Ultra Low Power RF Link for Sub-1GHz ISM

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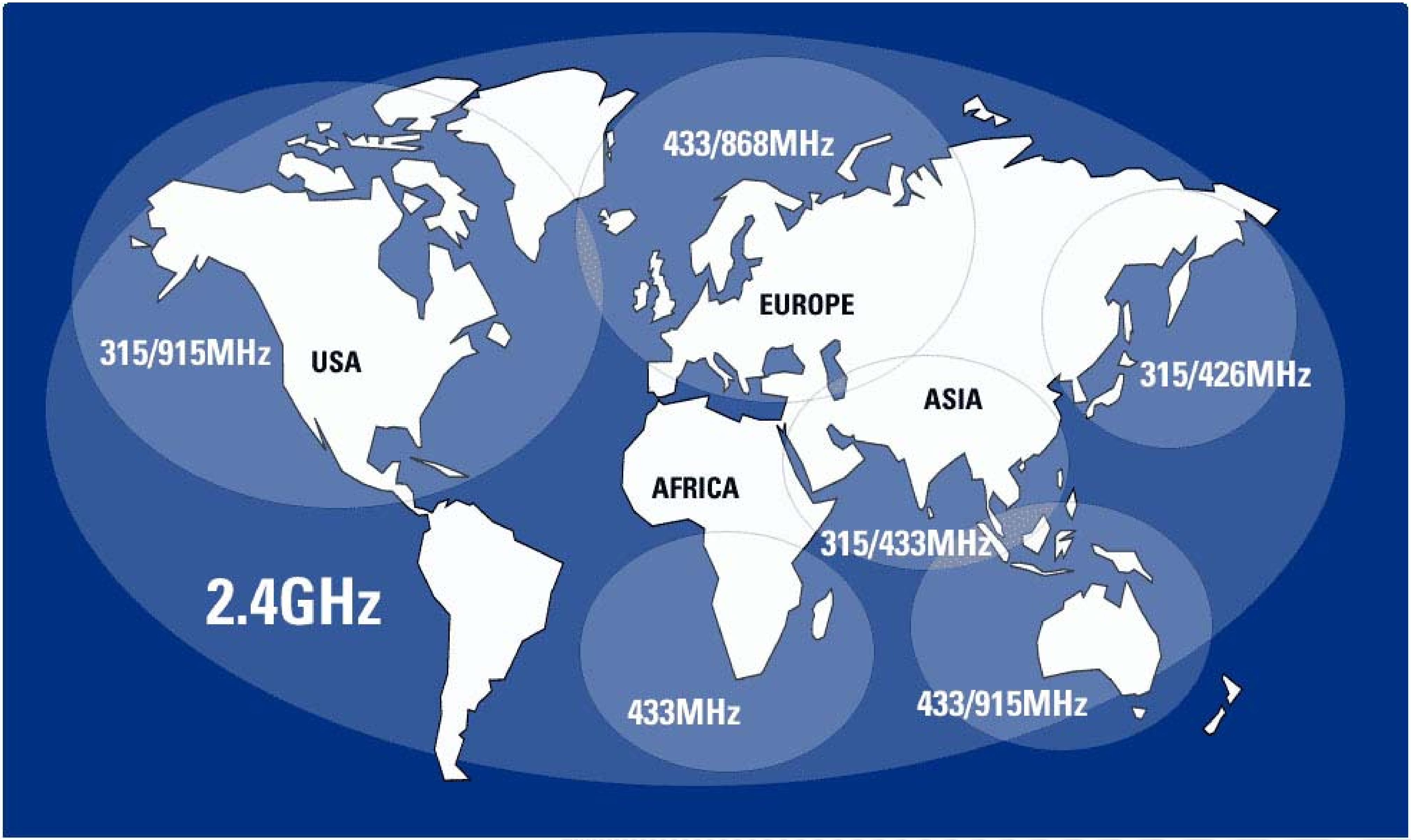
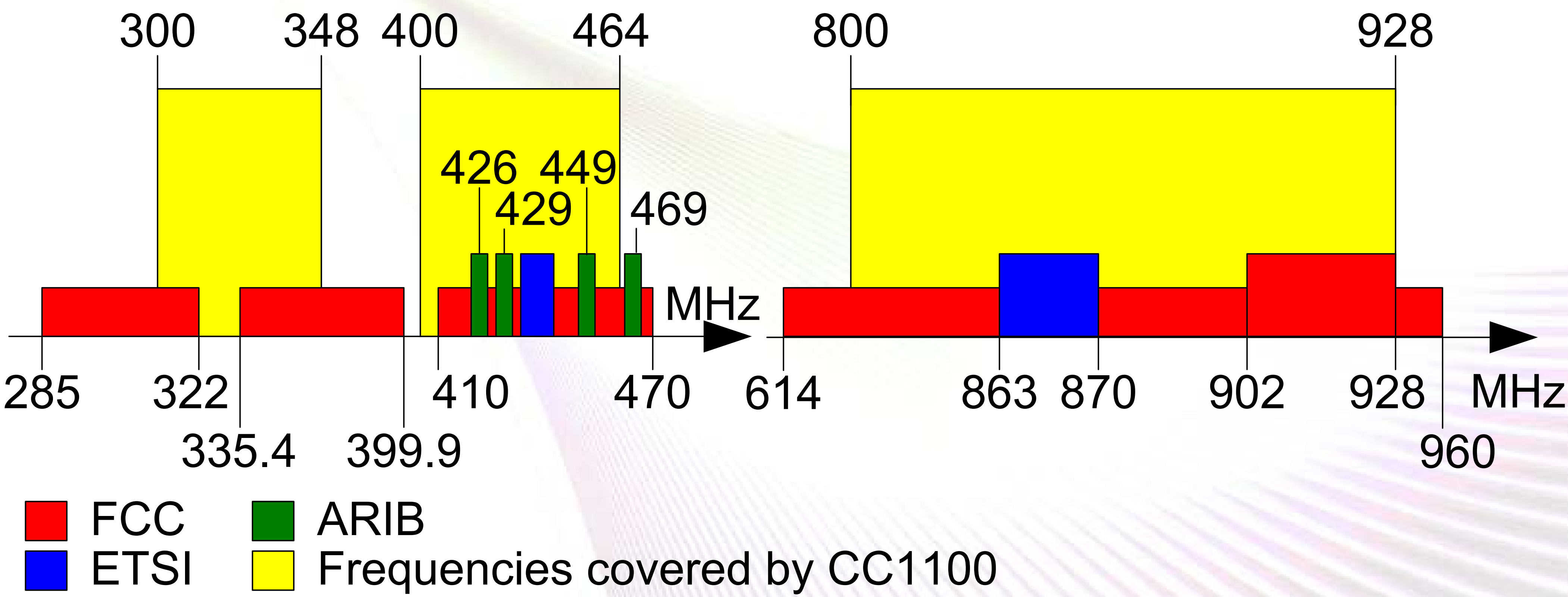
Agenda

- Frequency allocation and regulations
- Device selection
- Hardware
- Software
- Support/how to get started

ISM/SRD License-Free Frequency Bands

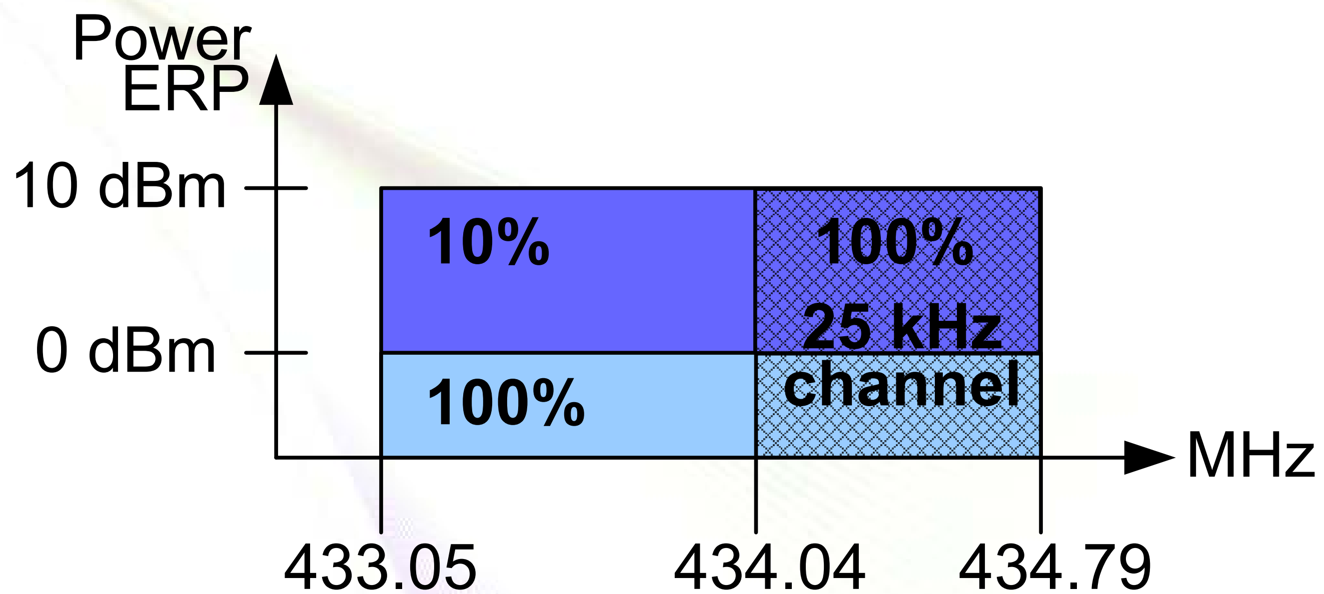


Sub-1GHz Frequency Bands



ETSI - SRD Regulations in Europe

- **433 MHz band: EN 300 220 V1.3.1 & V2.1.1**



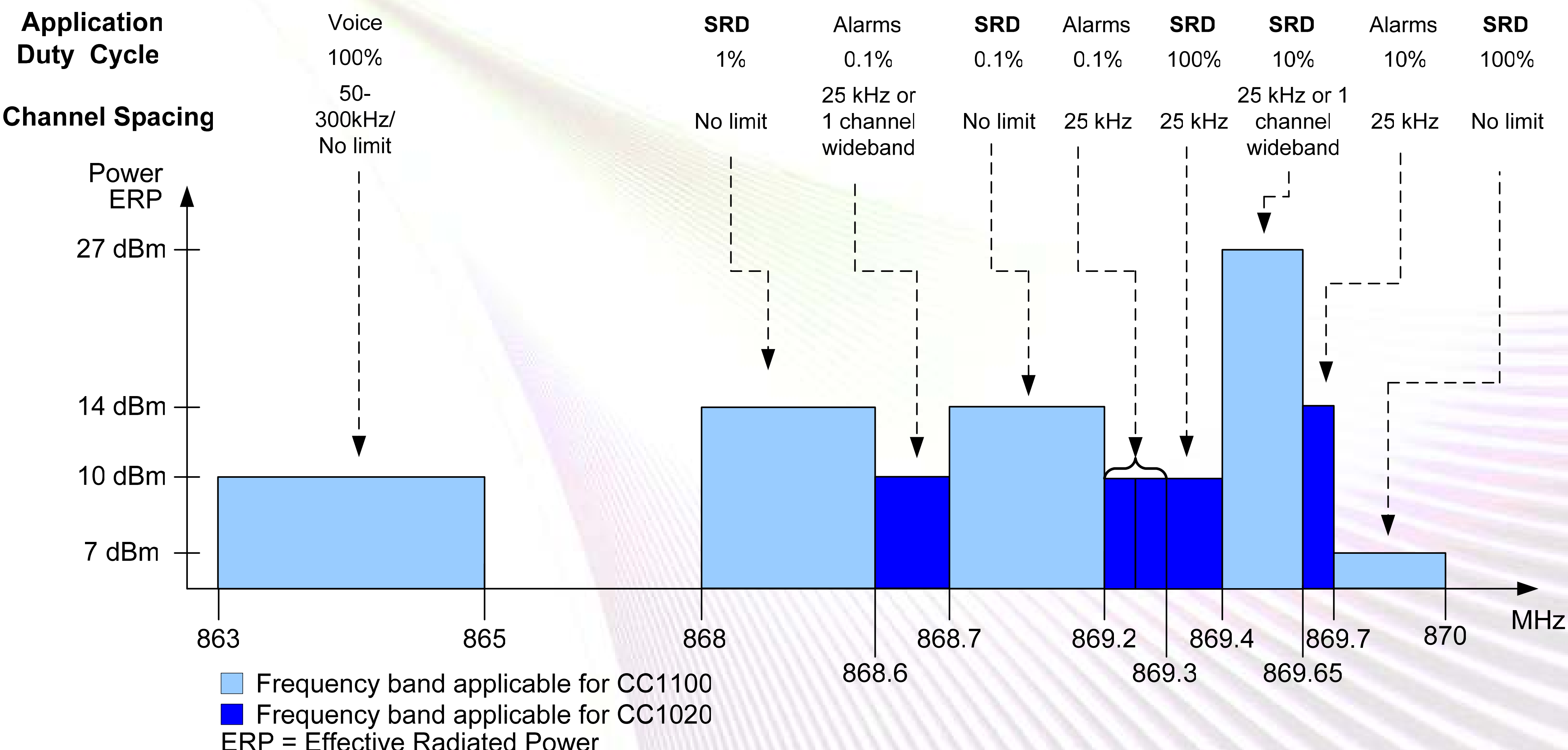
Class	Frequency band	Output power	Duty cycle (max)	Channel spacing
1e (f)*	433.05-434.79 MHz	10 mW (10 dBm)	10 %	No requirements
1e1 (f1)*	433.05-434.79 MHz	1 mW (0 dBm)	100 %	No requirements
1e2 (f2)*	434.04-434.79 MHz	10 mW (10 dBm)	100 %	25 kHz

***Class name according to new ETSI standard**

ETSI = European Telecommunications Standards Institute

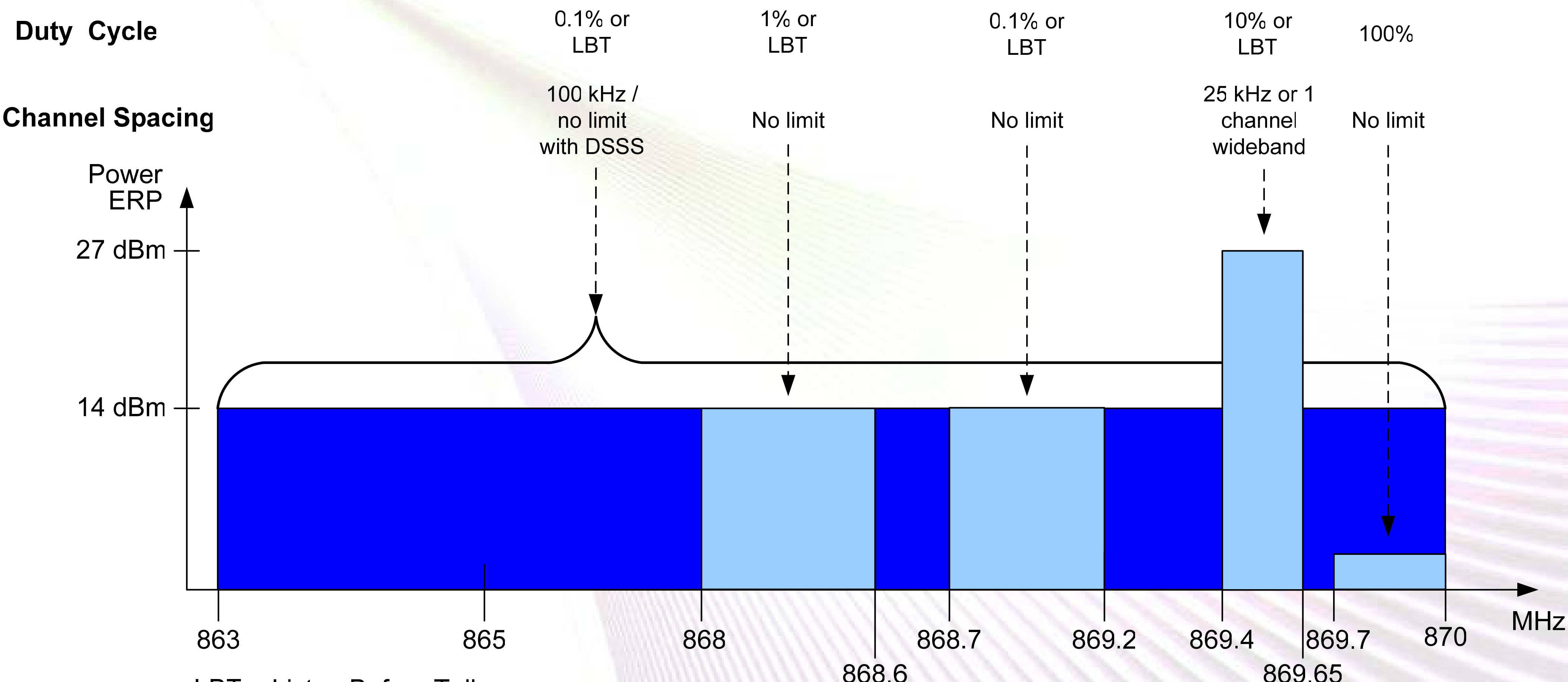
ETSI - SRD Regulations in Europe

- **868 MHz band: EN 300 220 V1.3.1**



ETSI - SRD Regulations in Europe

- **868 MHz band: EN 300 220 V2.1.1**



LBT = Listen Before Talk
ERP = Effective Radiated Power

ETSI - Listen Before Talk (LBT)

- **Minimum TX off time > 100 ms**
- **Minimum listening time: tL = tF + tPS**
  - Fixed time: tF = 5 ms. Pseudo Random time: tPS between 0 ms and 5 ms
- **There is no requirement for a listening time before sending an acknowledgement**
- **The limit for a single transmission TX on-time is 1 s**
- **The limit for a transmission dialogue is 4 s**

TX power / Channel spacing	< 100 mW	500 mW
6,25 kHz	-102 dBm	-106 dBm
12,5 kHz	-99 dBm	-103 dBm
20/25 kHz	-96 dBm	-100 dBm
50 kHz	-93 dBm	-97 dBm
100 kHz	-90 dBm	-94 dBm
200 kHz	-87 dBm	-91 dBm
500 kHz (wideband)	-83 dBm	-
600 kHz (wideband)	-82 dBm	-

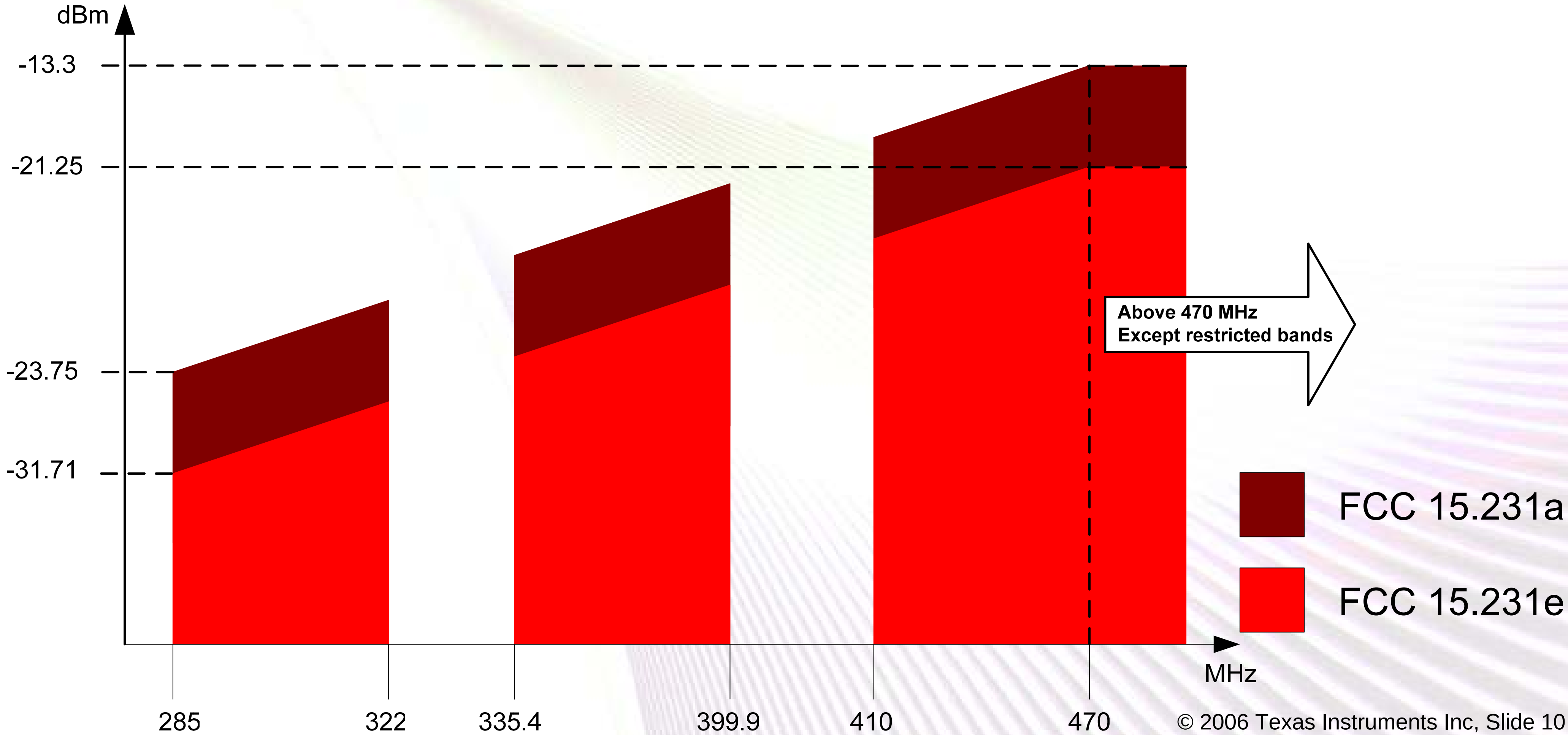
LBT threshold

ETSI – Spurious Emission

- If the operating frequency is < 470 MHz the equipment shall be measured from 9 kHz to 4 GHz
- If the operating frequency is > 470 MHz the equipment shall be measured from 9 kHz to 12.75 GHz
- Measured without modulation

FCC – SRD Regulations

- **FCC 15.231, Control Applications**
  - Limited to certain application types
  - Duty cycling can increase the allowed output power with up to 20 dB



FCC – SRD Regulations

- **902 - 928 MHz band**
  - FCC 15.249, Single channel
  - FCC 15.247, Spread Spectrum
    - FHSS - Frequency Hopping Spread Spectrum
    - Digital Modulation (e.g. DSSS - Direct Sequence Spread Spectrum)

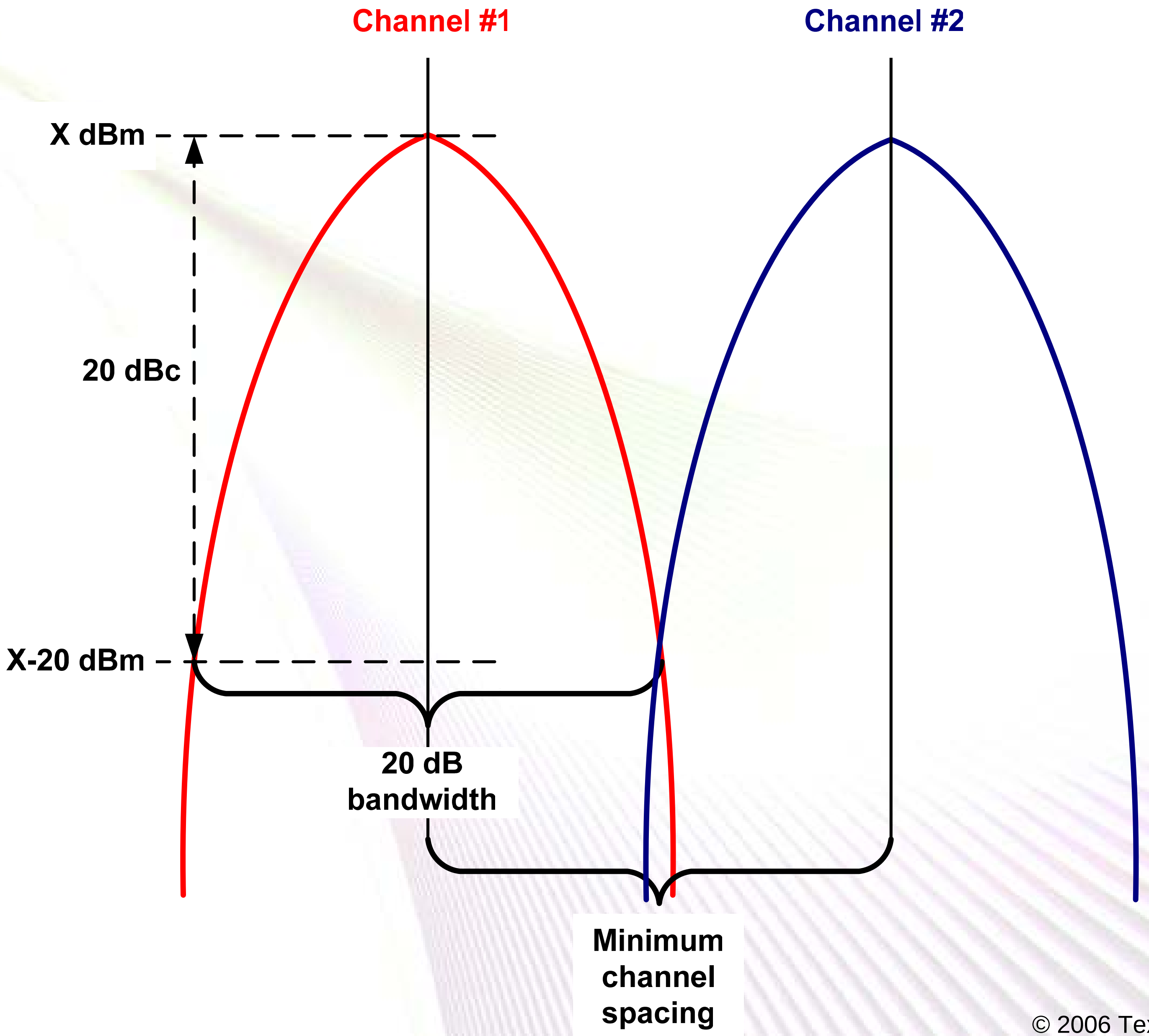
FCC – 15.247 Requirements

- **FHSS – Frequency Hopping Spread Spectrum**
  - Channel spacing must be larger than 20 dB bandwidth and minimum 25 kHz
  - 20 dB bandwidth less than 500 kHz

20 dB bandwidth	Required channels	Dwell time	Max output power
< 250 kHz	$\geq$ 50	0.4 sec within 20 sec period	30 dBm + 6 dBi antenna gain
> 250 kHz	$\geq$ 25	0.4 sec within 10 sec period	24 dBm + 6 dBi antenna gain

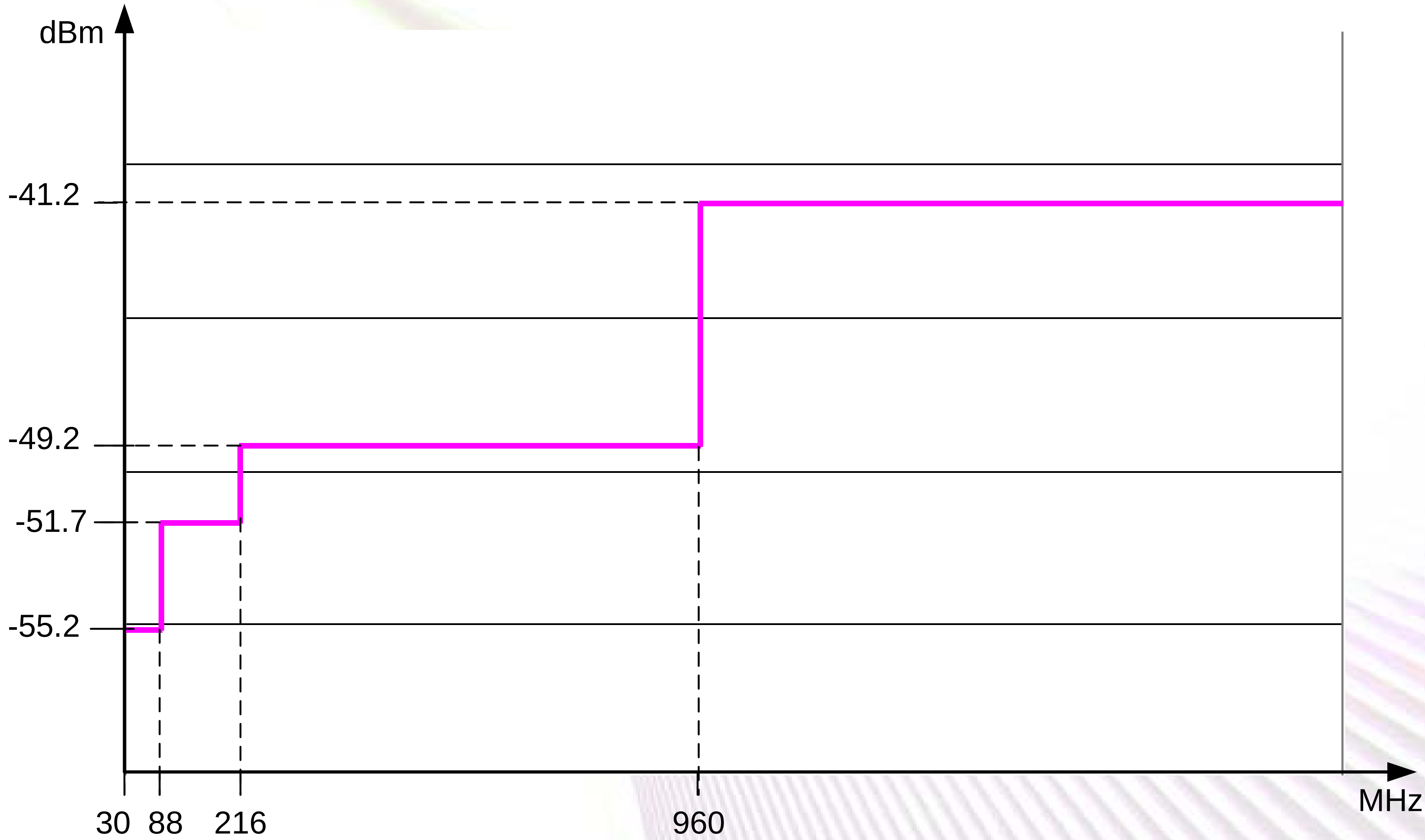
- **Digital modulation (DSSS)**
  - Minimum 6 dB bandwidth of 500 kHz
  - Peak power spectral density shall not be greater than 8 dBm in any 3 kHz band
  - Maximum allowed output power is 30 dBm + 6 dBi antenna gain.

FCC – 20 dB Bandwidth



FCC – Spurious Emission 15.209

- **Measured with quasi-peak detector below 1 GHz**
- **Measured with averaging detector above 1 GHz**



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MSP430 for Wireless

- **MSP430 Microcontroller + CC RF,**
  a perfect fit for low power wireless solutions
  - Designed for low power
  - VCC = 1.8V … 3.6V
  - Simple connection through SPI

MSP430 – CCxxxx Connection

- **SPI Communication between MSP430 and CCxxxx.**
- **MSP430 peripherals USART, USCI and USI support SPI.**
- **MSP430 with SPI support:**
  - MSP430F12x2, MSP430F13x, MSP430F14x, MSP430F15x, MSP430x16x
  - MSP430F20x2, MSP43020x3, Planned: MSP430F22x2, MSP430F22x4, MSP430F24x, MSP430F26x, MSP430F241x, MSP430F261x
  - MSP430F42x, MSP430FE42x, MSP430F43x, MSP430F44x
  - MSP430FG461x

x = Flash and RAM size of MSP430

MSP430 Memory Size Options

MSP430Fyzxz	Flash	RAM
x = 0	1kByte + 256Byte	128 Bytes
x = 1	2kByte + 256Byte	128 Bytes
x = 2	4kByte + 256Byte	256 Bytes
x = 3	8kByte + 256Byte	256 Bytes
x = 5	16kByte + 256Byte	512 Bytes
x = 6	24kByte + 256Byte	1kByte
x = 7	32kByte + 256Byte	1kByte
x = 8	48kByte + 256Byte	2kByte
x = 9	60kByte + 256Byte	2kByte
x = 10	32kByte + 256Byte	5kByte
x = 11	48kByte + 256Byte	10kByte
x = 12	55kByte + 256Byte	5kByte
x = 16	92kByte + 256Byte	4kByte
x = 17	92kByte + 256Byte	8kByte
x = 18	116kByte + 256Byte	8kByte
x = 19	120kByte + 256Byte	4kByte

- Typically RAM size is important to store data packets for RF transmission

cost efficient

general purpose

high end

'y' = 1 or 2 ⇨ no LCD

'y' = 4 ⇨ with LCD

'z' or 'zz' for combination of peripherals

MSP430 Recommendations

- **Cost efficient**
  - **MSP430F22x2**: 8…32kByte Flash, 512…1kByte RAM
    2 x 16-Bit Timer, USCI, ADC10
  - **MSP430F22x4**: 8…32kByte Flash, 512…1kByte RAM
    2 x 16-Bit Timer, USCI, ADC10, 2 OpAmps
  - **MSP430F41x:** 4…32kByte Flash, 256…1kByte RAM
    2 x 16-Bit Timer, Comparator_A, LCD
- **General Purpose**
  - **MSP430F161x**: 32..55kByte Flash, 5k…10kByte RAM
    2 x 16-Bit Timer, 2 x USART, HW-Multiplier,
    ADC12, DAC12
- **High End**
  - **MSP430F261x**: 92-120kByte Flash, 5k…10kByte RAM
    2 x 16-Bit Timer, 2 x USCI, HW-Multiplier,
    ADC12, DAC12 (planned for mid of 2007)
  - **MSP430FG461x**: 92-120kByte Flash, 5k…10kByte RAM
    2 x 16-Bit Timer, USCI, UART, HW-Multiplier,
    ADC12, DAC12, LCD_A

Chipcon Product Generations

Sub-1GHz Product Comparison Chart

17 Results - Show All Results   1 - 10 of 17 Results | Next >   Page 1 | 2   Customize Columns   Download Spreadsheet

Compare / Uncheck All	Part Number	Status	Frequency (min) (MHz)	Frequency (max) (MHz)	Standby Current (uA)	Operating Voltage (min) (V)	Operating Voltage (max) (V)	Modulation Techniques	Output Power (dBm)	Current Consumption (RX) (mA)	Current Consumption (TX) (mA)	FSK Data Rate (max) (kbps)	Receiver Sensitivit (FSK) (dBm)
☐	CC1000	ACTIVE	300	1000		2.1	3.6	FSK& OOK		7.4	10.4	76.8	-11
☐	CC1010	ACTIVE	300	1000		2.7	3.6	FSK OOK		23.9	25.2	76.8	-10
☐	CC1020	ACTIVE	402 804	470 940		2.3	3.6	FSK GFSK OOK		19.9	19.9	153.6	-11
☐	CC1021	ACTIVE	402 804	470 940		2.1	3.6	FSK GFSK OOK		19.9	19.9	153.6	-10
☐	CC1050	ACTIVE	300	1000		2.1	3.6	FSK OOK			9.1	76.8	
☐	CC1070	ACTIVE	402 804	470 940		2.3	3.6	FSK GFSK OOK			20.5	153.6	
☐	CC1100	ACTIVE	300 400 800	348 464 928		1.8	3.6	FSK GFSK MSK OOK		14	16.2	500	-11
☐	CC1110	PREVIEW	300 400 800	348 464 928		2	3.6	2-FSK GFSK MSK		22	31	500	-10
☐	CC1150	ACTIVE	300 400 800	348 464 928		1.8	3.6	FSK GFSK MSK OOK			15.9	500	

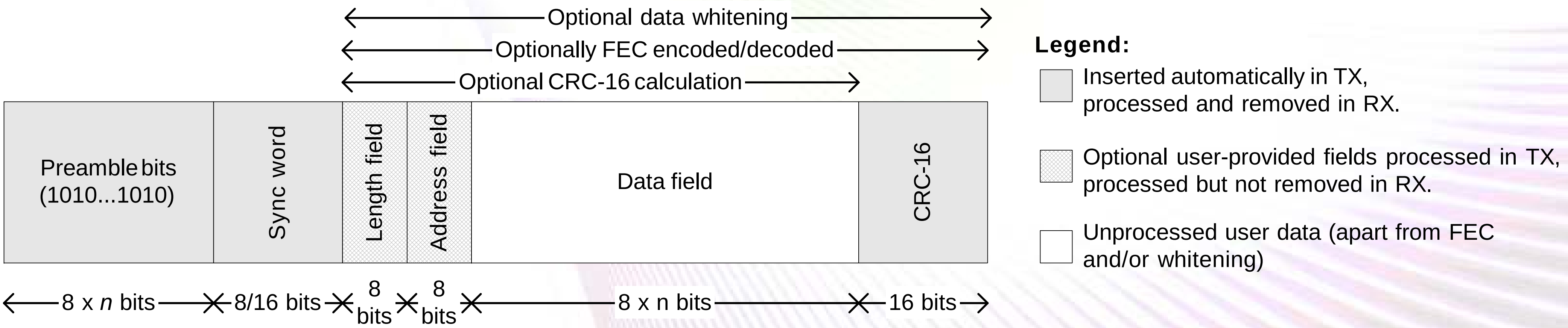
CC1100 – Multichannel Low-Cost RF Transceiver

Important Features:

- Powerful digital features making it easy to build a high-performance RF system using an inexpensive microcontroller
- RX: 15.6 mA , TX: 28.8 mA at +10 dBm output power, Power down: 400 nA
- Burst mode data transmission with high over-the-air data rate reduces current consumption
- Automatic RX polling using Wake-on-Radio: 1.8 µA
- High sensitivity (-110 dBm at 1.2 kbps)
- Programmable data rate from 1.2 - 500 kbps
- Robust solution with excellent selectivity and blocking performance

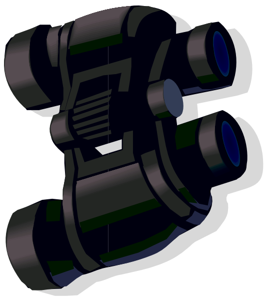
CC1100 Packet Handling

- **Full packet handling included**
  - Preamble generation
  - Sync word insertion/detection
  - Address check
  - Flexible packet length
  - Automatic CRC



Protocol Concepts

- **Polling receiver**
  - A polling receiver wakes up periodically and searches for data
  - Timing depends on behavior of the transmitter
  - CC1100 and CC2500 include wake-on-radio function where the radio performs polling without MCU intervention (based on internal RC oscillator)



Power-down	Wake up	Check for data	Power-down	Wake up	Check for data

- **Beaconing**
  - A beacon packet is transmitted periodically to ensure synchronization
  - Example: The RadioDesk™ USB dongle transmits a beacon every frame (nominally every 4 ms)

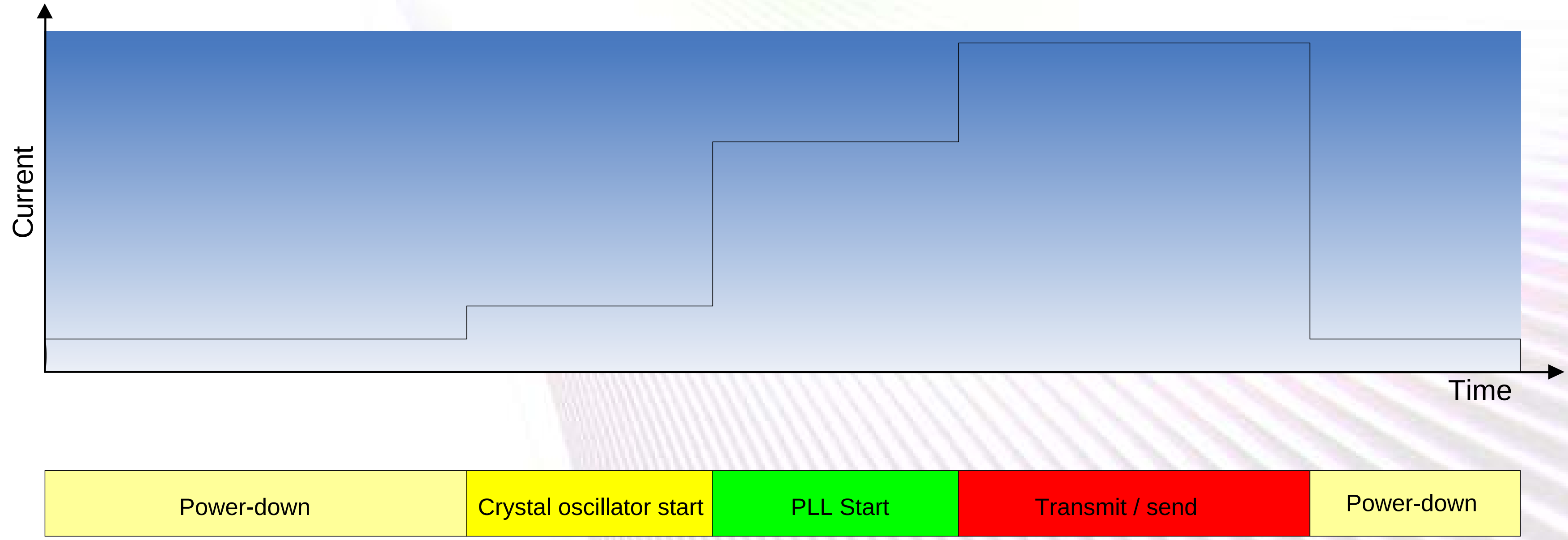
Power-down	Beacon	Power-down	Beacon

Choice of Packet Length is a trade off!

- **Parameters to consider are:**
  - Probability of packet loss
  - Impact of packet loss (added processing, increased RF on-time)
  - Acceptable latency
  - Packet overhead
  - Acceptable buffer memory or maximum FIFO size
- **Use long packets to:**
  - Minimize packet overhead
  - To maximize RF idle time between packets
- **Check/test the required preamble length**
  - CC1100 @ 250 kbps: 4 bytes preamble recommended
  - CC1100 @ 500 kbps: 8 bytes preamble recommended
- **Use short packets to:**
  - To minimize packet loss and retransmission
  - To minimize latency

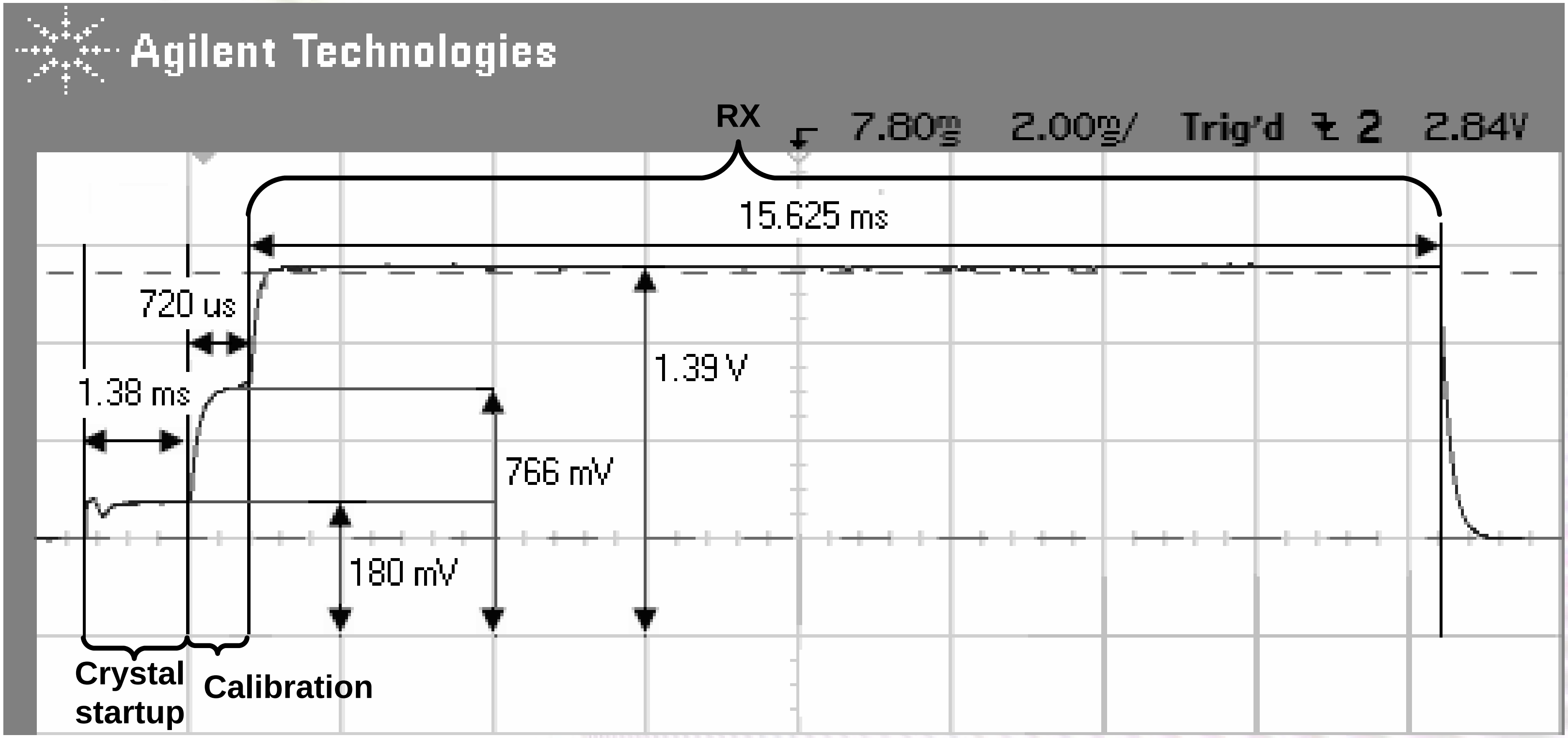
Waking up the Radio

- Waking up a radio from sleep takes it through several consecutive steps
- The current used in each step, and how long each step lasts, is important when figuring what the average current will be
- Looking at these figures is also very important when comparing different radios



Waking up the Radio

- **CC1100 – full calibration**



Methods to achieve Low Power RF

- Limit the RF on-time (TX and RX)
- Use sleep modes/power saving modes/wake-on-radio
- Do not transmit with higher power than you need
- Use accurate crystals to minimize drift between devices
- Use a good switch mode voltage regulator
- Make sure you can utilize all of the battery capacity
- Run at the lowest possible voltage
- Minimize calibration time
- Minimize frequency hopping synchronization time
- Take care when choosing packet length
- If power availability is unevenly distributed, design your protocol to take advantage of this
- Discard false packets/error packets as quickly as possible
- Use as high a over-the-air data rate as you only can and burst the data
- Choose an appropriate modulation (NRZ – not Manchester coding)

CC1100 Alternatives

- **CC1000**
  - Low current consumption.
  - Covers the whole frequency band from 300 – 1000 MHz.

	RX current 433/868	TX current 0 dBm
CC1000	7.4/9.6 mA	10.4/16.5 mA
CC1100	15/15 mA	15.5/16.9 mA

- **CC1020**
  - High performance – sensitivity, selectivity, blocking
  - Complies with narrowband requirements, e.g. ARIB STD-T67.

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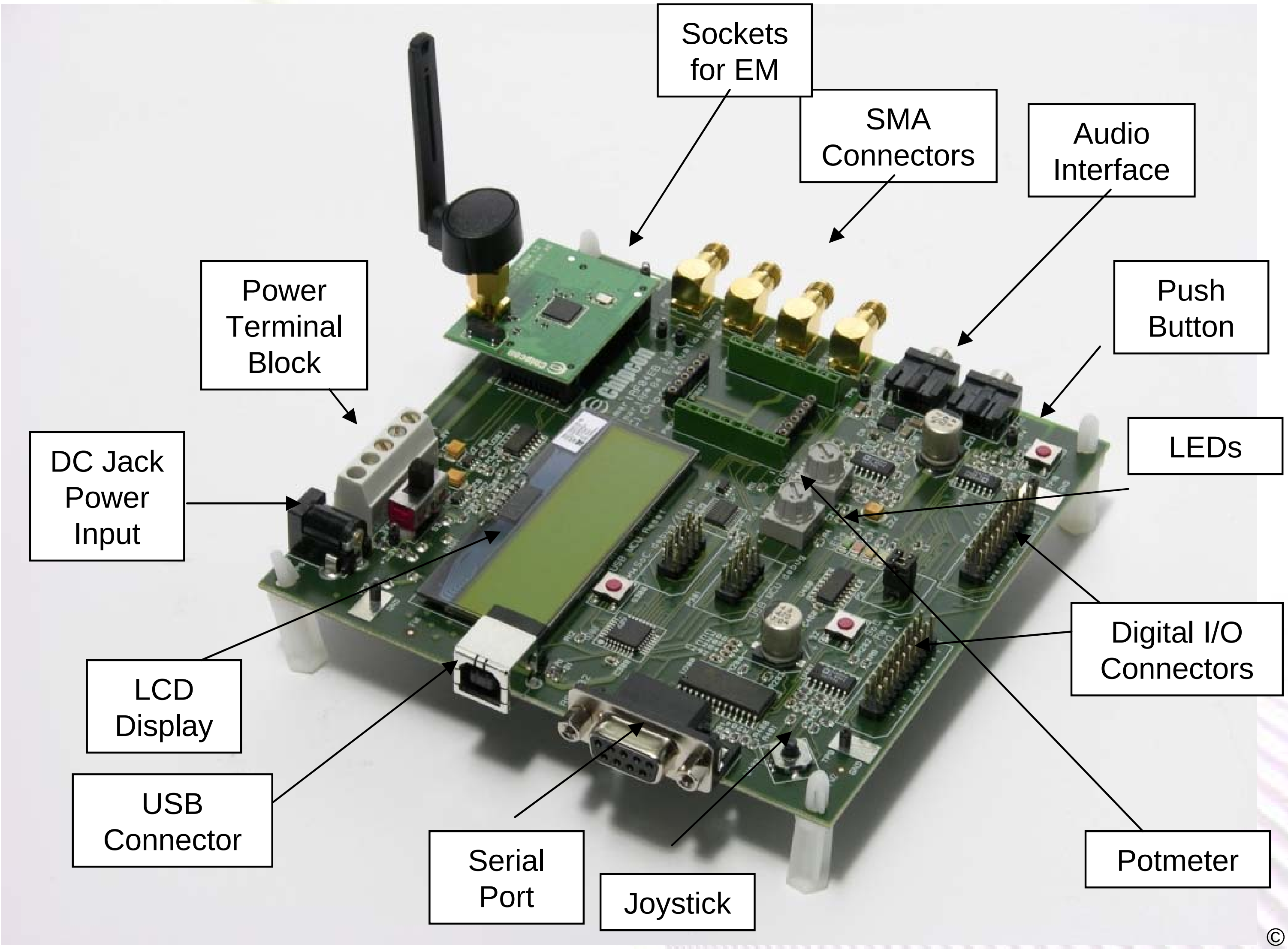
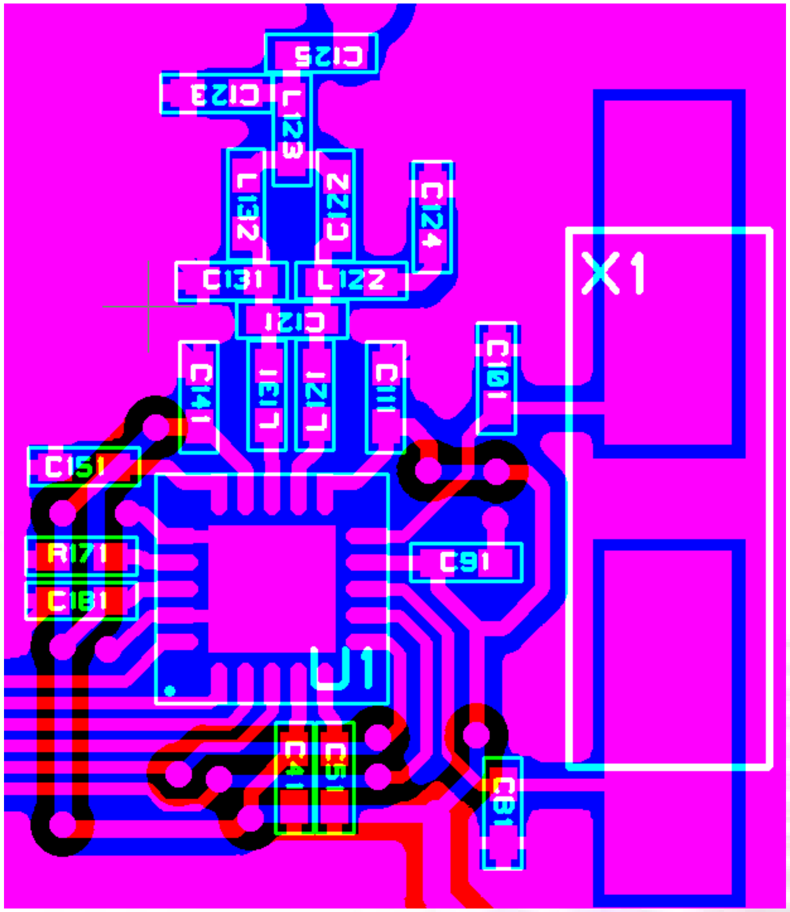
Development Tools

- **SmartRF04EB + CC1100EM**

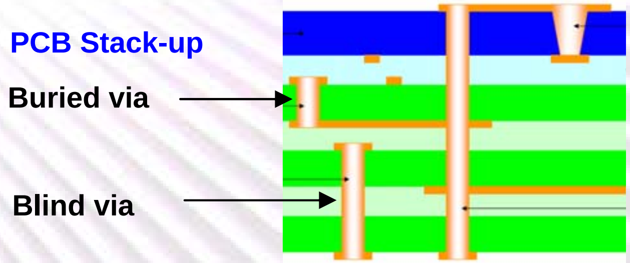


Hardware Development – Layout Considerations

- **Copy CC1100EM reference design!**
  - Use the exact same values and placement on decoupling capacitors and matching components.
  - Place vias close to decoupling capacitors.
  - Ensure 50 ohm trace from balun to antenna.
  - Remember vias on the ground pad under the chip.
  - Use the same distance between the balun on layer 1 and the ground layer beneath.
  - Implement a solid ground layer under the RF circuitry.
  - Ensure that useful test pins are available on the PCB.
  - Connect ground on layer 1 to the ground plane beneath with several vias.
  - Note: different designs for 315/433 MHz and 868/915 MHz

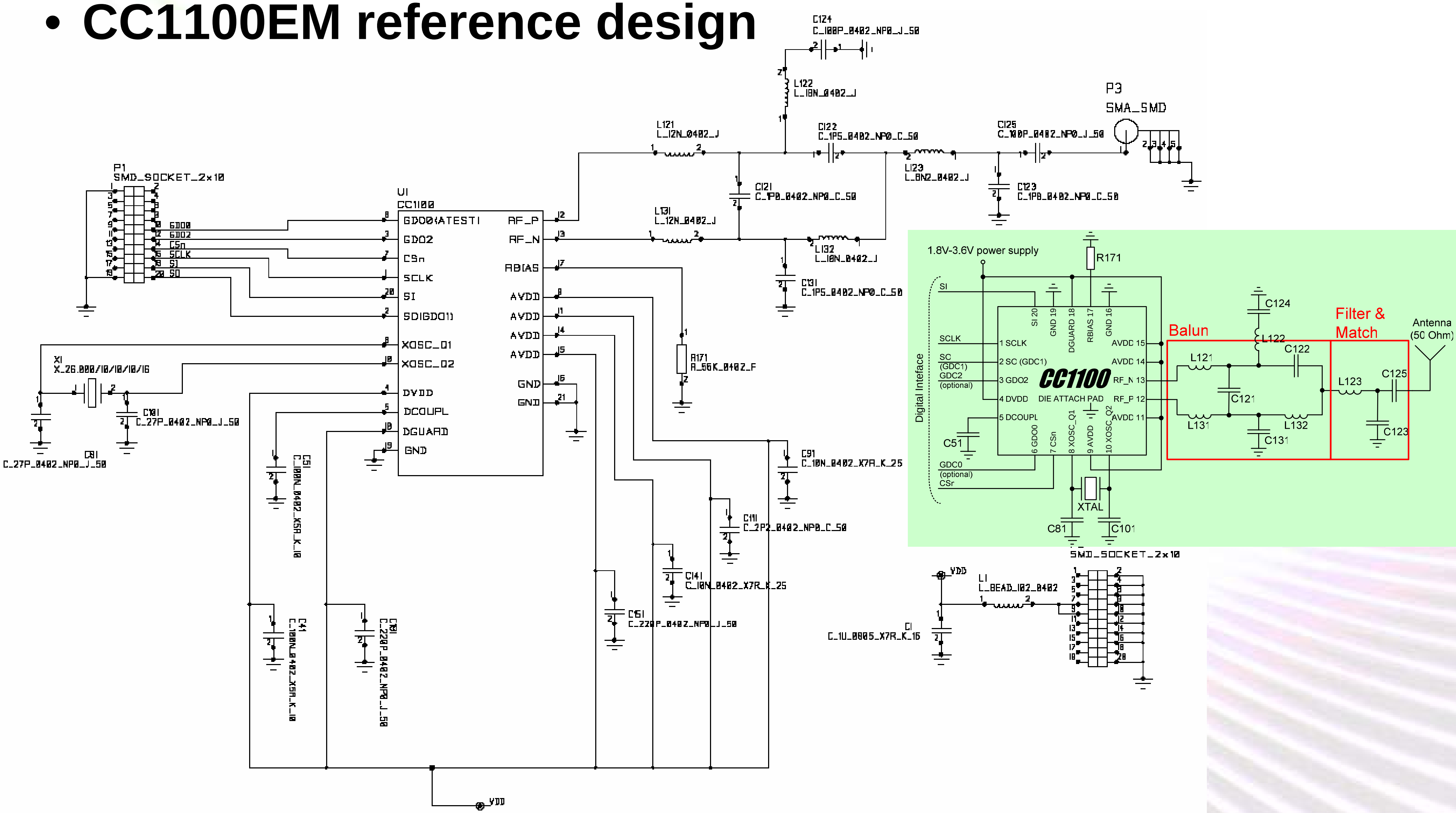


Layout: CC1100EM 868/915MHz reference design



Hardware Development

- **CC1100EM reference design**



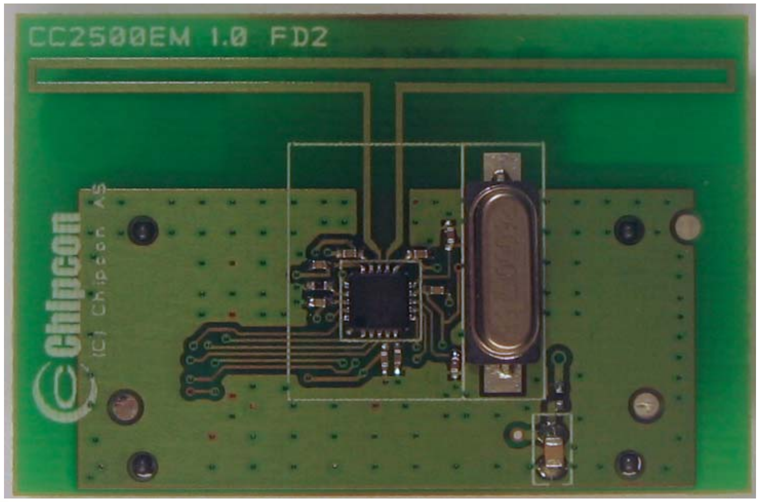
Antennas

- **Single ended antennas**
  - Usually matched to 50 ohm
  - Needs a balun if the chip has a differential output
  - Easy to measure the performance with a network analyzer
  - Possible to get good performance

- **Differential antennas**
  - Can be matched directly to the impedance of the RF pins
  - Can be used to reduce the number of external components
  - Complicated to make a good design, needs to be simulated
  - Difficult to measure the performance
  - Possible to get good performance

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

Antenna Parameters

- **Important parameters**
  - Directivity, D. Difference between maximum radiation intensity and average radiation intensity
  - Gain, G. Describes efficiency and radiation properties
  - Polarization. Describes the direction of the electric field
  - Impedance mismatch determines how much of the available power that are delivered to the antenna
  - Bandwidth is the frequency band where the antenna has sufficient performance

$$D = \frac{U_{\max}}{U_{avg}}$$

$$G = \frac{P_{rad}}{P_{in}} D$$

Antenna Suppliers

- **Antenova:** http://www.antenova.com/index.htm
- **Badland:** http://www.badland.co.uk
- **Laird Technologies:** http://www.centurion.com/home/wirelessint.asp
- **Fractus:** http://www.fractus.com
- **gigaAnt:** http://www.gigaant.com
- **RainSun:** http://www.rainsun.com
- **Woken Technologies:** http://www.woken.com.tw

RF Product Development

- **Integrating RF technology into the product – alternatives?**
  - RF-IC (transceivers/transmitters)
  - System-on-chip (SoC)
  - 3rd party modules typically contains
    - Antenna
    - RF components (filter, balun, matching)
    - Crystal
    - MCU
- **The best solution exists!**
  - But it‘s not the same for everybody!

Make or buy?

- **Make (RF-IC, SoC) if**
  - High quantities
  - Medium/long term project
  - High cost pressure
  - Sophisticated system requirements
  - Have access to required competence

- **Buy (Module) if**
  - Low quantities (typically <20k units)
  - Short time-to-market
  - Low initial costs
  - Basic system requirements
  - Lack of RF competence

Certification

- **FCC**
  - Unlicensed wireless transmitters must be tested in an FCC authorized laboratory
  - Send test report to FCC and apply for certification
  - If certification is granted FCC issues an ID number that must be placed on each transmitter (end product).
  - For receivers a Declaration of Conformity is needed
- **ETSI**
  - Self-declaration
  - To obtain the CE marking compliance with SRD regulations must be demonstrated
  - Manufacturer declares compliance with a written DoC and by placing the CE marking on the product
  - Technical documentation must be kept for 10 years

CE = Conformité Européene

DoC = Declaration of Conformity

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SmartRF® Studio

- ***Converts user inputs to register values***
  - RF frequency
  - Data rate
  - Output power
  - Deviation
  - Modulation
  - RX filter bandwidth

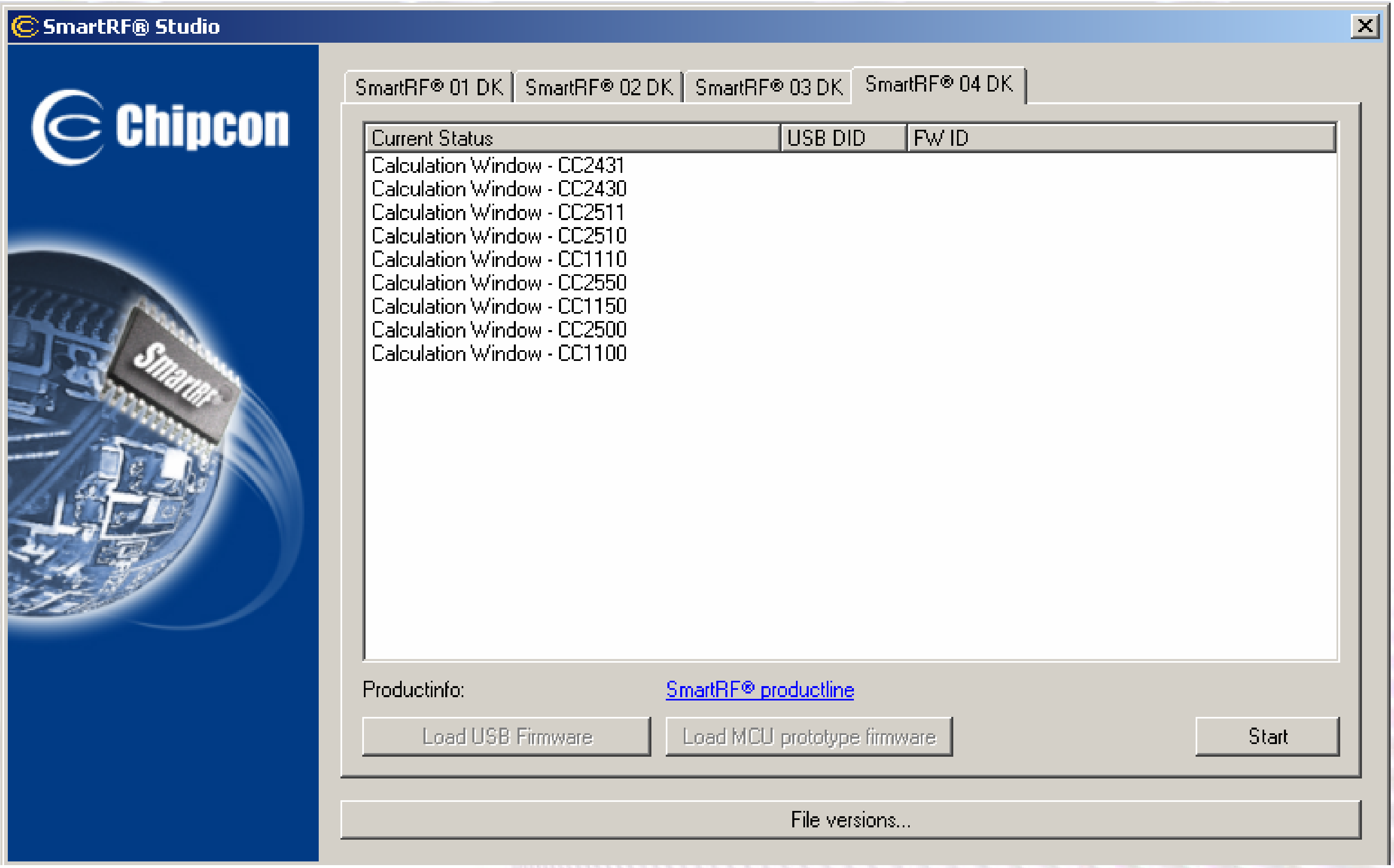
- ***Allows remote control/configuration of EMs and prototype board when connected to SmartRF04EB***

- ***Supports quick and simple performance testing***
  - Output power/Sensitivity: Simple RX/TX
  - One way packet test: Packet RX/TX
  - Two way packet test: Packet Error Rate (PER) test

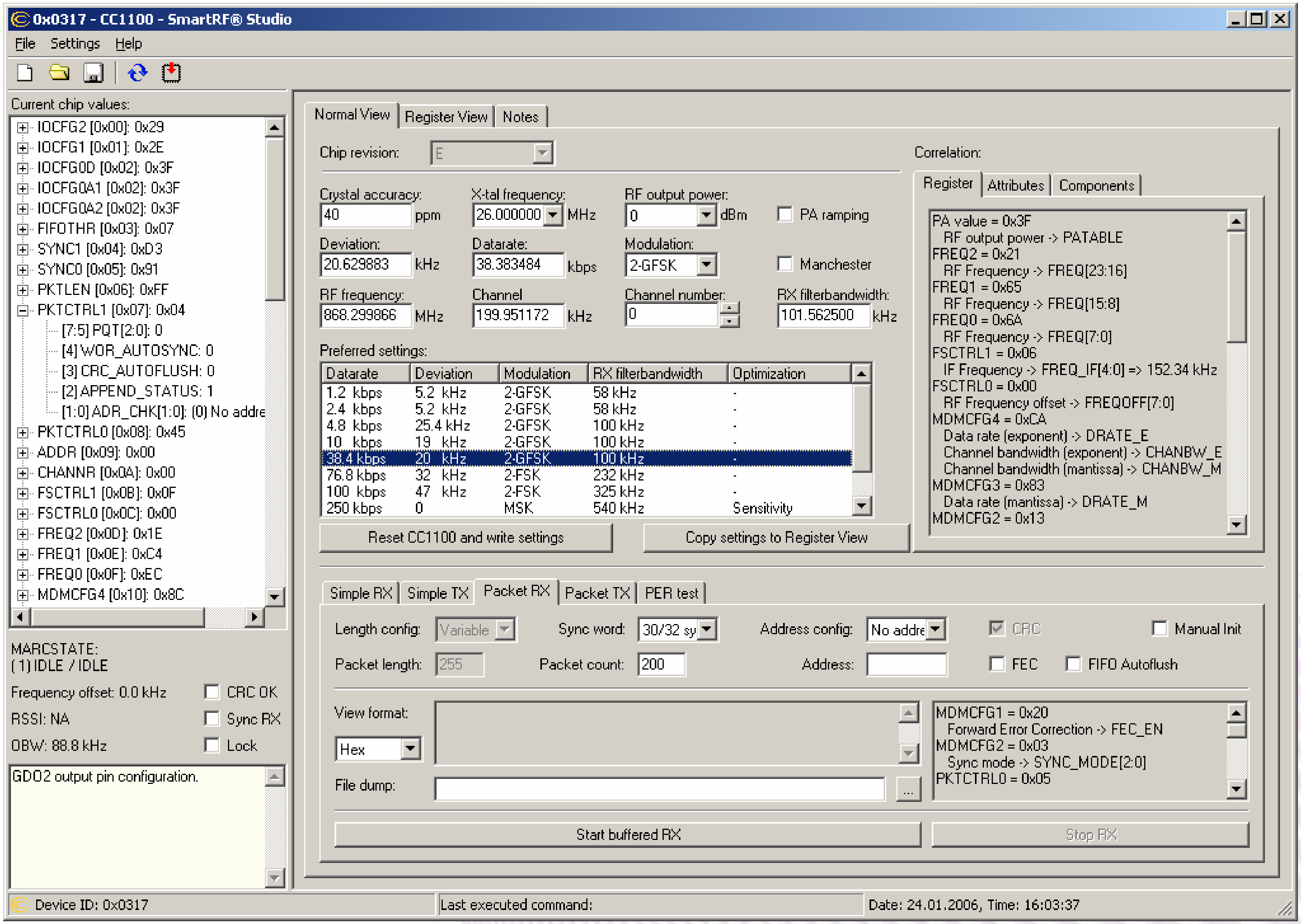
SmartRF® Studio

- ***Offers export/import of register settings and C-code structure***
- ***Supports development kit firmware upgrade via USB***
- ***Load USB firmware:***
  - *Allows uploading of example software to the MCU on SmartRF04EB*
- ***Load MCU prototype firmware:***
  - *Inactivates the MCU on SmartRF04EB to allow an external MCU full control over e.g. the CC1100*

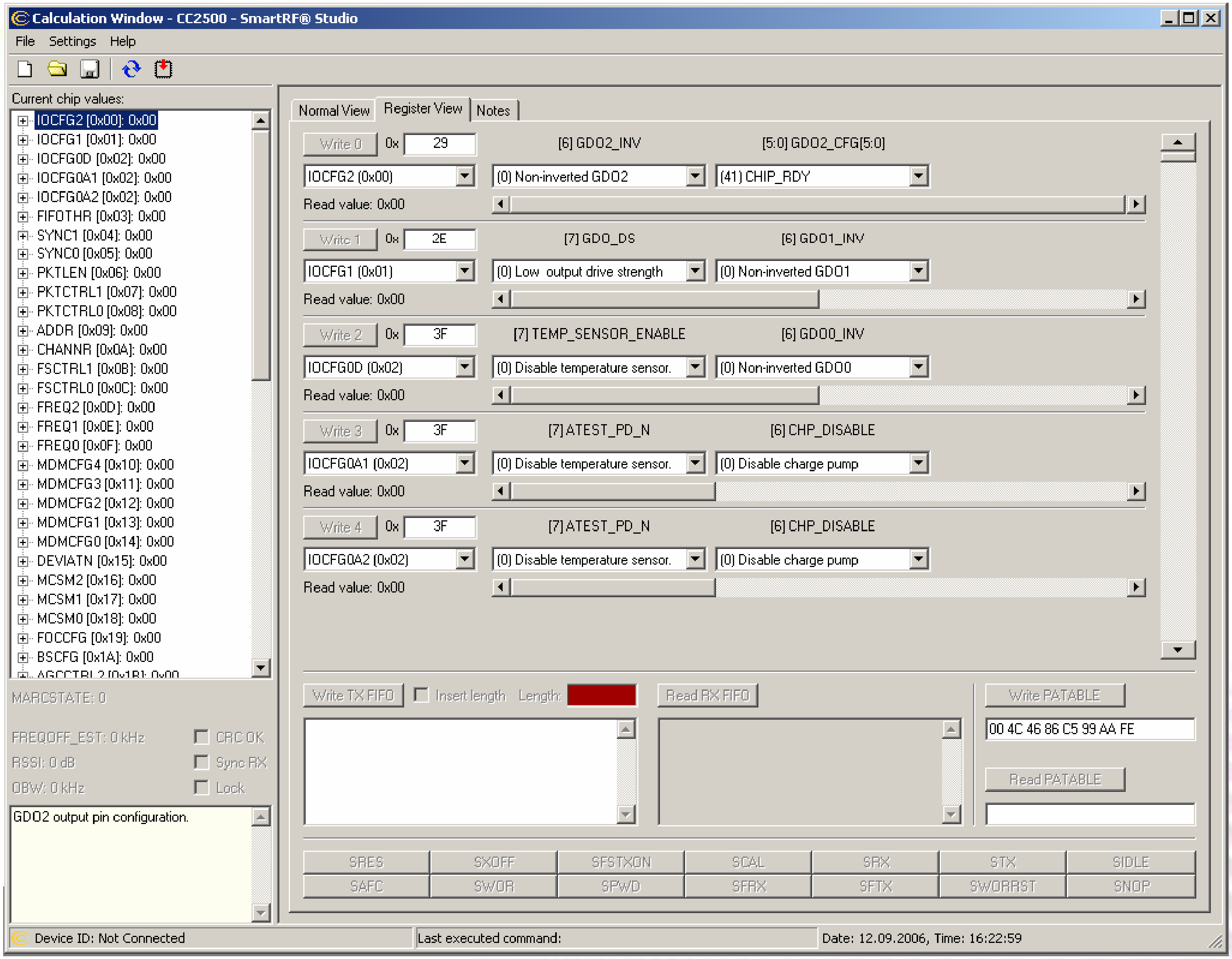
SmartRF® Studio Start Window



SmartRF® Studio Normal View



SmartRF® Studio Register View



Libraries and Examples

- **Software developed using uVision2 from Keil**
  - C51 C-compiler for the 8051 platform
  - CC2500_CC1100_Examples_Libraries.zip

- **HAL - Hardware Abstraction Layer**
  - Low level hardware interface functions (ADC/Timer/SPI)
  - Function to send and receive packets
- **CUL - Chipcon Utility Library**
  - SW sync search and CRC calculation
  - (CCxx00 Serial Mode)
- **EB - Evaluation Board**
  - Functions for accessing peripherals on the SmartRF04EB (buttons/joystick/potmeter/LED/IO-ports/RS232/LCD)

Libraries and Examples

- **Transceiver Examples:**

MCU:

- Audio

- Joystick

- Potmeter

- SPI

- Timer01

- Timer23

Radio:

- Link

- Link1

- WOR (Wake On Radio; AN38)

- WORwithAck (Wake On Radio; AN38)

- SerialLink

- Link2 (Packets larger than the FIFO size)

*- InfiniteLink (*Packets longer than 256 bytes*)*

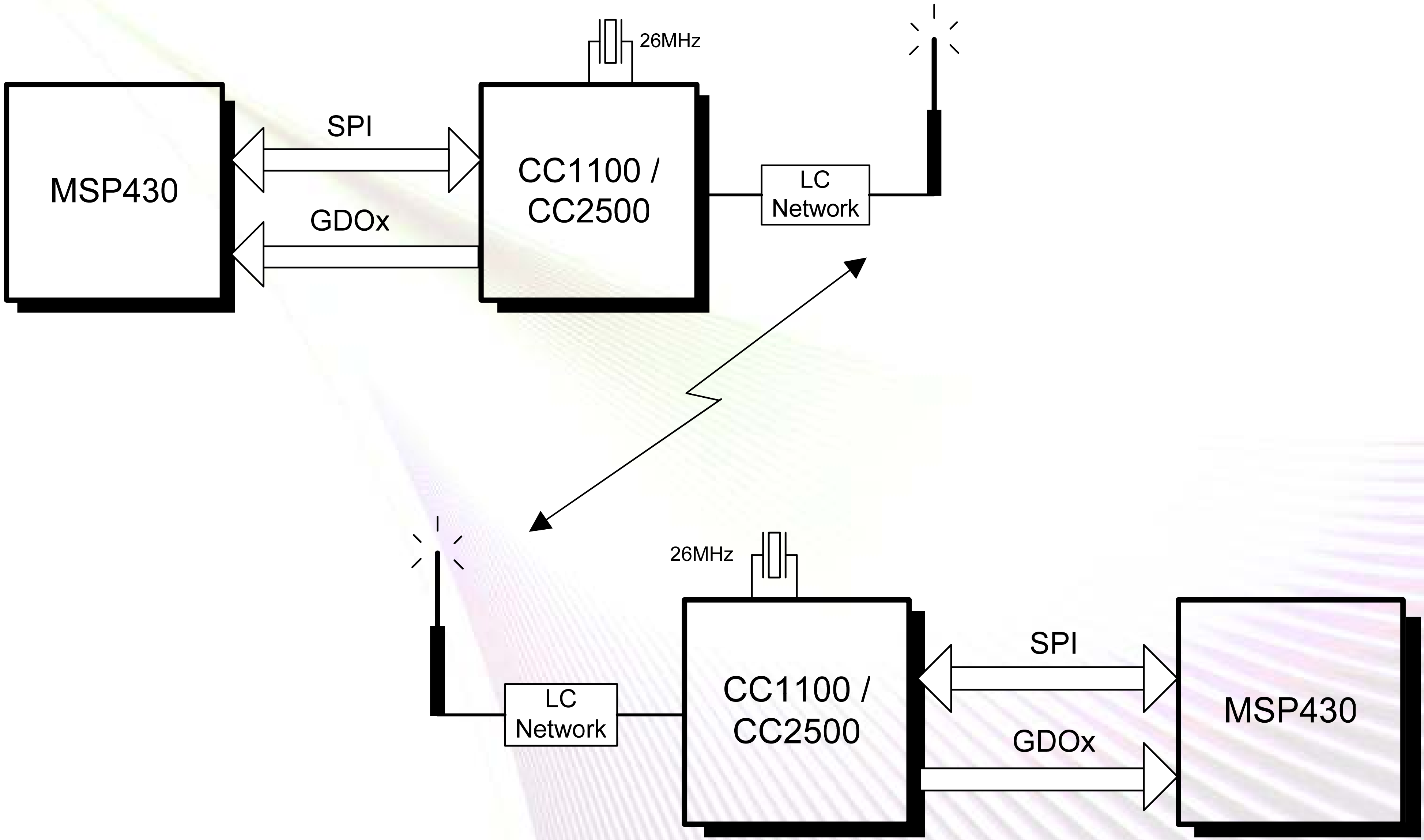
What is the TI HAL Library?

- **Register read/write functions (MSP430 to CC1100/2500)**
  - Read register
  - Write register
  - Read burst
  - Write burst
  - Status read
  - Strobe write
  - CC1100/2500 reset
- **CC1100/2500 are targeted at non-Zigbee ISM-band apps**
- **Library based on CC1100/CC2500 Examples and Libraries from Chipcon**
- **SPI functions only; no protocol functions**
- **Demo application project included**

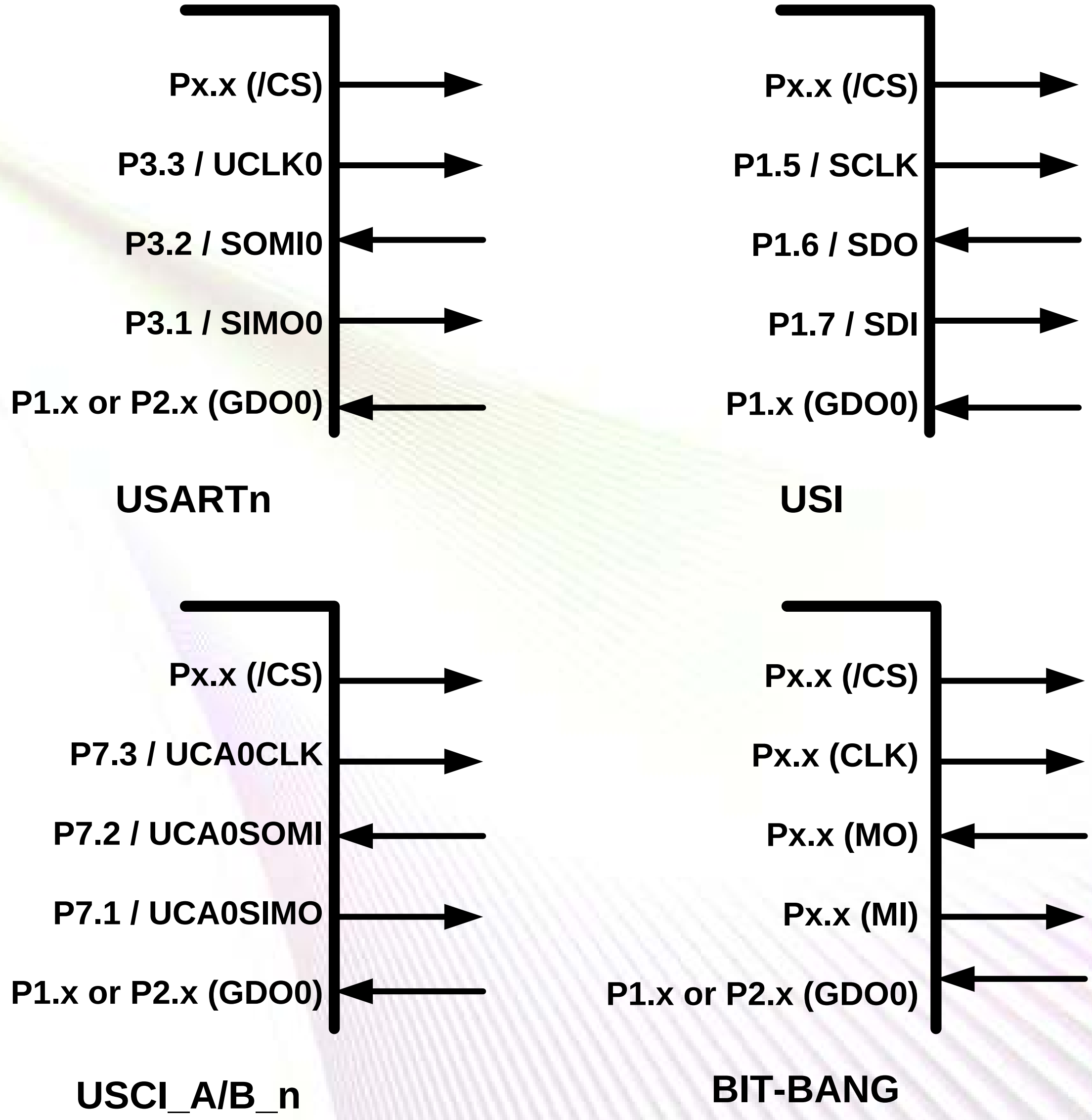
What is the TI HAL Library? (cont.)

- **Works with any SPI-capable MSP430 interface**
  - USART0
  - USART1
  - USCI_A0
  - USCI_A1
  - USCI_B0
  - USCI_B1
  - USI
  - Bit-bang I/Os
- **Hardware abstraction assists porting between MSP430 devices**
- **Not tested for other Chipcon devices**
- **Tested with MCLK between 1-8MHz and SMCLK dividers of /1 and /8**

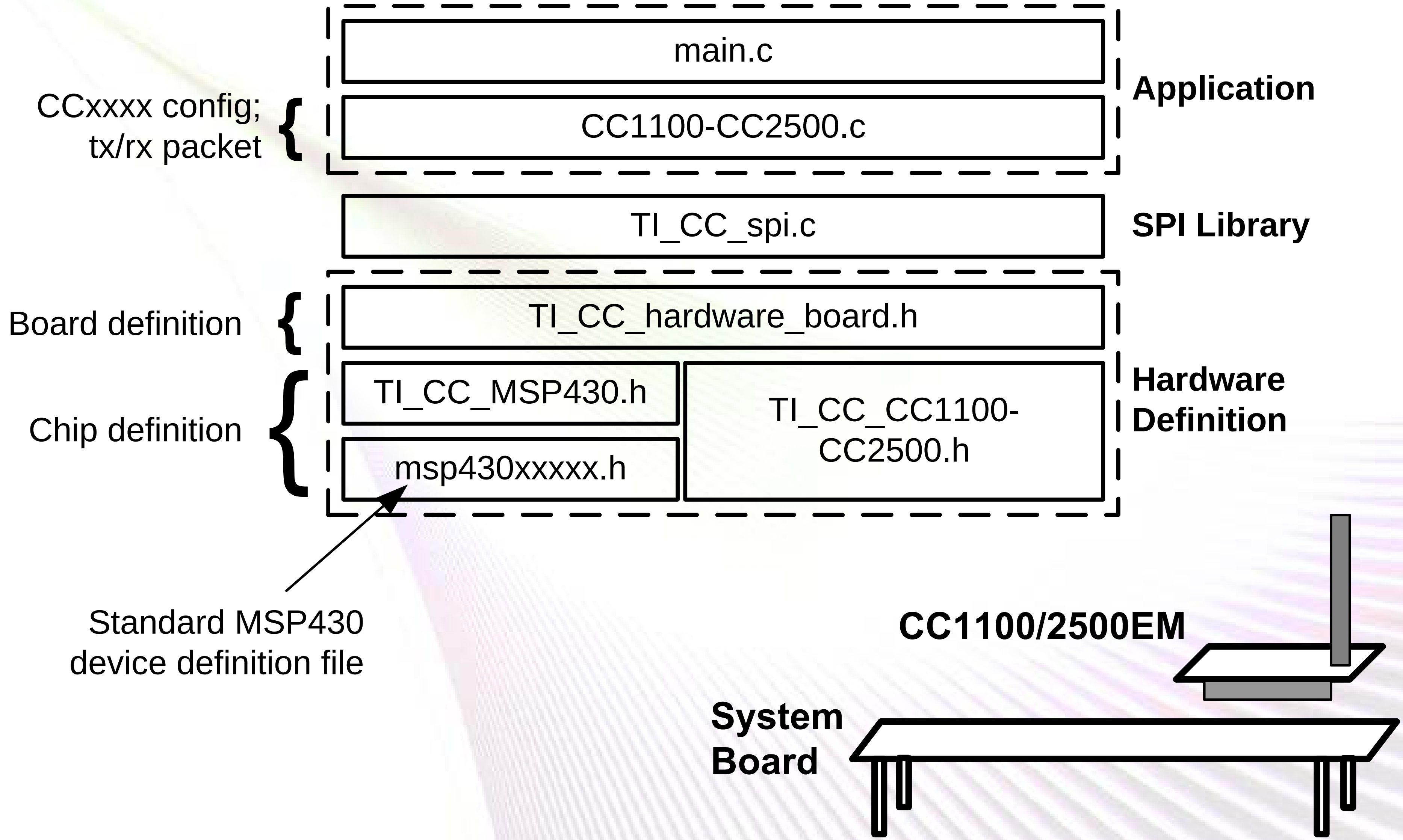
Target Hardware



MSP430 SPI Interfaces



Demo Application Stack



File Organization

TI_CC_CC1100-CC2500.h	Definitions specific to the CC1100/2500 devices
TI_CC_MSP430.h	Definitions specific to the MSP430 device
TI_CC_hardware_board.h	Definitions specific to the board (connections between MSP430 and CCxxxx)
TI_CC_spi.h	Function declarations for hal_spi.c
TI_CC_spi.c	Functions for accessing CC1100/CC2500 registers via SPI from MSP430

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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

- **We have looked at**
  - Frequency allocation and regulations
  - Suitable MSP430 and Chipcon devices for various applications
  - Techniques for achieving low power
  - PCB design considerations
  - Antennas
  - RF modules vs. own designed boards
  - Certification
  - SmartRF® Tools
  - TI HAL Library for MSP430 + CC1100/CC2500
  - Getting started
  - Support

Thank you for your attention!

Questions?

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