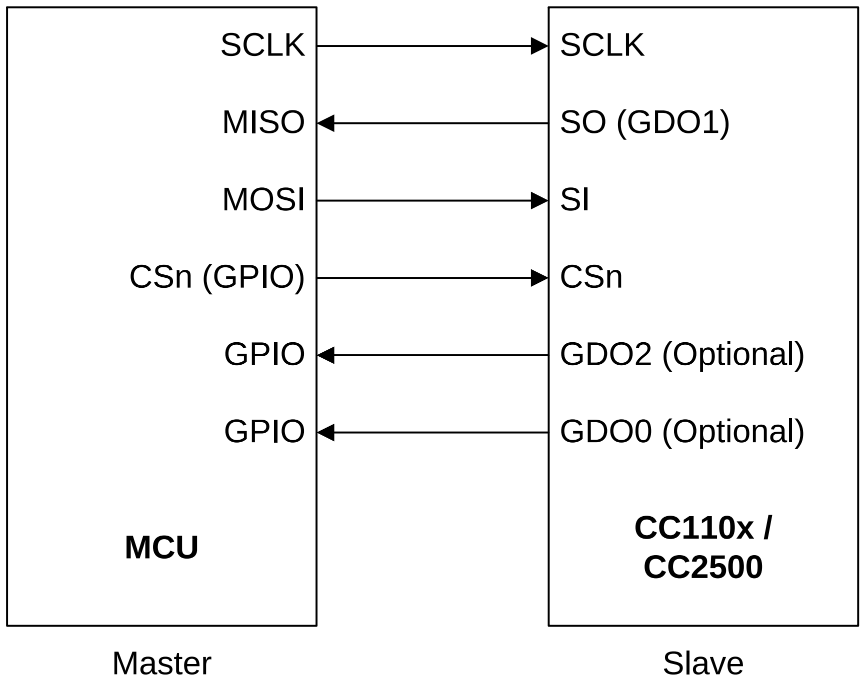
CC430 Vs CC1101

Abstract

- This presentations gives an overview of the different digital features available on CC110x and CC2500.

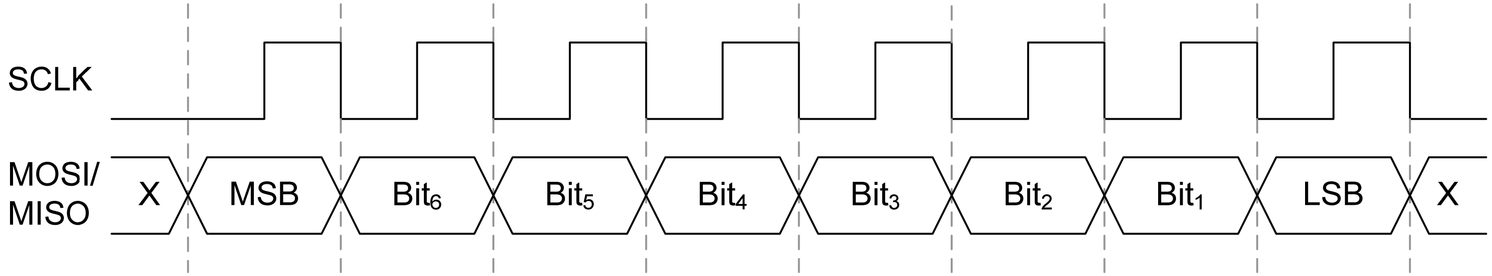
MCU

- CC110x and CC2500 is configured via a simple 4-wire SPI compatible interface



MCU Interface (2)

- All transfers are done MSB first
- Clock Phase: Data must be centered on the first positive going edge of the SCLK period
- Polarity: SCLK line should be low in idle state



SPI Access (1)

- Header Byte

$R/\overline{W}$	B	A_5	A_4	A_3	A_2	A_1	A_0

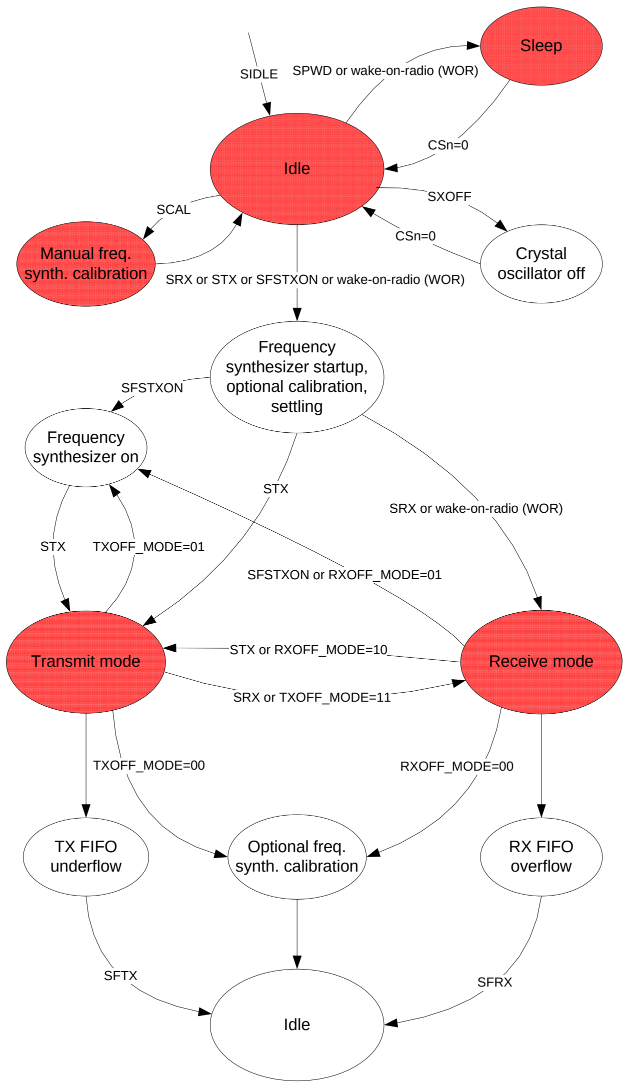
- Single Access (B = 0)
  - Only 1 byte read/written after the header byte

- Burst Access (B = 1)
  - Consecutive data bytes read/written after the header byte

SPI Access (2)

- Command Strobes (B = 0)
  - Single byte instructions which will start an internal sequence
  - Commonly used strobes: SPWD, SIDLE, SCAL, STX, SRX

- See DN503 for more details



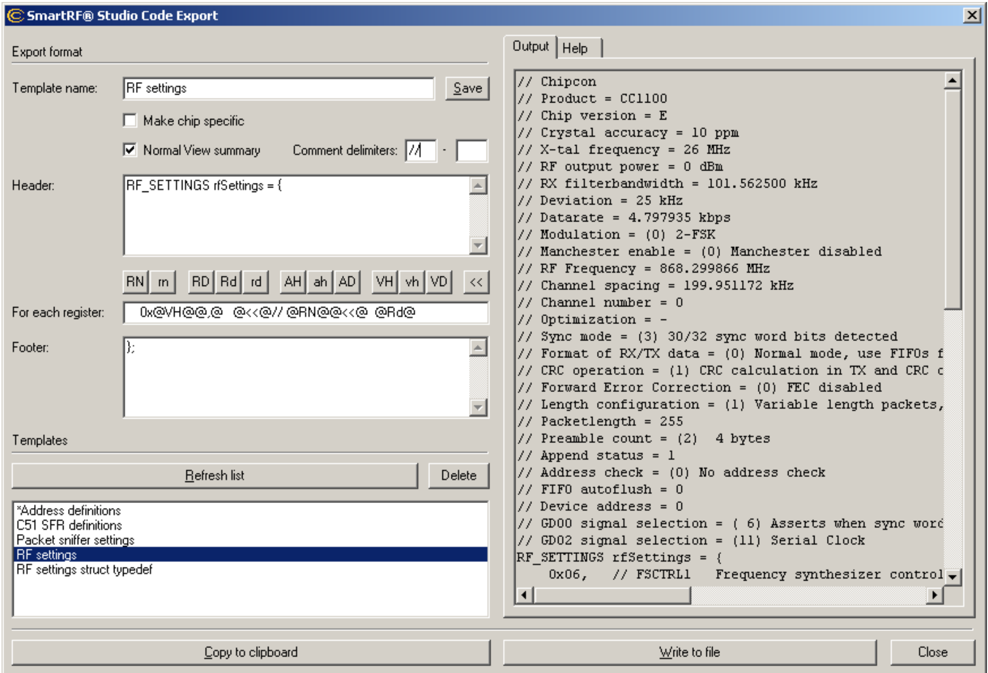
Chip Status Byte

- When the header byte, data byte, or command strobe is sent on the SPI interface, the chip status byte is returned from the radio on the SO pin
  - This gives the application fast access to info regarding the internal state of the radio

Bits	Name	Description		
7	CHIP_RDYn	Stays high until power and crystal have stabilized. Should always be low when using the SPI interface.		
6:4	STATE[2:0]	Indicates the current main state machine mode		
		Value	State	Description
		000	IDLE	Idle state (Also reported for some transitional states instead of SETTLING or CALIBRATE)
		001	RX	Receive mode
		010	TX	Transmit mode
		011	FSTXON	Frequency synthesizer is on, ready to start transmitting
		100	CALIBRATE	Frequency synthesizer calibration is running
		101	SETTLING	PLL is settling
		110	RXFIFO_OVERFLOW	RX FIFO has overflowed. Read out any useful data, then flush the FIFO with SFRX
		111	TXFIFO_UNDERFLOW	TX FIFO has underflowed. Acknowledge with SFTX
3:0	FIFO_BYTES_AVAILABLE[3:0]	The number of bytes available in the RX FIFO or free bytes in the TX FIFO		

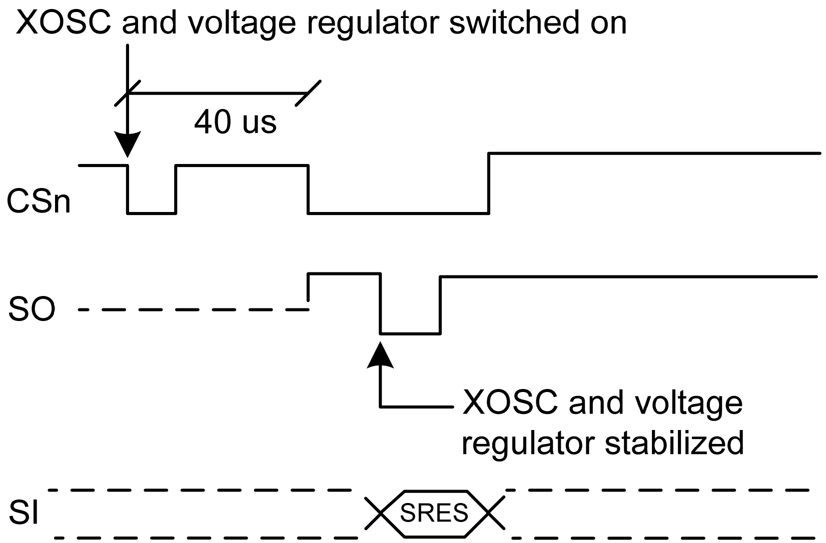
Configuration

- 3 steps have to be taken before starting to transmit / receive:
  - Init MCU
  - Reset CC1100
  - Configure CC1100
    - Use the Code Export feature from SmartRF® Studio (See Design Note DN301, Code Export from SmartRF® Studio)
    - Also see Design Note DN501, PATABLE Access



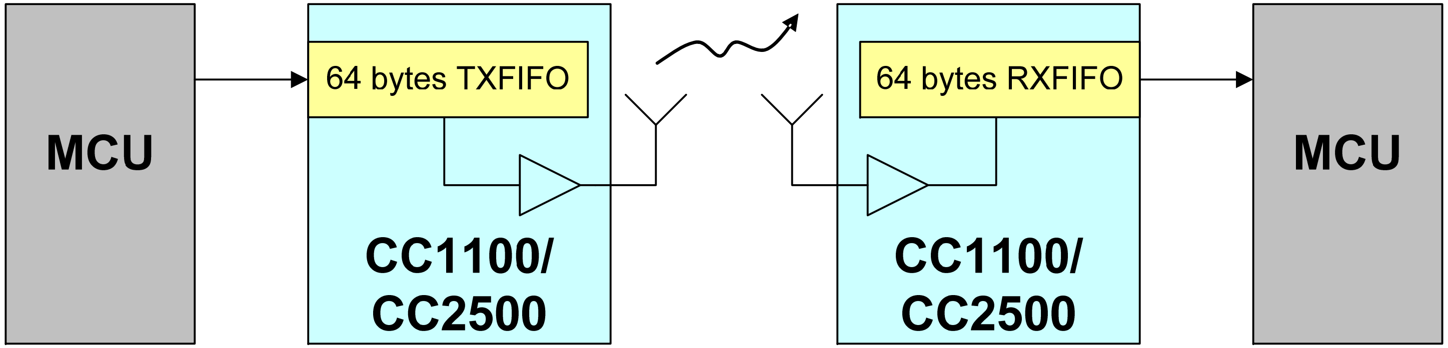
Reset

- If the power supply does not comply with the requirements specified in the data sheet, the chip should be assumed to have a unknown state until a SW reset is implemented.



- Design Note DN503, SPI Access, goes into detail on the different SPI accesses and the use of the chip status byte.

TXFIFO and RXFIFO (1)



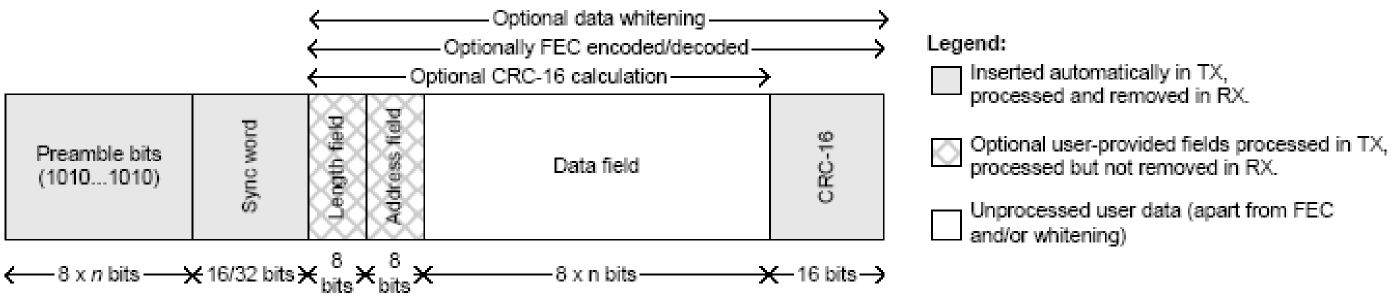
- Separate RX and TX data FIFOs (64 bytes each)
  - The MCU is available to perform other tasks while the radio active

TXFIFO and RXFIFO (2)

- Example
  - 64 bytes are written to the TXFIFO using burst mode
  - The SCLK frequency is 10 MHz
  - Time to fill up the TXFIFO = $(64 \cdot 8)/(100 \cdot 10^{-9}) + 63 \cdot 100 \cdot 10^{-9} = 57.5$ us

- Possible to write to the complete TXFIFO during the time it takes to go from IDLE to TX without calibration

Packet Format (1)



- 3 different packet length configurations
  - Fixed Packet Length Mode
    - In this mode the application always knows how many bytes it should read from the RXFIFO and how much memory is needed for data storage

Packet Format (2)

- Variable Packet Length Mode
  - In this mode, the radio can discard packets based on the length byte

- Infinite Packet Length Mode
  - This mode allows for continuous transmission of data

Packet Filtering in RX Mode

- 3 types of filtering
  - Address Filtering
    - Packet is discarded if the received address is not equal to the address in the ADDR register
  - Maximum Length Filtering
    - Packet is discarded if the received length byte is greater than the max length stored in the PKTLEN register
  - No data are written to the RXFIFO if the packet is discarded, and RX mode is automatically restarted regardless of the “Off-Mode” setting

Packet Filtering in RX Mode

- CRC Filtering
  - The CRC auto flush function will flush the *entire* RX FIFO if the CRC check fail
- After a faulty packet has been flushed from the RXFIFO, the radio enter the mode determined by the “Off-Mode” setting
- No need to read the complete packet from the RXFIFO to determine if the CRC is OK or not

“Off-Modes”

- The ”Off-modes” determine which state the radio will enter after a packet has been sent/received
  - Possible state are:
    - IDLE
    - FSTXON
    - TX
    - RX
  - Useful for:
    - Back-to-back transmission of packets
    - Transmitting ACK after receiving a packet

RSSI

- The RSSI value is an estimate of the signal level in a chosen channel
  - Adaptive Channel Selection
  - Listen-before-Talk Systems
  - Adaptive output power to reduce current consumption

- See DN505 for details on RSSI

Clear Channel Assesment (CCA)

- When strobing TX while in RX mode, the radio will enter TX state if the channel is clear
- Four different CCA modes:

Always

CS	Receiving	CCA
0	0	1
0	1	1
1	0	1
1	1	1

RSSI below threshold

CS	Receiving	CCA
0	0	1
0	1	1
1	0	0
1	1	0

Unless currently receiving a packet

CS	Receiving	CCA
0	0	1
0	1	0
1	0	1
1	1	0

RSSI below threshold unless currently receiving a packet

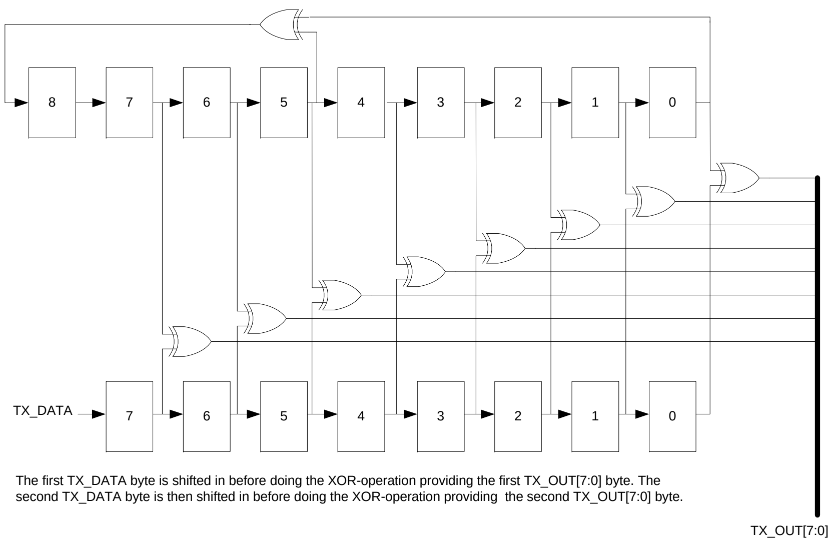
CS	Receiving	CCA
0	0	1
0	1	0
1	0	0
1	1	0

Received Signal Qualifiers

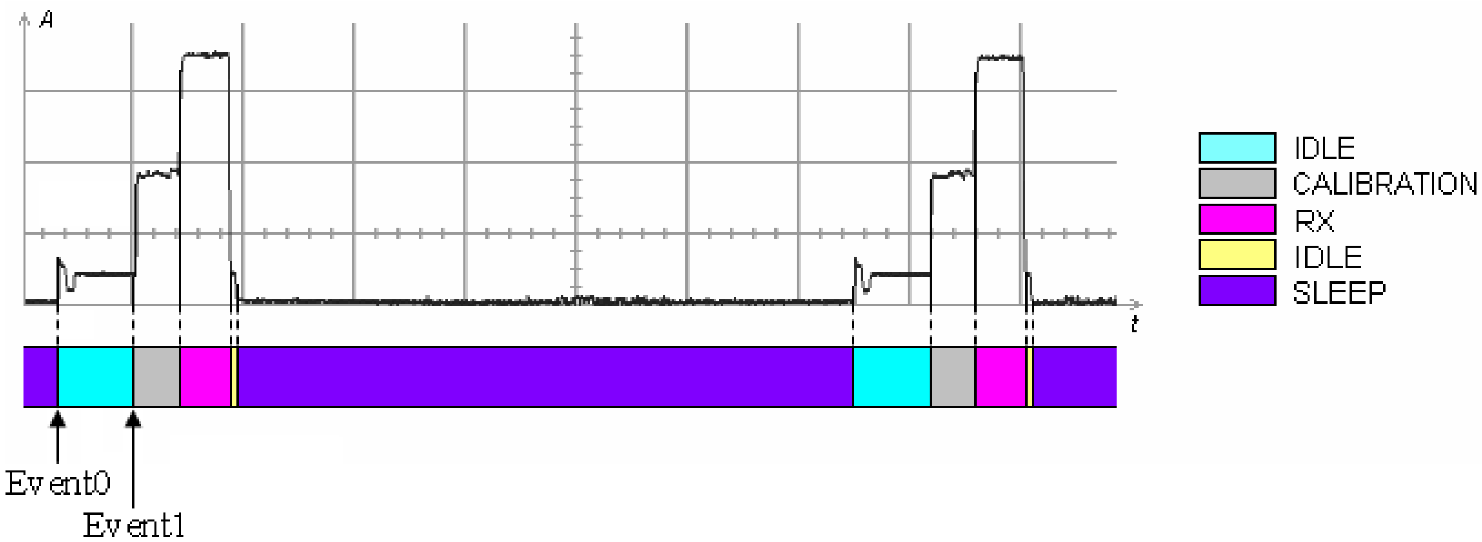
- When RX is activated the transceiver will start looking for a valid sync word
  - Sync Word Qualifier
    - A valid sync word must be detected before data is put in the RXFIFO
  - Preamble Quality Threshold (PQT)
    - The receiver will not start to look for a valid sync word before the quality of the preamble is above a programmable threshold
- Reduce the likelihood of receiving false packets will reduce the current consumption

Whitening

- Optional Data Whitening/De-whitening
  - Gives smoothest power distribution over the OBW
  - Gives regulation loops in the receiver uniform operation conditions
  - Might be used for ”Encryption/decryption”



Wake On Radio (WOR)



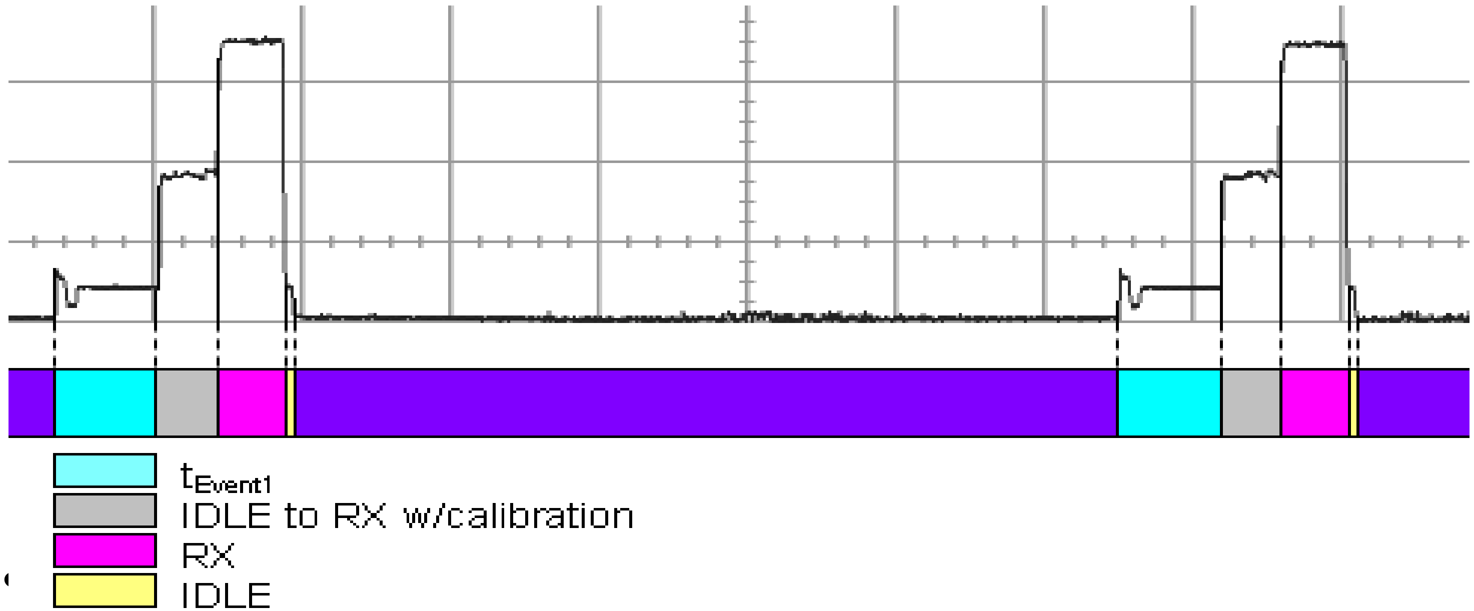
- Event 0: Digital regulator turned on and XOSC started
- Event 1: RX strobe issued
- See AN047 for more details

Wake On Radio (WOR)

- The MCU does only have to be notified when the radio has received a valid sync word
- Wake-on-radio function allows very low average power consumption in a polling receiver

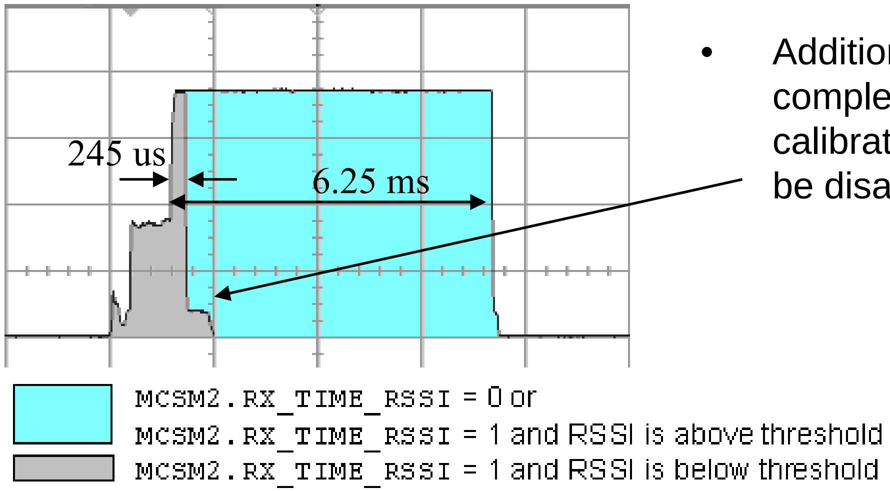
Wake-On Radio

- Wake-on-radio function allows very low average power consumption in a polling receiver (a few tens of μA)



  – Go to IDLE, RX (new sync search), TX or FSTXON

WOR Case Study (1)



- Additional time in IDLE to complete RC oscillator calibration. RC calibration can be disabled

- Assume 50 ms polling interval
- T_event1 is 346 us
- RX timeout programmed to 6.25 ms
- Current:
  - SLEEP: 0.9 uA - IDLE: 1.6 mA
  - SYNTH: 8.2 mA - RX: 16 mA

WOR Case Study (2)

1) RX timeout only (independent of RF signal)

or

2) Check for carrier sense and signal above threshold

- Average current with PLL calibration:
  - 0.346 ms·1.6 mA + 0.809 ms·8.2 mA + 6.25 ms·16 mA + 42.595 ms·0.0009 mA / 50 ms = <u>2.14 mA</u>
- Average current without PLL calibration:
  - 0.346 ms·1.6 mA + 0.09 ms·8.2 mA + 6.25 ms·16 mA + 42.595 ms·0.0009 mA / 50 ms = <u>2.02 mA</u>

WOR Case Study (3)

Check for carrier sense and signal below threshold

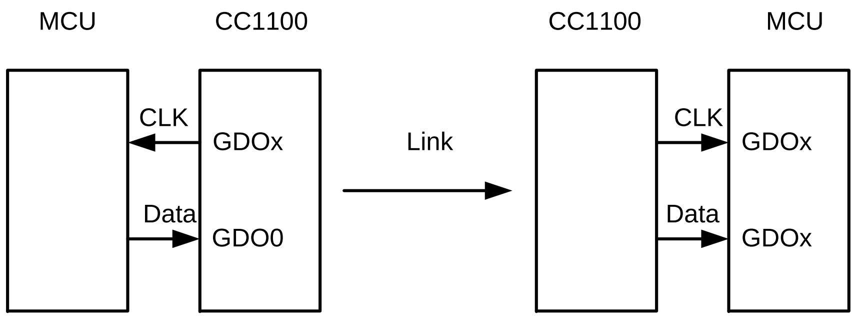
- Average current with PLL calibration:
  - 0.346 ms·1.6 mA + 0.809 ms·8.2 mA + 0.245 ms·16 mA + 0.580 ms·1.6 mA + 48.02 ms·0.0009 mA / 50 ms = 0.24 mA
- Average current without PLL calibration:
  - 0.346 ms·1.6 mA + 0.09 ms·8.2 mA + 0.245 ms·16 mA + 1.299 ms·1.6 mA + 48.739 ms·0.0009 mA / 50 ms = 0.14 mA
- Average current without PLL and RC calibration:
  - 0.346 ms·1.6 mA + 0.09 ms·8.2 mA + 0.245 ms·16 mA + 49.319 ms·0.0009 mA / 50 ms = 0.11 mA

PLL and VCO Calibration

- Calibration is needed to operate at the correct RF frequency
- Full calibration
  - Not a good solution for FHSS systems
- Relaxed calibration
- Calibration replaced by a look-up table
  - Used to minimize blanking interval in FHSS systems

Synchronous Serial Operation

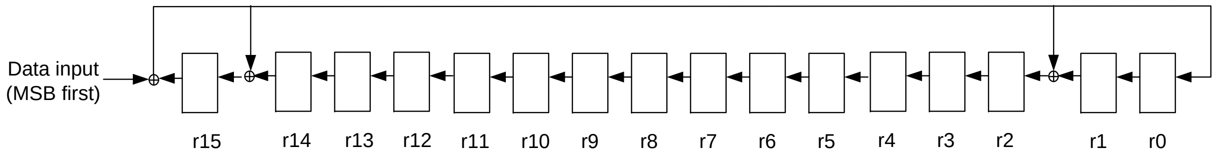
- Data is transferred on a two-wire serial interface
- The data output pin can be any of the GDOx pins
- GDO0 will automatically be configured as an input when strobing TX



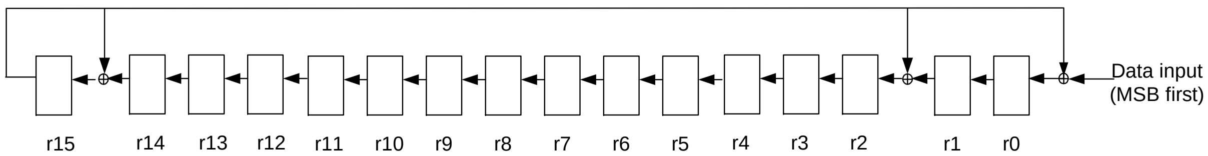
- Preamble and sync word insertion/detection can be used in this mode (CC1100 does not provide the clock to the MCU before sync word is sent / received).
- The SerialLink example shows how serial mode can be implemented when preamble and sync word insertion/detection is disabled

CRC

- Two CRC implementations:
  - Normal mode CRC (`PKTCTRL0.CC2400_EN` = 0)



  - CC2400 CRC (`PKTCTRL0.CC2400_EN` = 1)



  - CRC filtering (`PKTCTRL1.CRC_AUTOFLUSH` = 1) or data whitening (`PKTCTRL0.WHITE_DATA` = 1) cannot be used when `PKTCTRL0.CC2400_EN` = 1

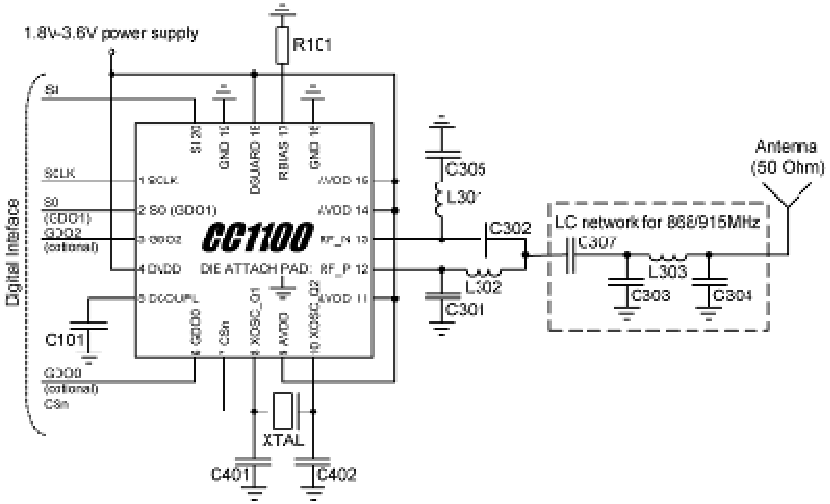
- The SW library has support for calculating the normal mode CRC manually (culCalcCRC, C:\Keil\C51\LIB\Chipcon\srf04\Cul\CCxx00)

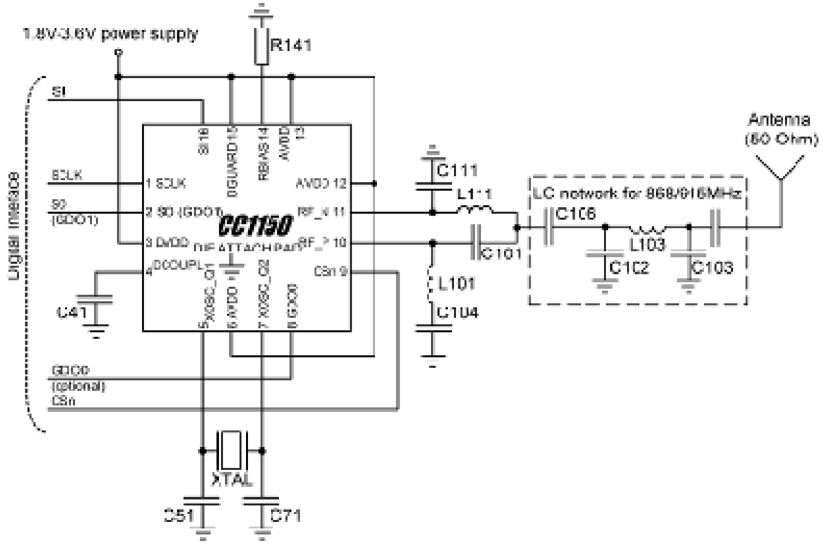
Design Notes for CC11xx Digital features

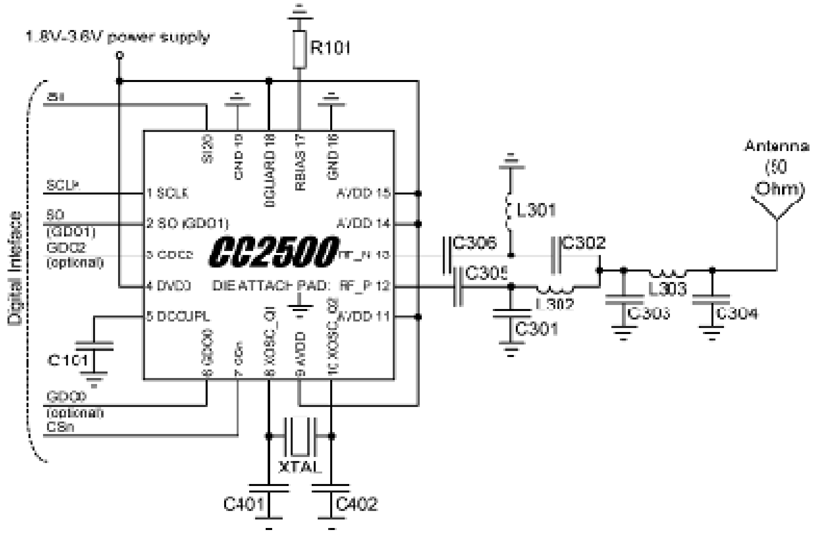
- DN500 – PacketTransmission Basics
- DN501 – PATABLE Access
- DN502 – CRC Implementation
- DN503 – SPI Access
- DN504 – FEC Implementation
- DN505 – RSSI interpretation and timing
- DN506 – GDO Pin Usage
- DN110 – Main Radio control state transition time
- DN111 – Current consumption for a Polling receiver
- DN010 – Close-in Reception with CC1101
- DN009 – Upgrading from Cc1100 to CC1101
- DN400 – Interfacing CC1100 – Cc2500 with MSP430
- AN047 – CC110x/CC2500 Wake On Radio

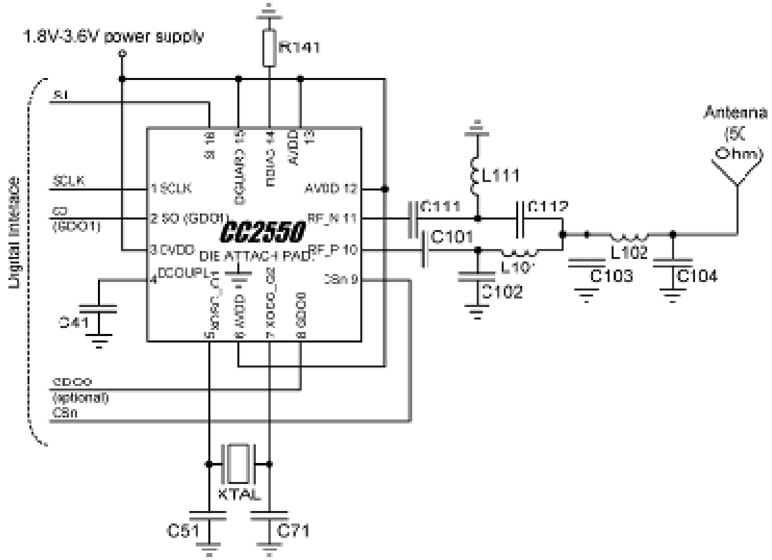
Hardware and Range extension for CC11xx

CC110x Application Circuits

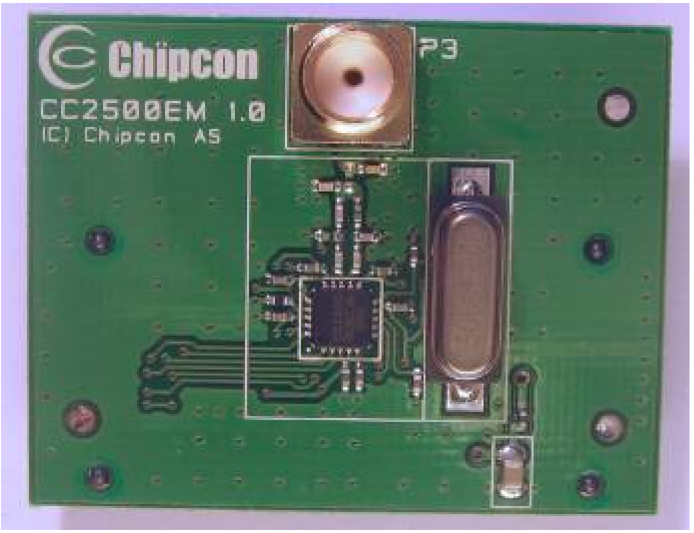








CC110x Reference Designs

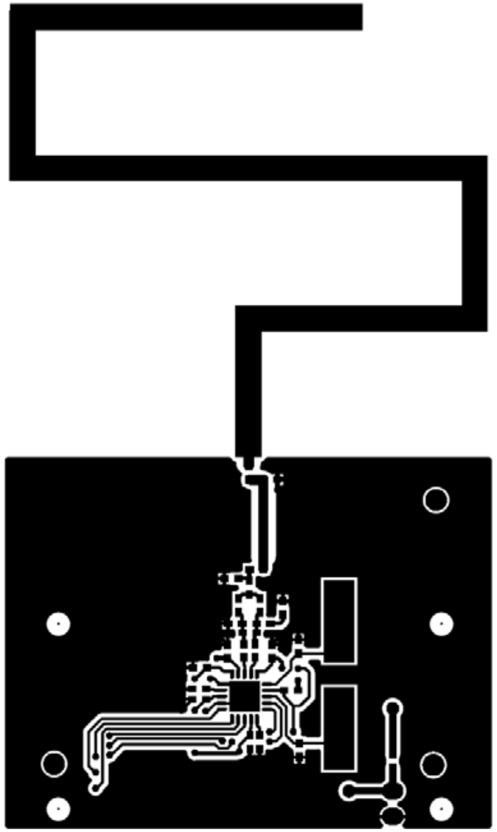


CC2500EM

CC1100EM

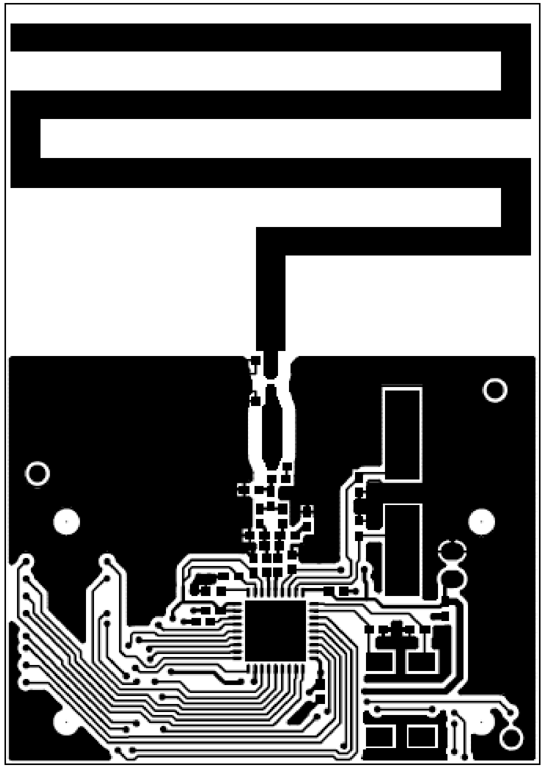
- **Hardware**
  - CC1100EM, CC1150EM, CC2500EM and CC2550EM reference designs
  - 2 CCxx00EM modules and 1 CCxx50EM module shipped with the relevant kit
  - Gerber files available from our website
  - Application designs CC2500: RadioDesk and RadioSonic

PCB antenna reference 1 with CC110x

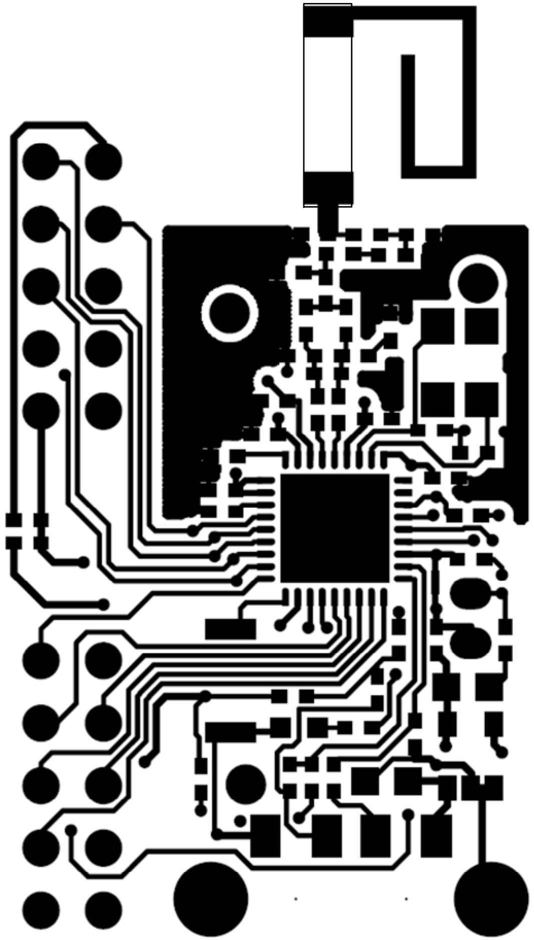


868/915 Bent Monopole

PCB antenna reference 2 with CC110x

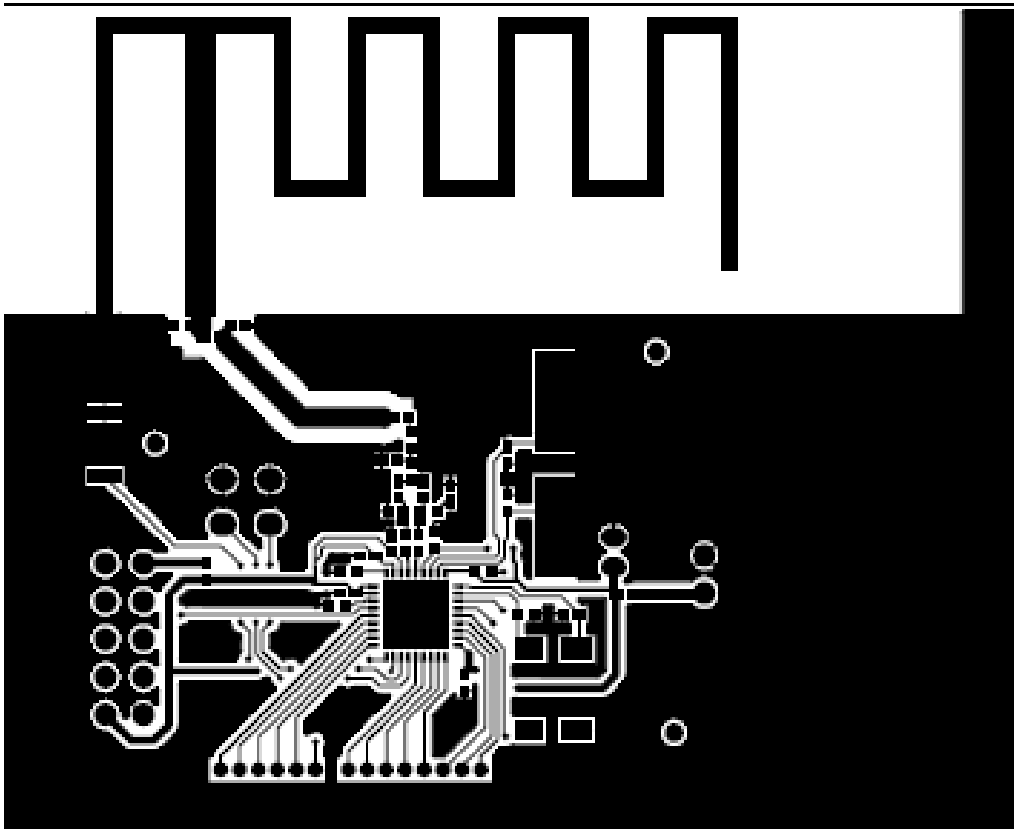


PCB antenna reference 1 with CC11xx



868/915 Chip Antenna from Johanson Technology

PCB antenna reference 2 with CC11xx



TI Antenna Reference Design 868/915 MHz

Reference design	Products	Size in mm	Properties	Documentation
Meandering Monopole antenna	All 868/915/950 MHz products	8.5 x 7.8	Small size Omnidirectional Easy to tune	DN016
Monopole antenna	All 868/915/950 MHz products	39.0 x 37.0	Medium size Omnidirectional Easy to tune	DN008
Monopole antenna	All 868/915/950 MHz products	39.0 x 24.0	Medium size Omnidirectional Easy to tune	DN024
Inverted F antenna	All 868/915/950 MHz products	20.0 x 43.0	Small size inverted F	DN023

Main Topics

- Range extension
  - Matching
  - LNA
  - PA
  - Antenna

- Practical range estimates
  - Open field environment
  - Indoor environments

Transmission budget

• ***Friis equation***

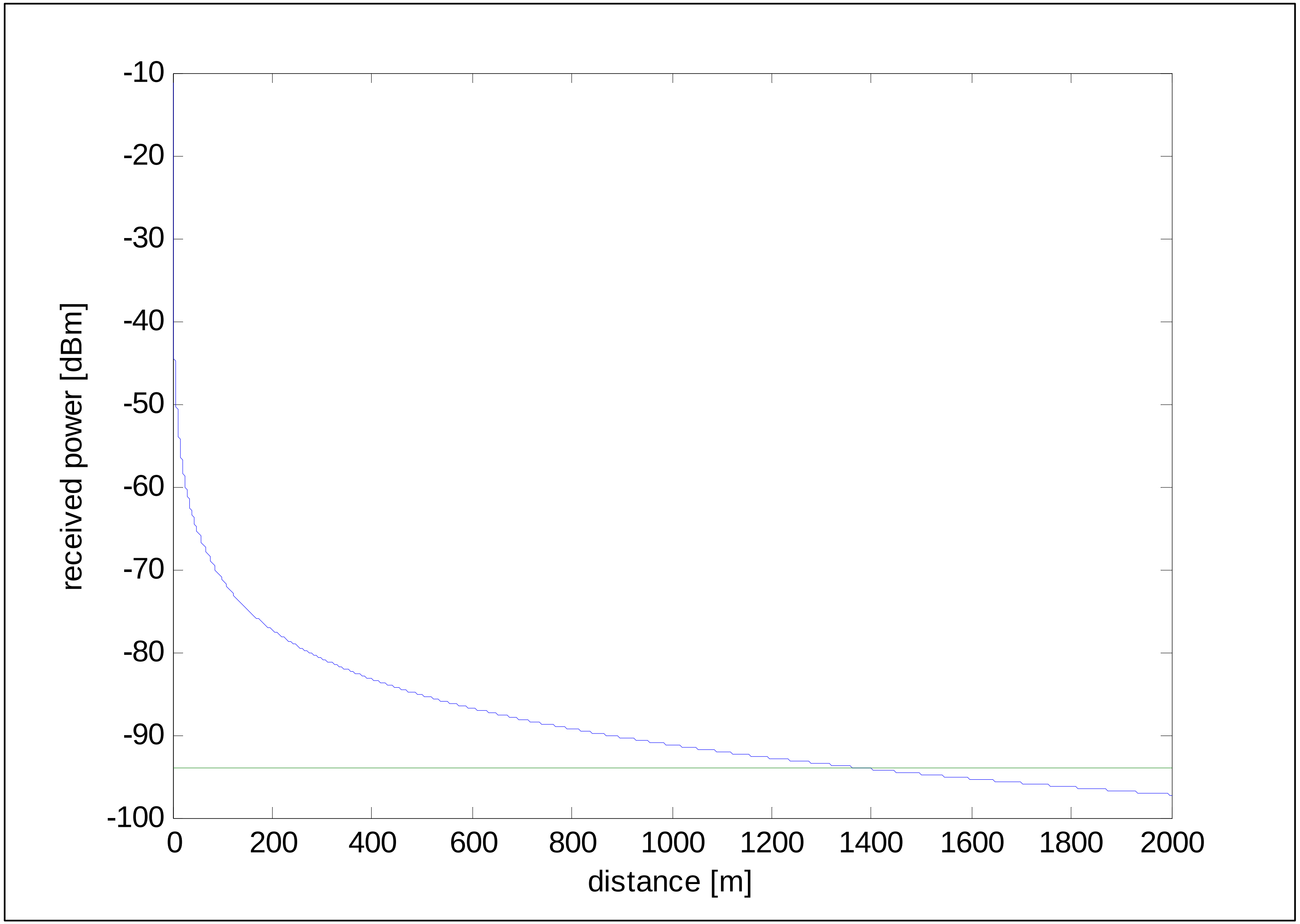
$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^2 d^n} \qquad n = 2$$

P_R: Power available from receiving antenna.
P_T: Power supplied to the transmitting antenna.
G_R: Gain in receiving antenna
G_T: Gain in transmitting antenna
λ : Wavelength λ =c/f, c=speed of light, f=frequency.
d: Distance [m]
C: Speed of light in complete vacuum 2.99792458*10^8 [m/s]

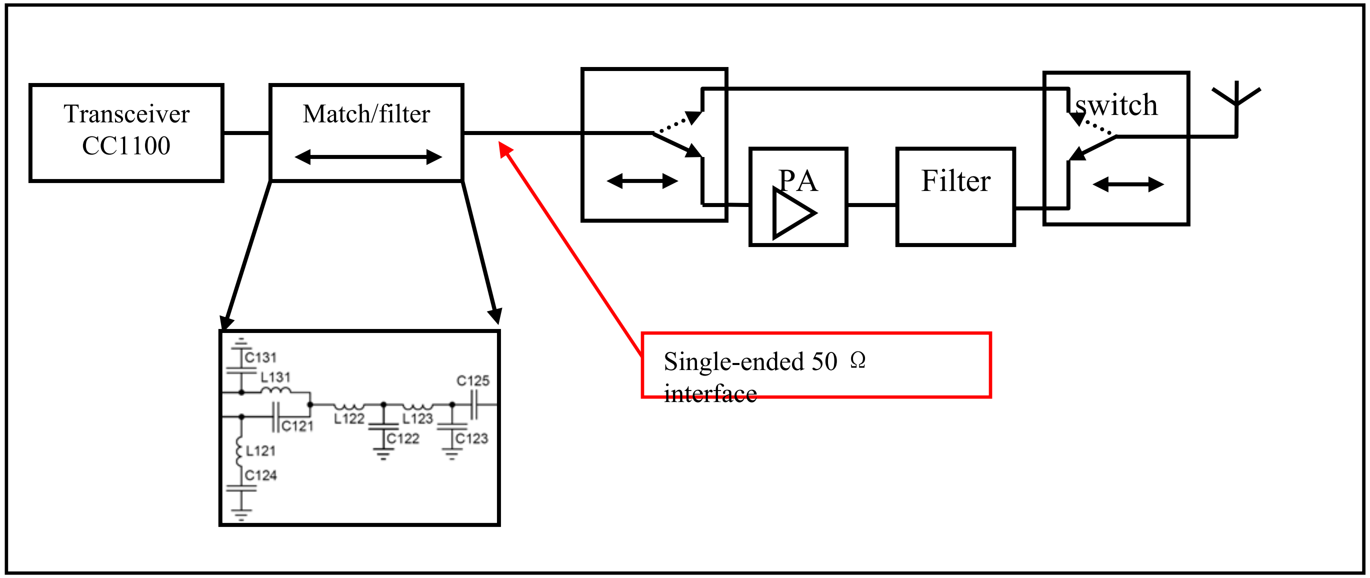
• ***Sensitivity***

The minimum signal power required by receiver to successfully demodulate the received information with less than 1% packet error rate (PER). Normally specified with only thermal noise present.

Transmission budget

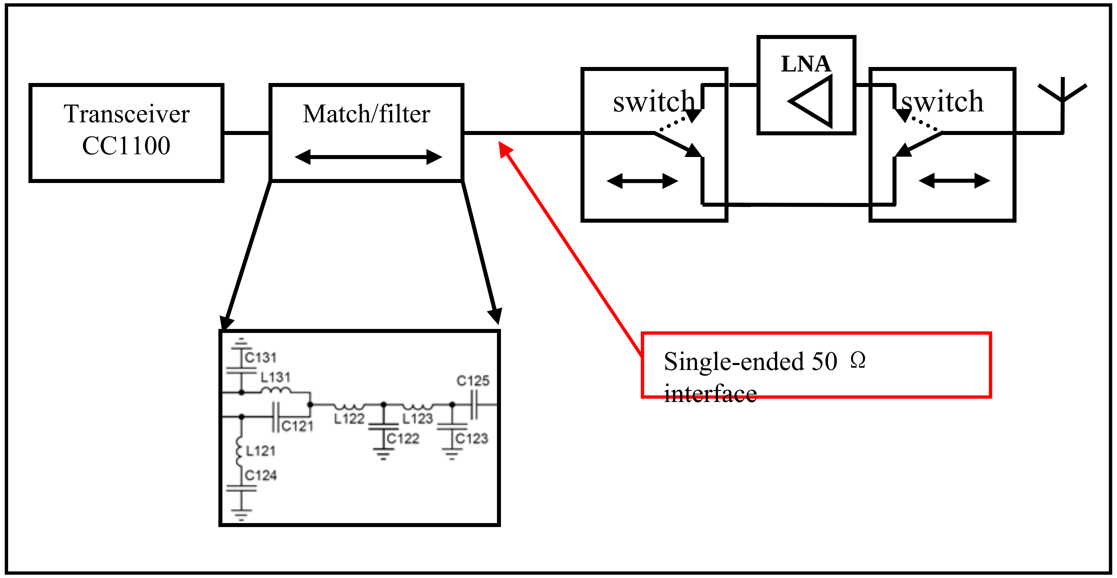


Range extension PA



- 50 Ω reference impedance
- extended range
- The added complexity

Range extension LNA



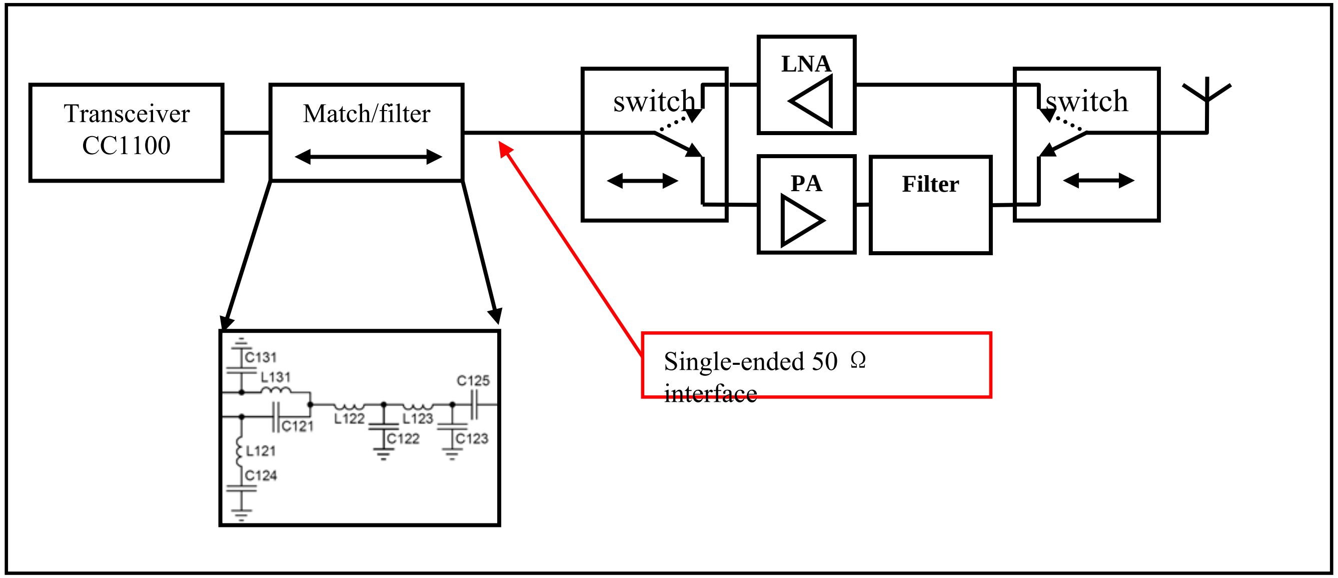
$$F_{Total} = F_{LNA} + \frac{F_{CC11XX}}{G_{LNA}}$$

Example

CC11xx approximate		NF =11dB
External	LNA GAIN	G=16dB
	LNA	NF=2.7dB

→ Total NF=3.3dB
→ Sensitivity improvement (11-3.3)dB=7.67dB
→ this more than doubles original range.

Range extension PA & LNA

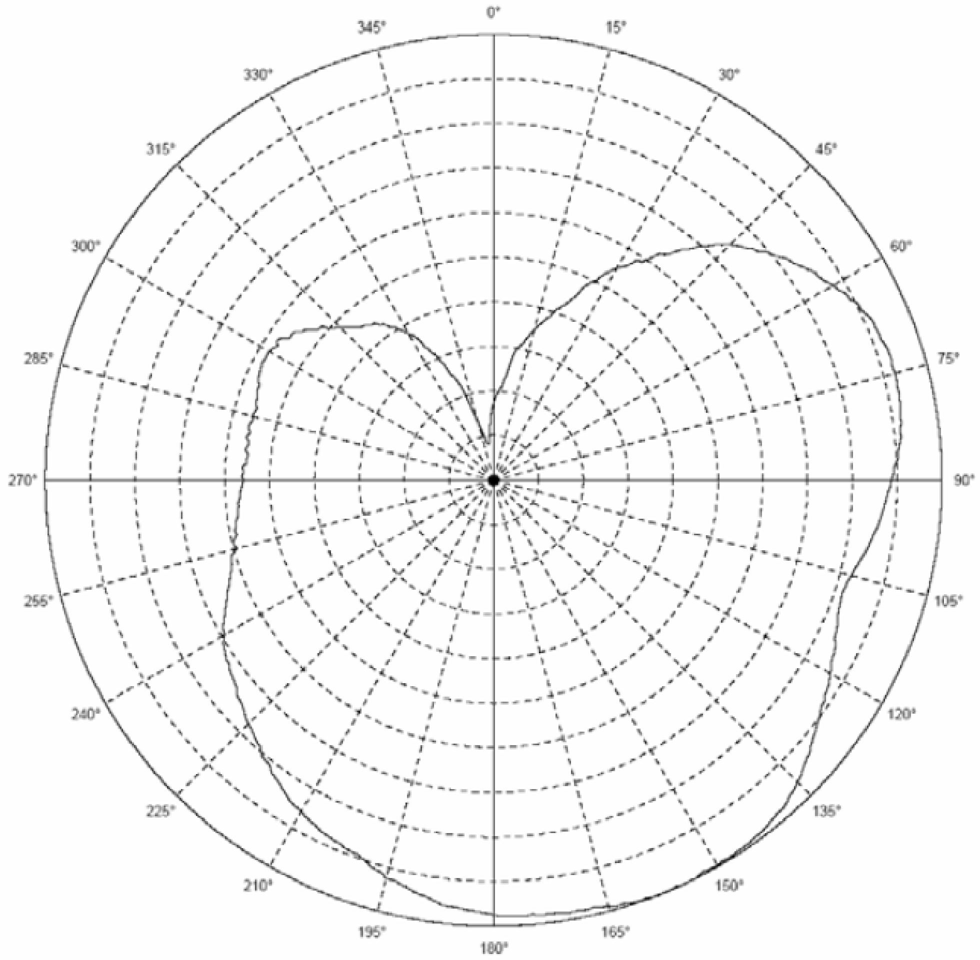


Example

Transmit power		36dBm
External	LNA GAIN	16dB
	LNA NF	2.7dB
CC1101 sensitivity 1.2kbps		-111dBm
CC1101 sensitivity improved by LNA		-118dBm
Total transmission budget		154dBm
Friis'free space atten. over 1400km is about		154dB

(Note this is purely a theoretical mathematical example and has no relevance for practical CC1101 applications)

Range extension Antenna



CF 866,000 MHz
2 dB/ div

Ref Lev: 6,0 dBm

Range extension adoption to requirements

FCC - SRD Regulations

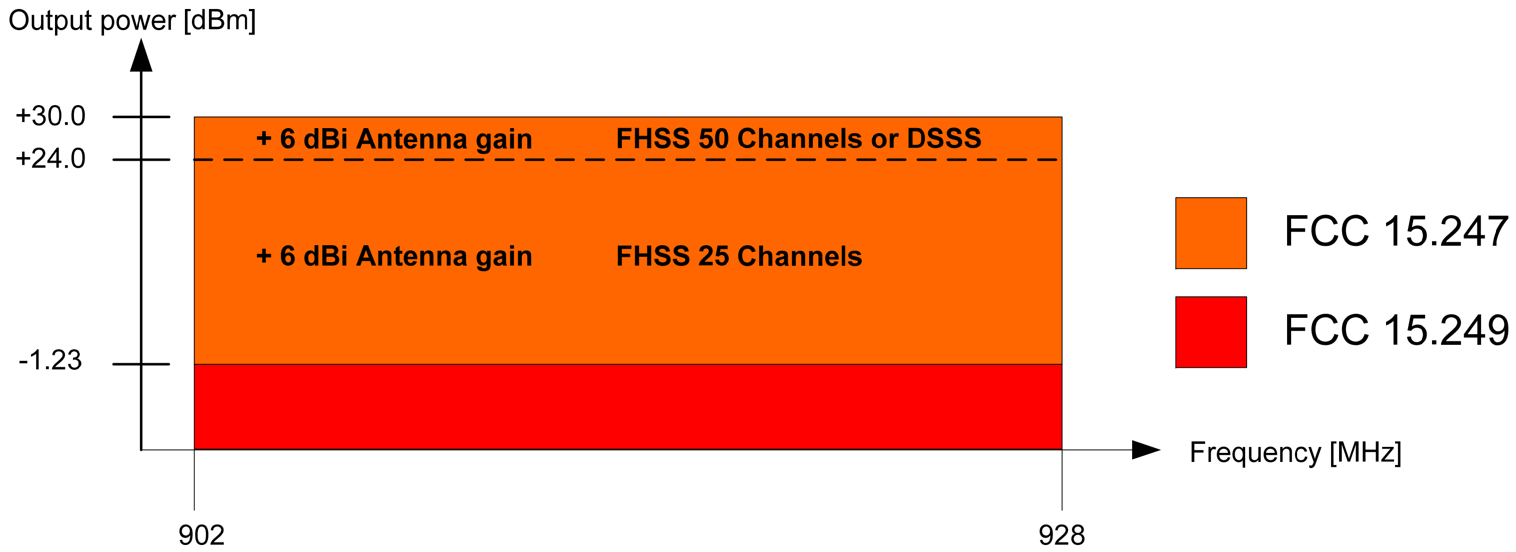
902 - 928 MHz band

FCC 15.249, Single channel

FCC 15.247, Spread Spectrum

FHSS - Frequency Hopping Spread Spectrum

Digital Modulation (e.g. DSSS - Direct Sequence Spread Spectrum)

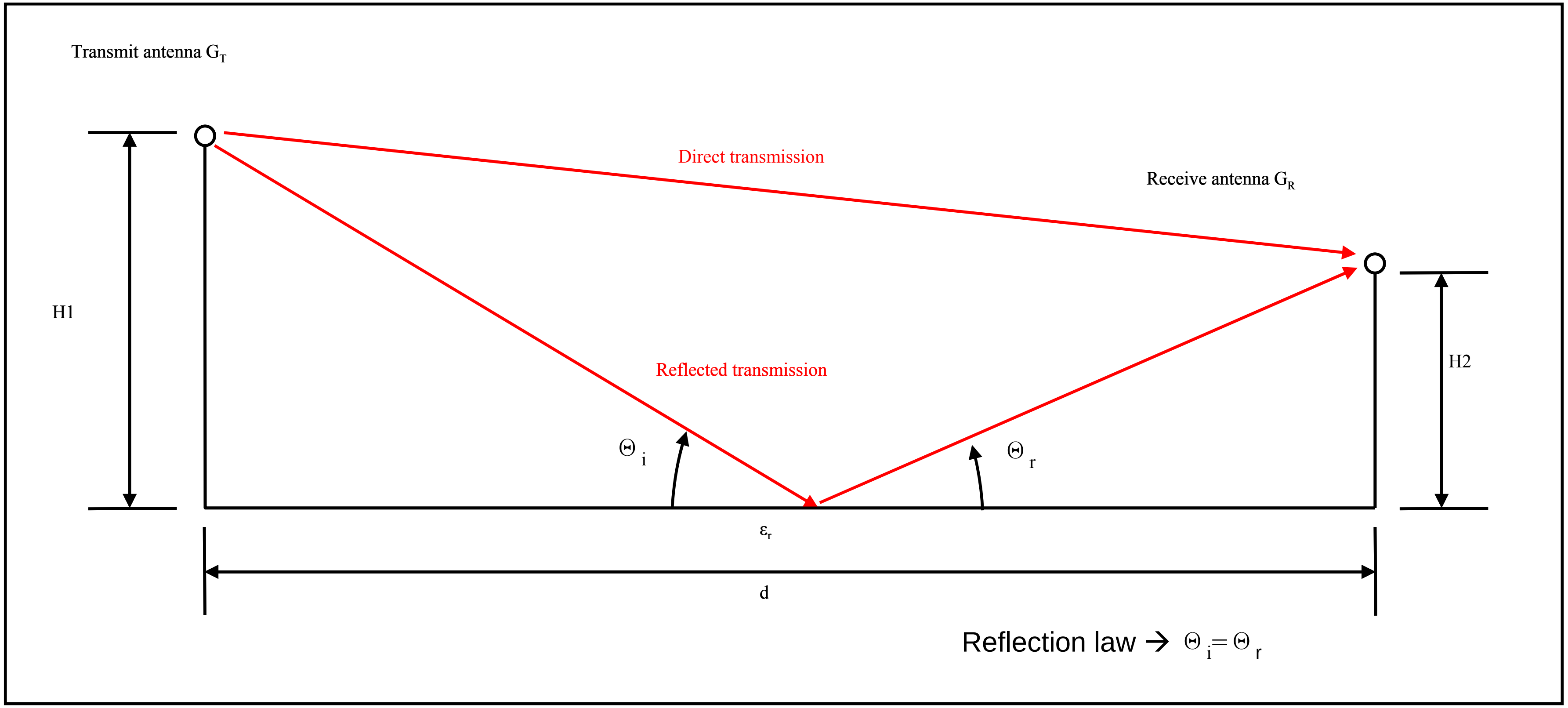


Practical range estimates

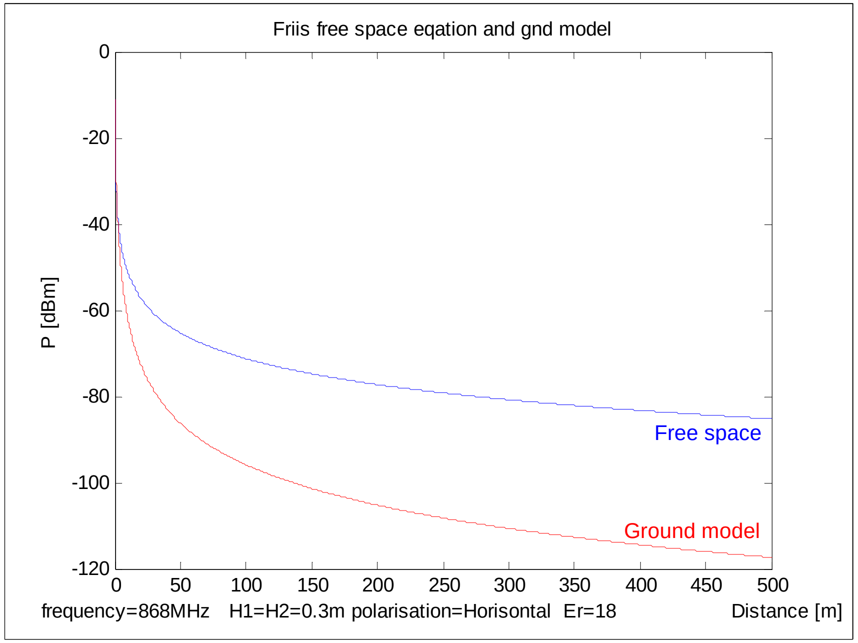
Practical range estimates

- Practical range estimates
  - Open field environment
    - Outdoor environments suitable for practical comparison measurements.
  - Indoor environments
    - Typical operational environments for the final product Indoor/outdoor, home, factory, vehicle …….

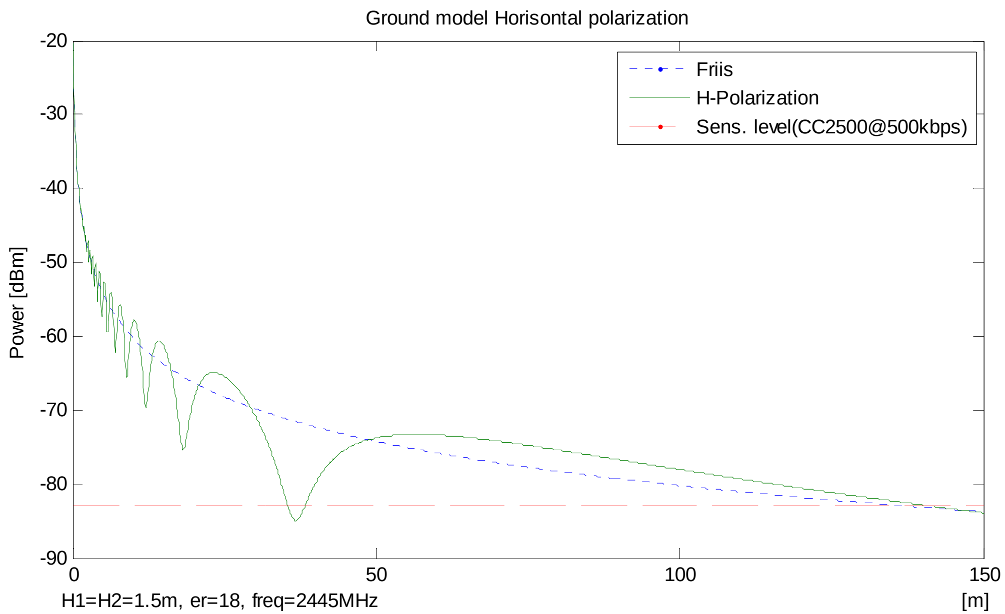
Practical range estimates open field



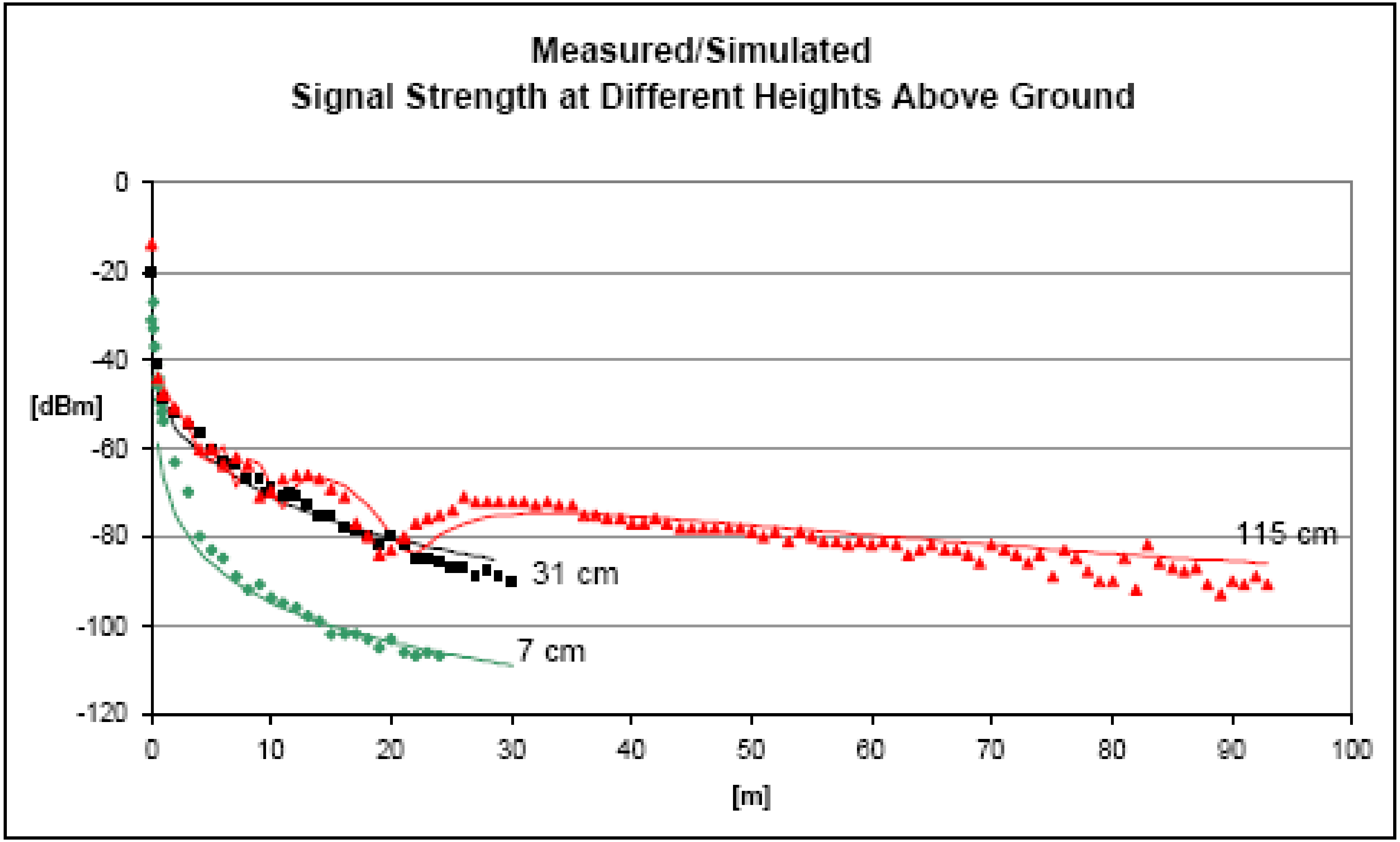
Practical range estimates open field



Practical range estimates open field



Practical range estimates open field



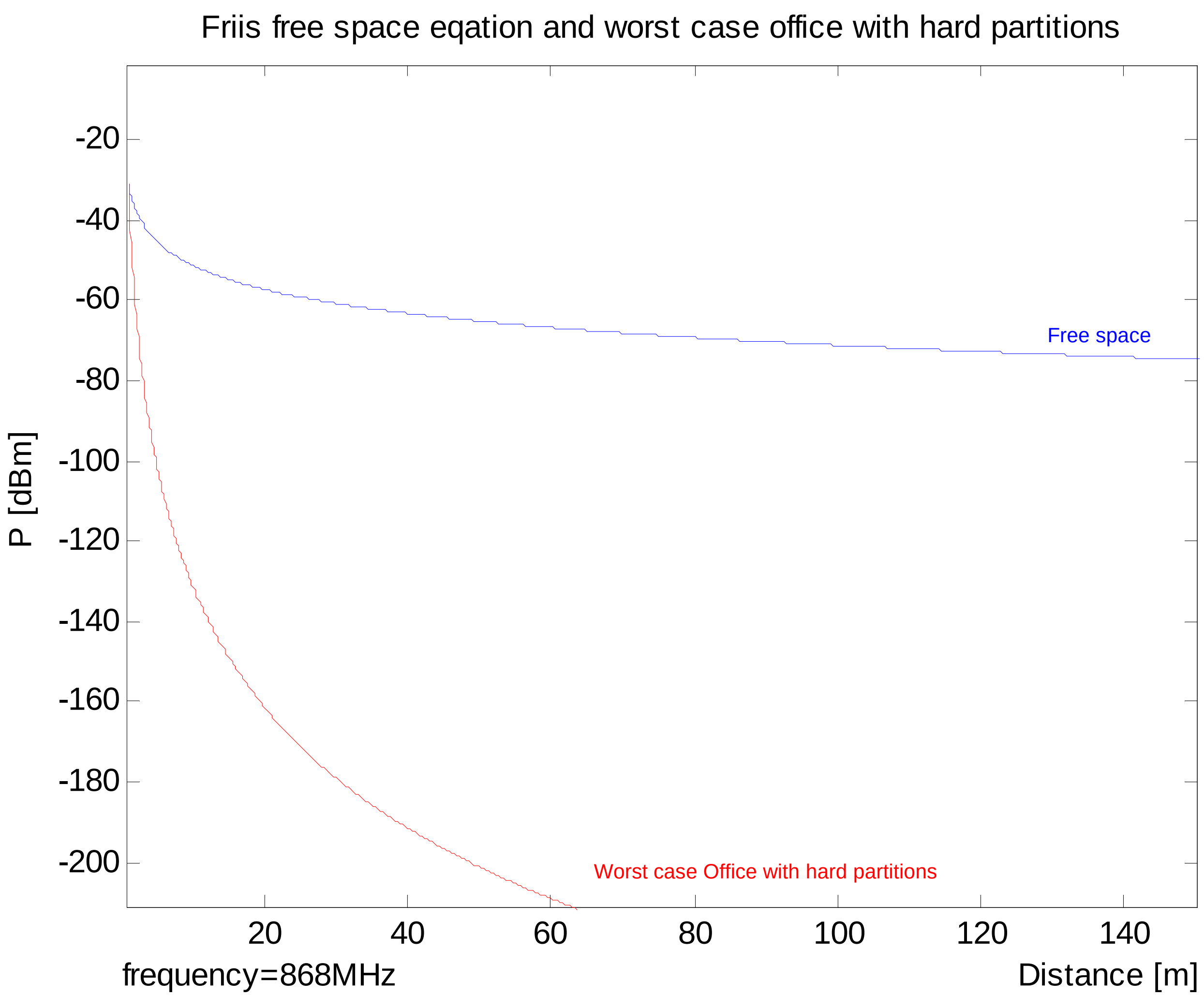
Practical range estimates Indoor

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi)^2 d^n} \qquad n = 2$$

Environment	n	std. deviation
• free space	2.0	
• Retail store	2.2	8.7
• Grocery store	1.8	5.7
• Office, hard partitions	3.0	7.0
• Office, soft partitions	2.6	14.1
• Metalworking factory, line of sight	1.6	5,8
• Metalworking factory, obstructed line of sight	3.3	6.8

Data copied from the SWRA046A Application report
By Matthew Loy and Iboun Sylla
http://focus.ti.com/lit/an/swra046a/swra046a.pdf

Practical range estimates example



Design Notes for CC11xx RF hardware

- **DN005 – CC11xx Sensitivity versus frequency offset and crystal accuracy**
- **DN025 – Johanson Technology Matched Balun Filter optimized for CC1101 at 868/915MHz**
- **DN017 – CC11xx 868/915MHz RF Matching**
- **DN001 – Antenna measurement with network Analyzer**
- **DN002 – Practical sensitivity testing**
- **DN013 – Programming output powers on CC1101**
- **AN003 – SRD Antennas**
- **AN001 – SRD regulation for license free transceiver operation**
- **AN050 – Using CC1101 in the European 868MHz SRD band**
- **AN068 – Design steps and results for changing PCB layer thickness**

Low Power RF Design Considerations in CC11xx

Application Scenarios

- High duty cycle
  – Active radio current consumption

- Low duty cycle
  – MCU sleep current
  – Regulator quiscent current
  – Average radio current consumption

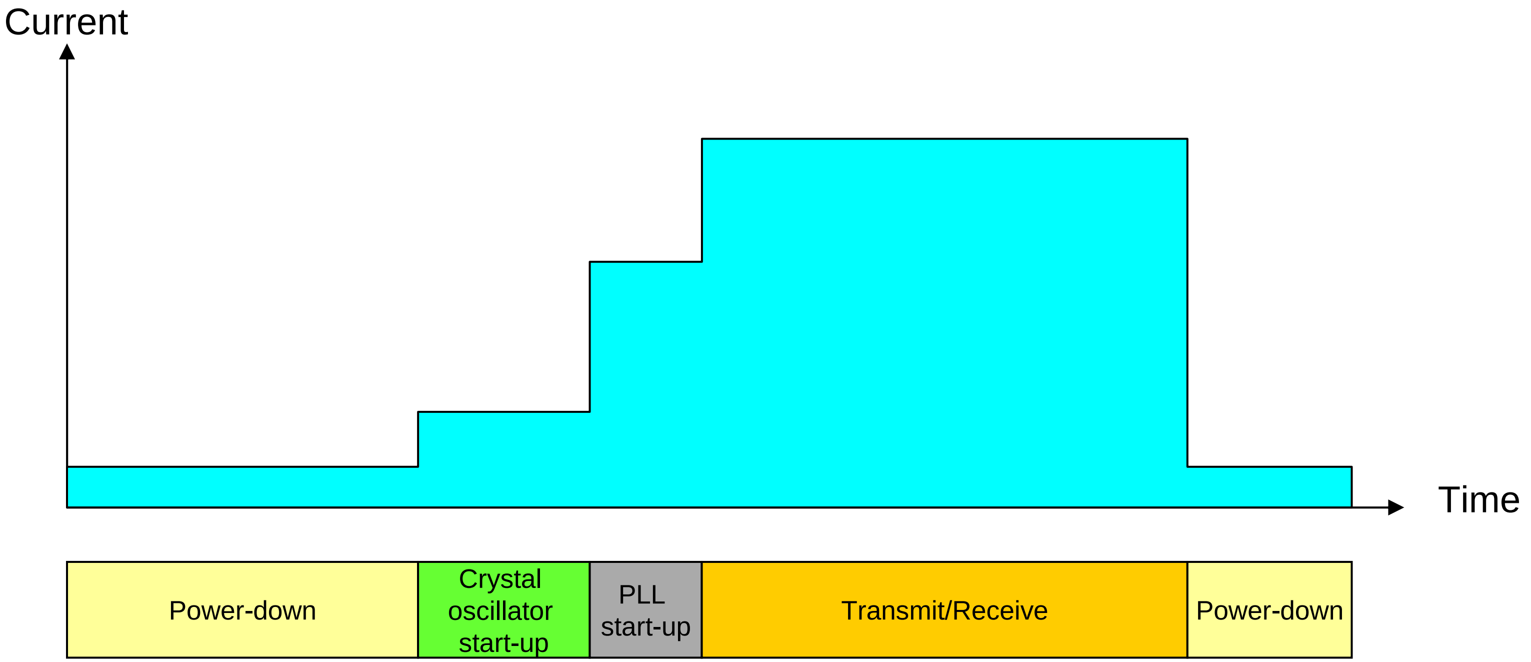
Low-Power Essentials

- Use the lowest possible duty cycle
  - Send data only when needed, do not send more data than necessary
  - Use the highest data rate you can (trade-off vs. range)
  - Watch out for protocol-related overhead

- Use the lowest possible voltage
  - RF chips have reduced current draw at lower voltages
  - Low voltage degrades RF performance
  - Above not a problem if on-chip regulator
- Use a switch-mode regulator with low quiescent current to maximize battery lifetime

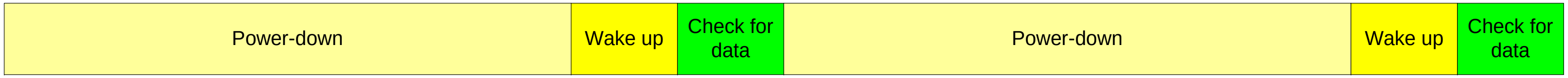
Waking up the Radio

- Waking up a radio from sleep takes it through several intermediate steps
- Calculate the average current to estimate battery lifetime

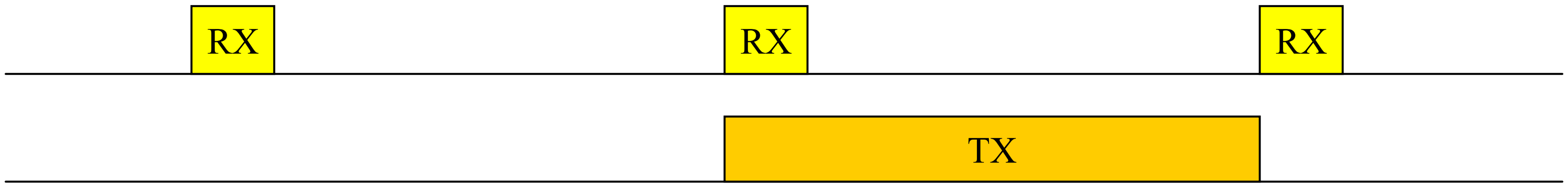


Polling Receiver

- Use a polling receiver if possible
  - Wakes up periodically and searches for data



  - Timing depends on behavior of the transmitter



RX-TX Switching

- For 2 way protocols, go as quickly as possible from transmit to receive mode or vice versa

Worst case:

Best case:

Adaptive Output Power Programming

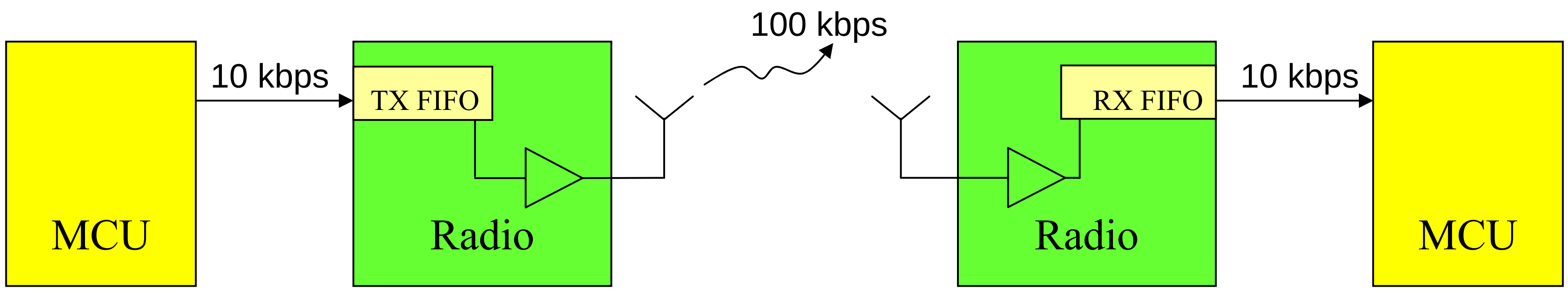
- Do not transmit more power than needed!

- The output power can be lowered when operating at close range to reduce TX current consumption

Burst Mode Data Transmission

- Assume a transceiver with on-chip TX and RX FIFOs

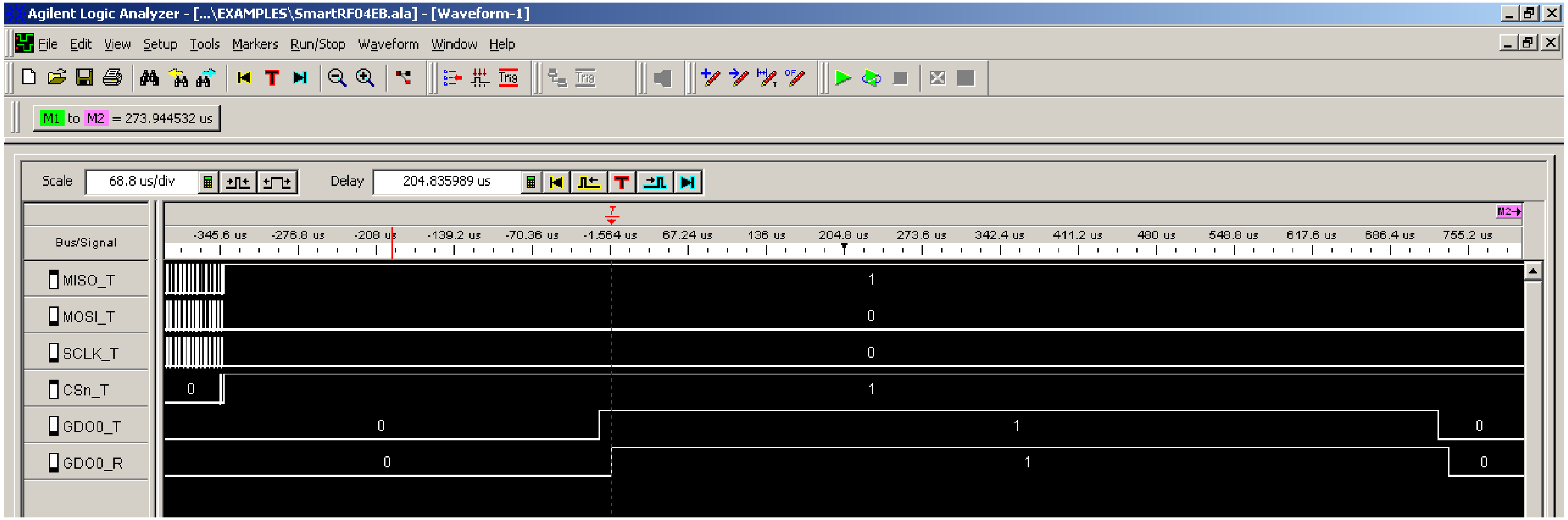
- Burst mode data transmission with high over-the-air data rate reduces overall power consumption



- Burst mode data transmission with slow over-the-air data rate improves range

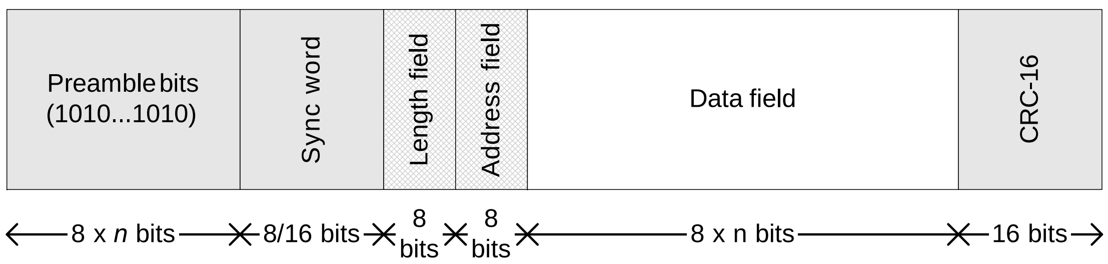
Minimize MCU Interaction

- TX:
  - Write data to TX FIFO
  - Set into TX with one simple command
  - Interrupt to MCU that packet is sent
- RX
  - Strobe into RX with one simple command
  - Interrupt to MCU that packet is received
  - Read RX FIFO



On-chip Packet Handling

- Puts less burden on the MCU
  - Preamble generation
  - Sync word insertion/detection
  - Address check
  - Flexible packet length (fixed, variable, or infinite)
  - Automatic CRC



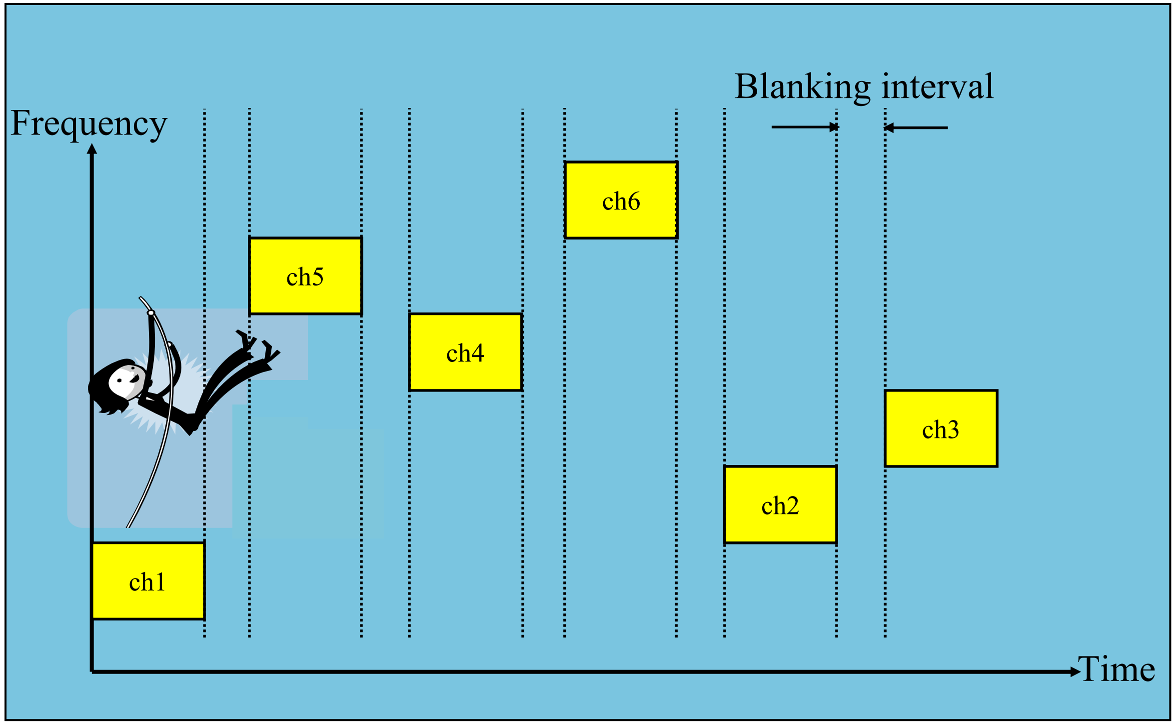
Discard False/Error Packets in RX

- Minimize time in RX processing false packets
  - Check carrier sense
  - Check for valid preamble
  - Check for valid sync word
  - Check length byte
  - Check for valid address

- Only notify MCU when a valid packet has been received
  - Automatic CRC check
    - Packet discarded if CRC fails
    - Interrupt to MCU if CRC OK

Frequency Hopping System

- Fast settling PLL important to minimize blanking interval
- Minimize synchronization time



PLL and VCO Calibration

- Calibration is needed to operate at the correct RF frequency
- Full calibration
  - Not a good solution for FHSS systems
- Relaxed calibration
- Calibration replaced by a look-up table
  - Used to minimize blanking interval in FHSS systems

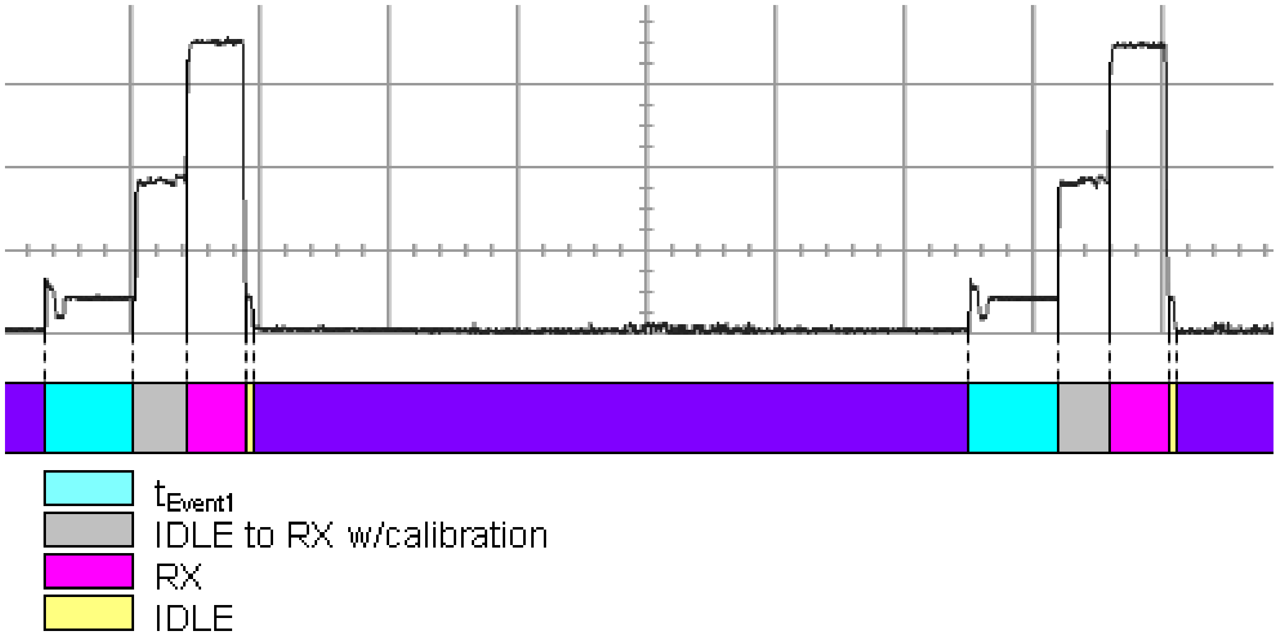
Data Sheet and Register Settings

- Read the data sheet carefully
- Register settings
  - Optimized for sensitivity?
  - Optimized for current consumption?
- Example (non-TI transceiver):

Mode	Sensitivity [dBm]	RX current [mA]
1	-112.5	20.1
2	-105.8	19.0
3	-92.2	17.6

Wake-On Radio in LPW product

- Wake-on-radio function allows very low average power consumption in a polling receiver (a few tens of μA)



Conclusion

- Minimum average current consumption when
  - Low SLEEP current
  - Fast crystal start-up time
  - Fast PLL calibration (and settling)
  - Terminate RX if there are no signal at the antenna
    - Carrier Sense
  - Low RX peak current
  - Minimum duty cycle
  - Minimum MCU activity

Questions?