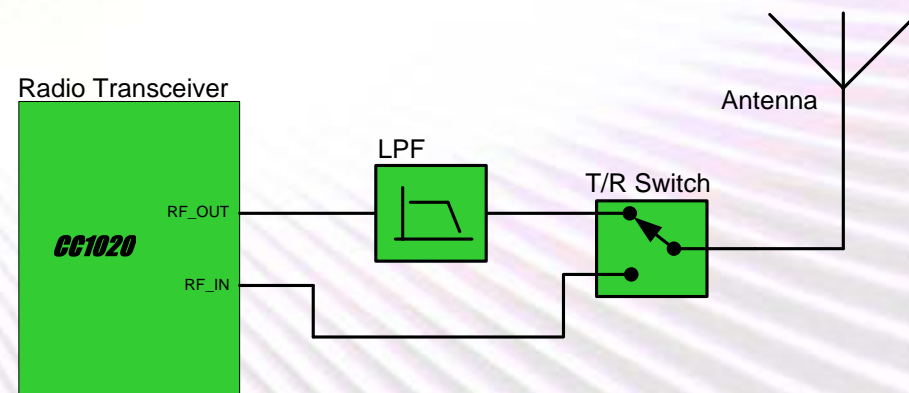
- Introduce high gain in front of the receiver

- External LNA needed
- Poor linearity (IP3)
- Poor blocking/selectivity
- “Removes” the losses in the SAW filter



- Lower noise bandwidth (narrowband)

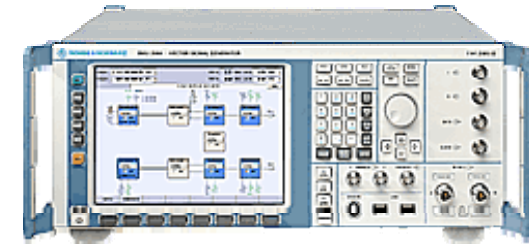
- Blocking/linearity not changed
- Good selectivity
- Good frequency control needed



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# RF Measurement Equipment

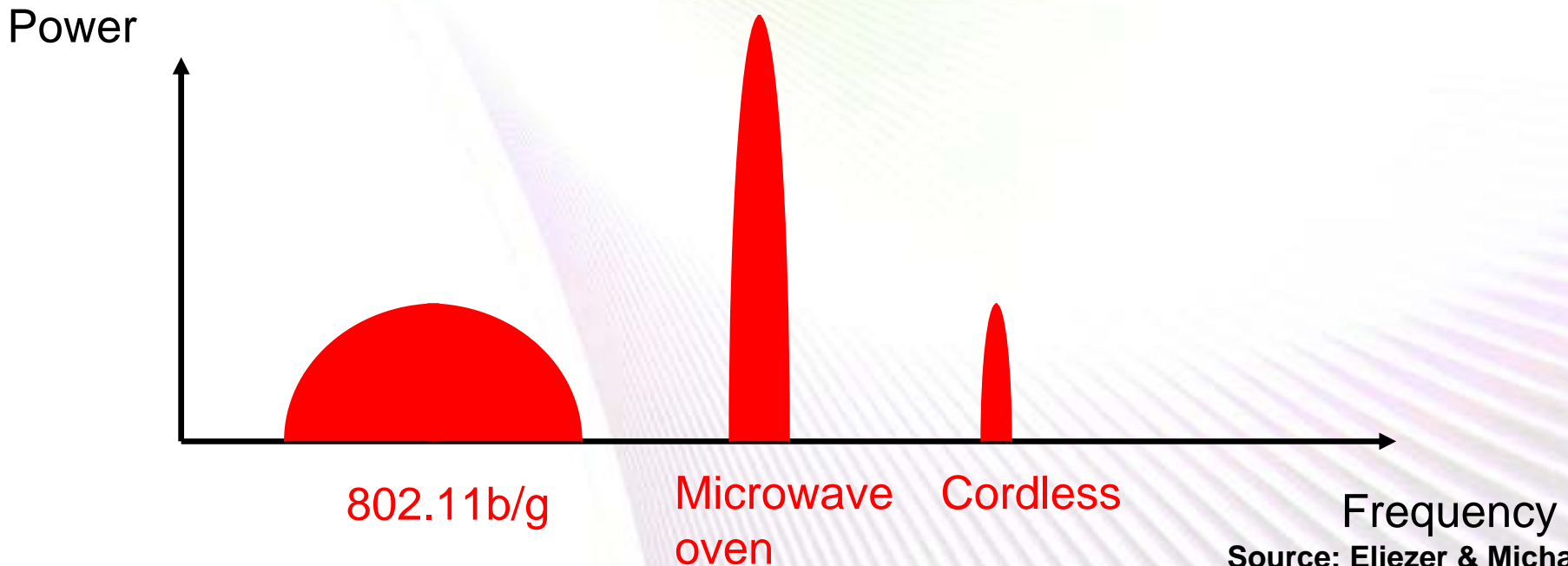
- **Vector Network Analyzers**
  - Component Characterisation – insertion loss
  - S-parameters - matching
- **Spectrum Analyzers**
  - Output Power, harmonics, spurious emission
  - Phase Noise
  - ACP
  - OBW
  - Modulation - deviation
- **Signal Generators**
  - Sensitivity (BER option needed)
  -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



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# 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



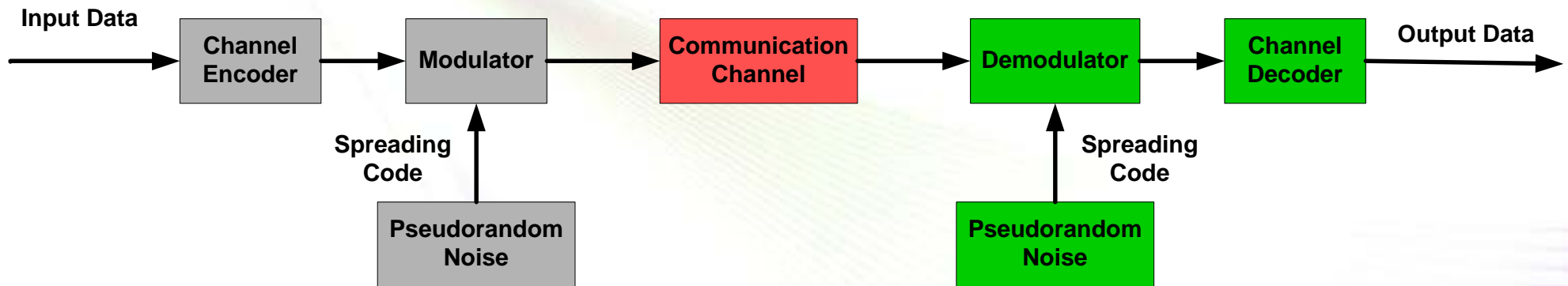
Source: Eliezer & Michael, TI

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# Spread Spectrum Systems

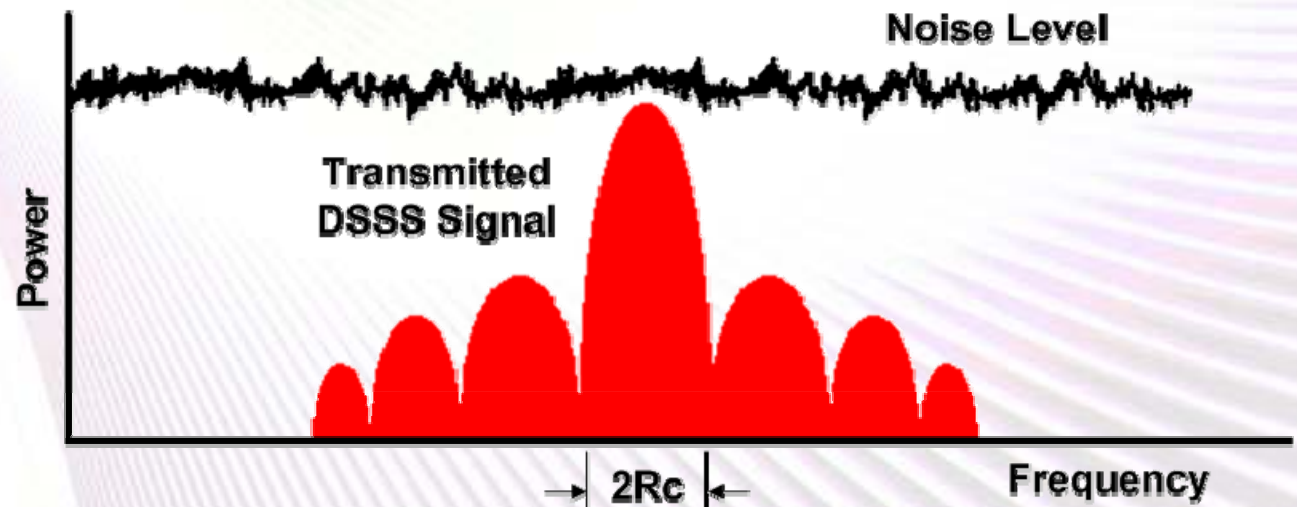
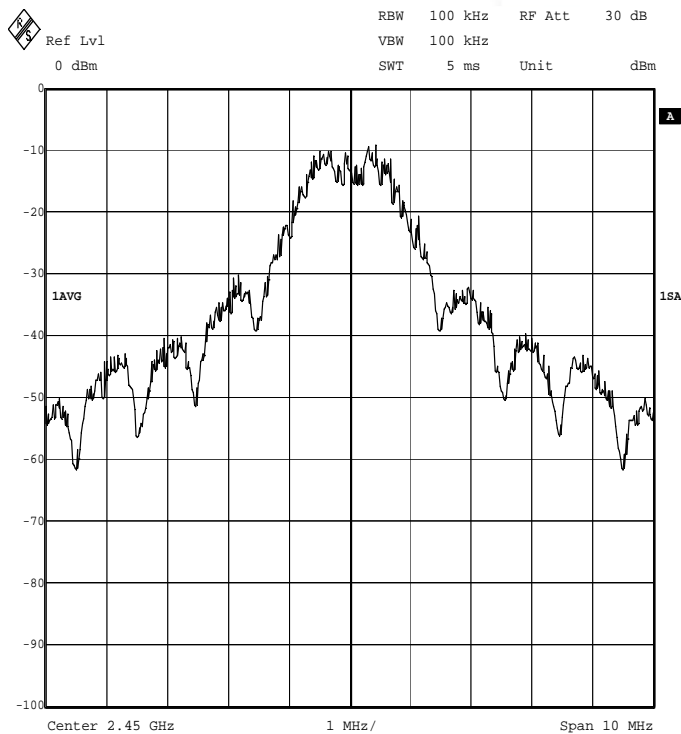
- Data sent using spread spectrum is intentionally spread over a wide frequency range
- Appears as noise, so it is difficult to detect and jam
- Resistant to noise and interference thus increasing the probability that the signal will be received correctly
- Unlikely to interfere with other signals even 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



# Direct Sequence Spread Spectrum

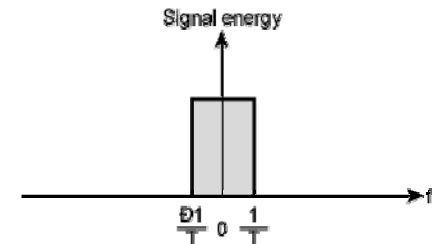
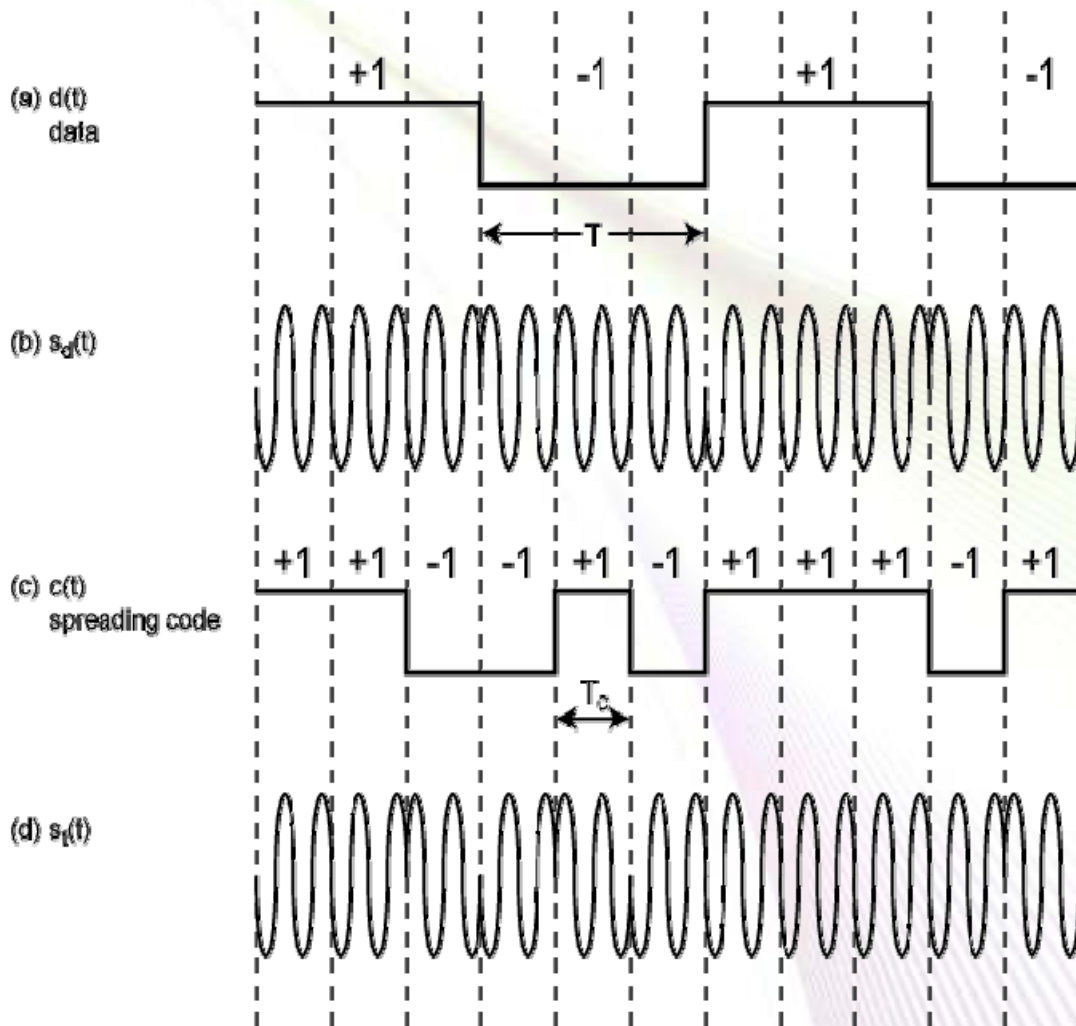
- Each bit represented by multiple bits using spreading code
- Spreading code spreads signal across wider frequency band
- Good resistance against interferers



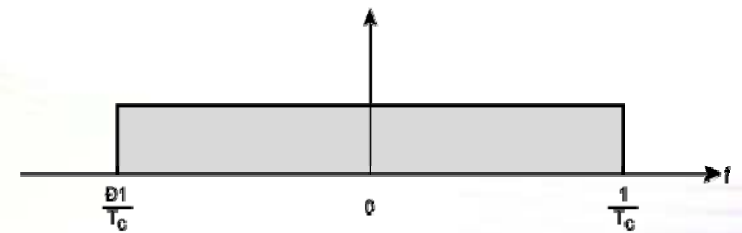
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Date: 23.OCT.2003 21:34:19

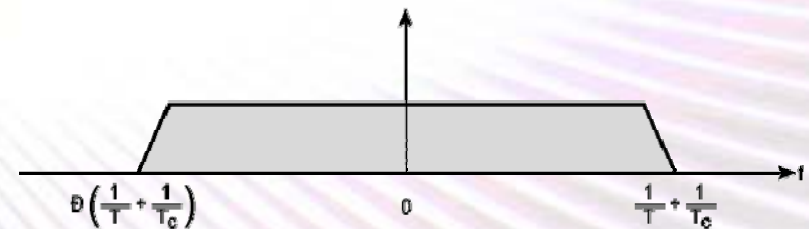
# DSSS – BPSK Example



(a) Spectrum of data signal



(b) Spectrum of pseudonoise signal



(c) Spectrum of combined signal

Source: William Stalling  
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# DSSS Spreading Mechanism

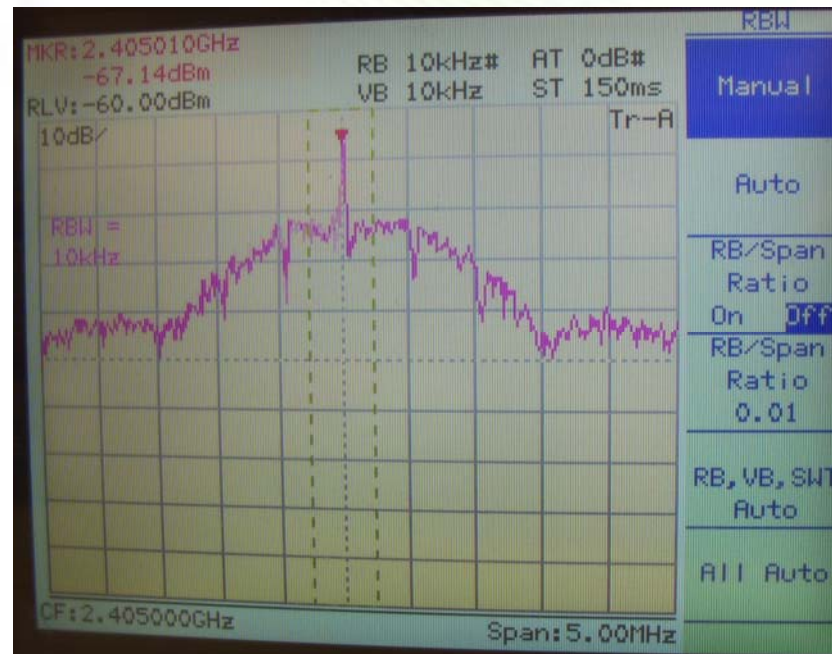
IEEE 802.15.4 (CC2420): 2 Mchips/s -> 250 kbps data rate

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

		Correct chip sequence for nibble = 5:																																	
		0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0																																	
		Incoming chip sequence (value is 5, but with 8 faulty chips):																																	
		0 1 1 1 0 1 1 1 0 0 0 0 0 0 1 0 0 1 1 0 0 0 0 1 0 0 1 1 1 1 0 0																																	
Nibble value	Comparison (XOR) with all possible chip sequences																																	Correlation value	
0	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 0 1 0 0 0 1 0 1 1 1 0	18																																	
1	1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 1 0 0 1 0 0 0 1 0	16																																	
2	0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0	14																																	
3	0 0 1 0 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	12																																	
4	0 1 0 1 0 0 1 0 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	14																																	
5	0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0	24																																	
6	1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 0 1	16																																	
7	1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1	14																																	
8	1 0 0 0 1 1 0 0 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 0 1 1	14																																	
9	1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1	16																																	
10	0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 1 1 1	14																																	
11	0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0	20																																	
12	0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0	14																																	
13	0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 0 1 1 1 0 0 0 1 1 0 0 0 1 0 0 0 1	12																																	
14	1 0 0 1 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	20																																	
15	1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 0 1 1 0 1 1 1 0 1 1 1 0 1 1 0 0 0	18																																	

# DSSS – Co-existence Performance

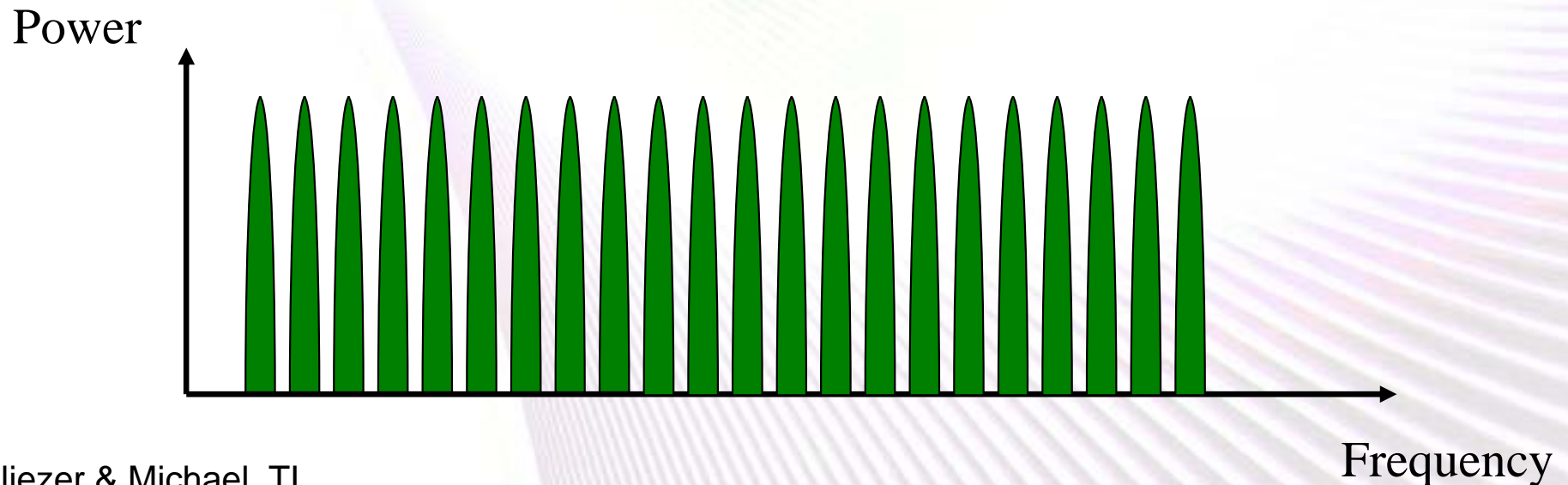
- CC2420 - In-band interference
- Power of interferer only 1 dB lower than CC2420 transmitter, NO packet errors
- Narrowband interferer shown as peak in the centre on top of the CC2420 spread spectrum
- A typical FSK receiver requires the desired signal to be 11 dB above interferer



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# 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



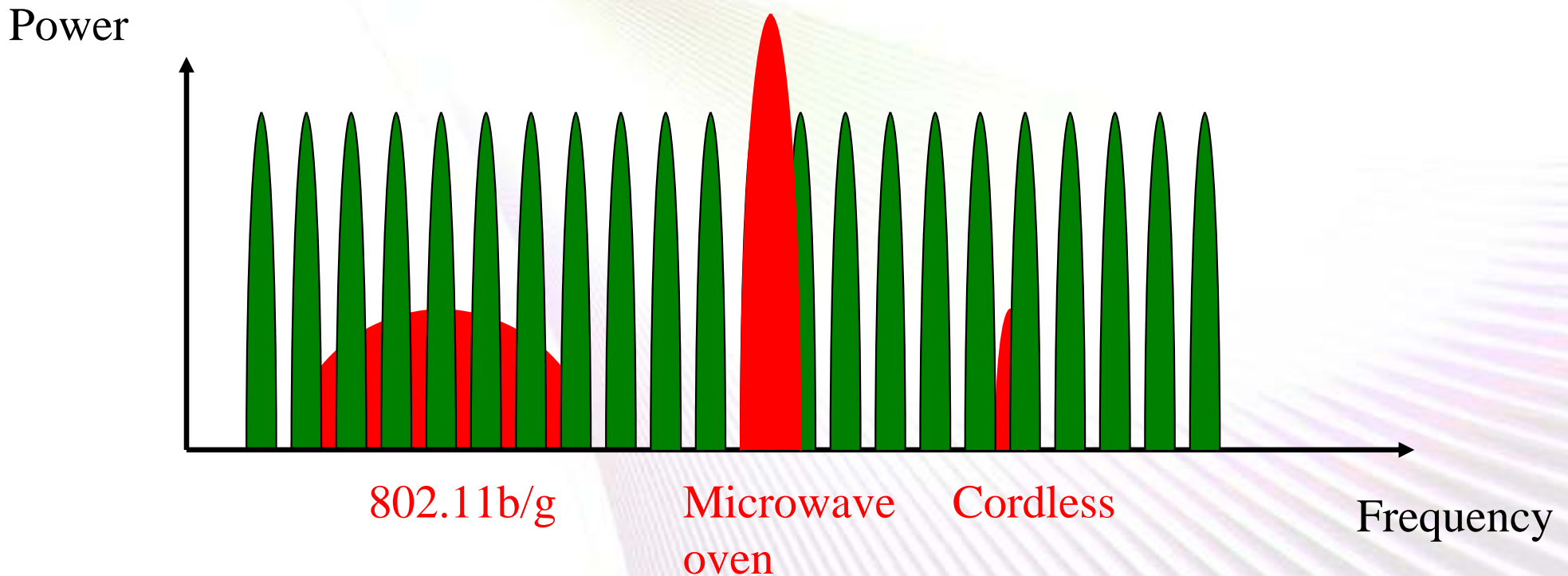
Source: Eliezer & Michael, TI

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# 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)

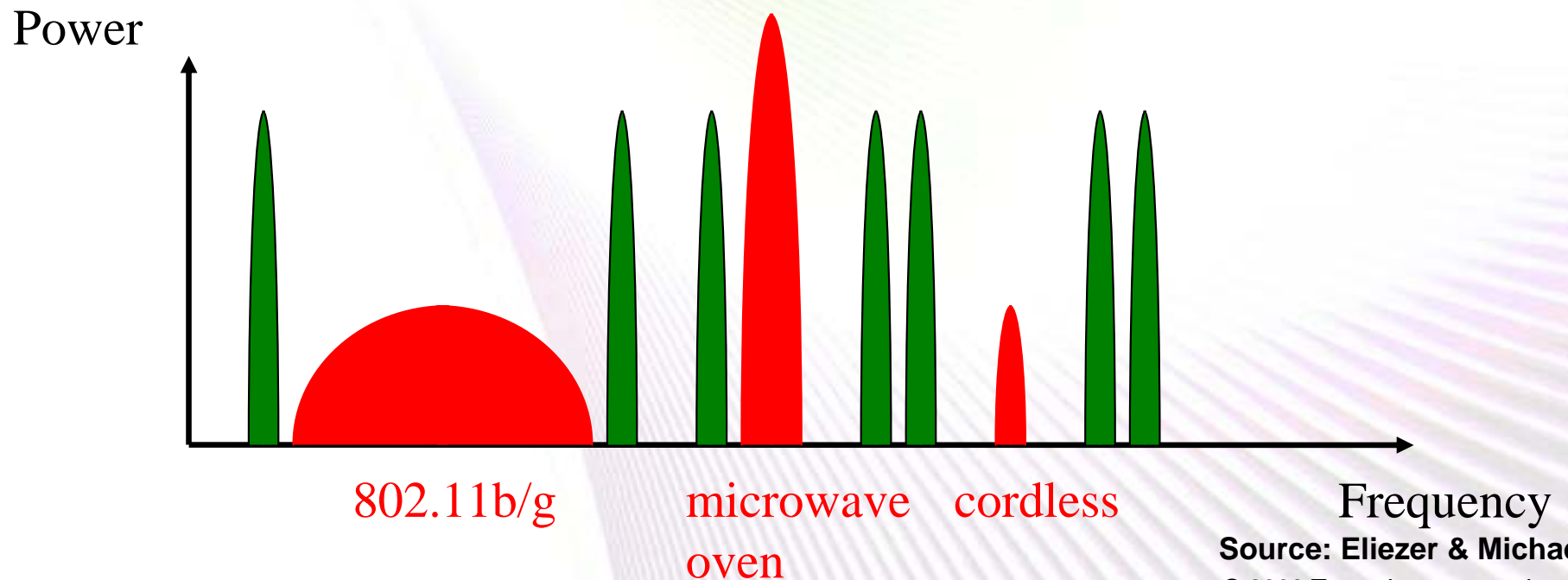


Source: Eliezer & Michael, TI

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# 2.4 GHz – Adaptive Frequency Hopping

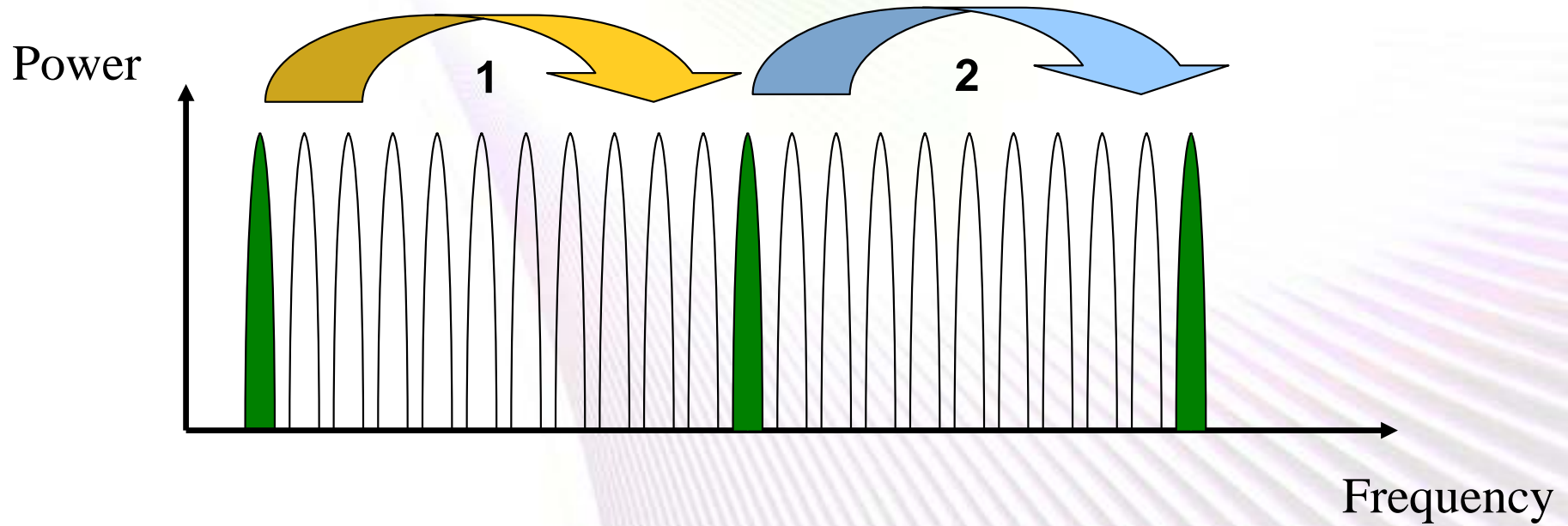
- Scan the entire frequency band at start-up and restrict usage to frequencies with the lowest energy content. RadioDesk and Bluetooth 1.2 and 2.0 are using AFH.
- Substitute frequencies experiencing interference on the fly.



Source: Eliezer & Michael, TI  
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# 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



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# 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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Logic	<a href="http://logic.ti.com">logic.ti.com</a>	Military	<a href="http://www.ti.com/military">www.ti.com/military</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>	Optical Networking	<a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>	Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>	Telephony	<a href="http://www.ti.com/telephony">www.ti.com/telephony</a>
Low Power Wireless	<a href="http://www.ti.com/lpw">www.ti.com/lpw</a>	Video & Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>
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