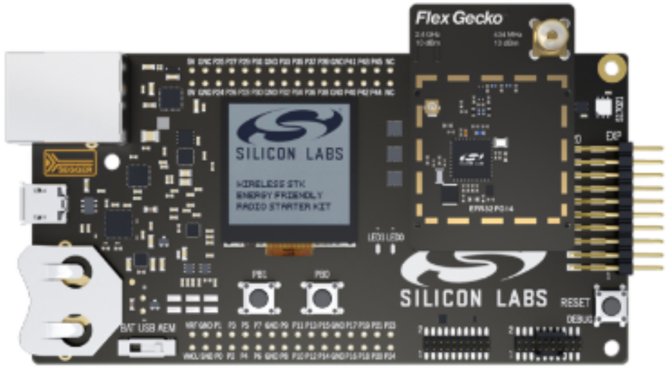
Tech Talks LIVE Schedule – Presentation will begin shortly

Silicon Labs LIVE:

Wireless Connectivity Tech Talks Summer Series

Topic	Date
Building a Proper Mesh Test Environment: How This Was Solved in Boston	Thursday, July 2
Come to your Senses with our Magnetic Sensor	Thursday, July 9
Exploring features of the BLE Security Manager	Thursday, July 23
New Bluetooth Mesh Light & Sensor Models	Thursday, July 30
Simplicity Studio v5 Introduction	Thursday, August 6
Long Range Connectivity using Proprietary RF Solution	**Thursday, August 13**
Wake Bluetooth from Deep Sleep using an RF Signal	Thursday, August 20

Please answer the poll while waiting and be entered to receive a Flex Gecko Starter Kit.



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WELCOME

Silicon Labs LIVE:

Wireless Connectivity Tech Talks
Summer Series

Long Range Connectivity Using Proprietary RF Solutions

AUGUST 2020

Content Overview

- This training includes an introduction to our long range solution on our Series 1 SoCs. We'll cover:
    1. Introduction to our proprietary wireless solutions
    2. Definition and theory of long range applications, focusing on link budget calculation and estimation of achievable range for common use-cases
    3. Details about our PHY implementation and its operation
    4. Current performance, system requirements, availability & accessibility

The Silicon Labs Difference

Proprietary

- Leadership
  - Leader in proprietary wireless
    - 12+ years of experience in proprietary wireless market
  - Trusted partnership with market leaders in metering, security, lighting, home and industrial automation

- Extensive portfolio comprising RF transceivers and Wireless SoC platform solutions
  - Excellent link budget up to 148 dBm for long range connectivity
  - Excellent performance in the presence of blockers
  - Industry leading integrated +20dBm PA
  - Full-featured radio configuration software and networking stacks

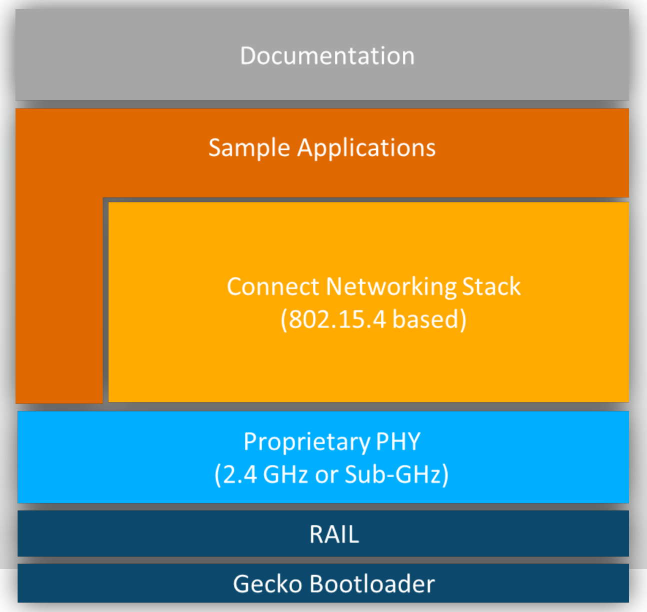
- Cutting-edge software and development tools
  - Comprehensive, easy-to-use tools and development environment
  - Radio Configurator, Packet Trace, Network Analyzer, AppBuilder, Energy Profiler

A Comprehensive Proprietary Portfolio

WIRELESS SOCS AND TRANSCEIVERS

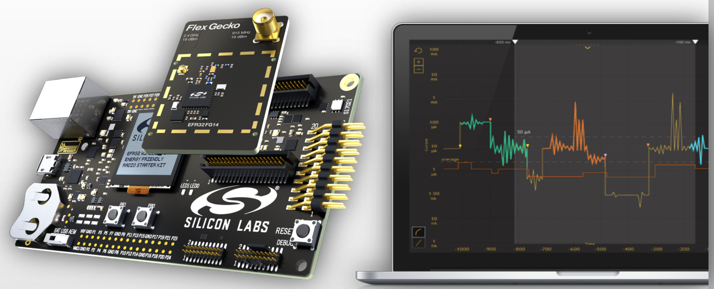
Ultra Low Power
2.4 GHz and Sub GHz
Industry Leading Multi-Protocol SoCs

FLEX SDK – RAIL API & CONNECT STACK



Predefined PHYs
Complete Development Suite
Sample Application With Source Code

TOOLS AND EASE-OF-USE

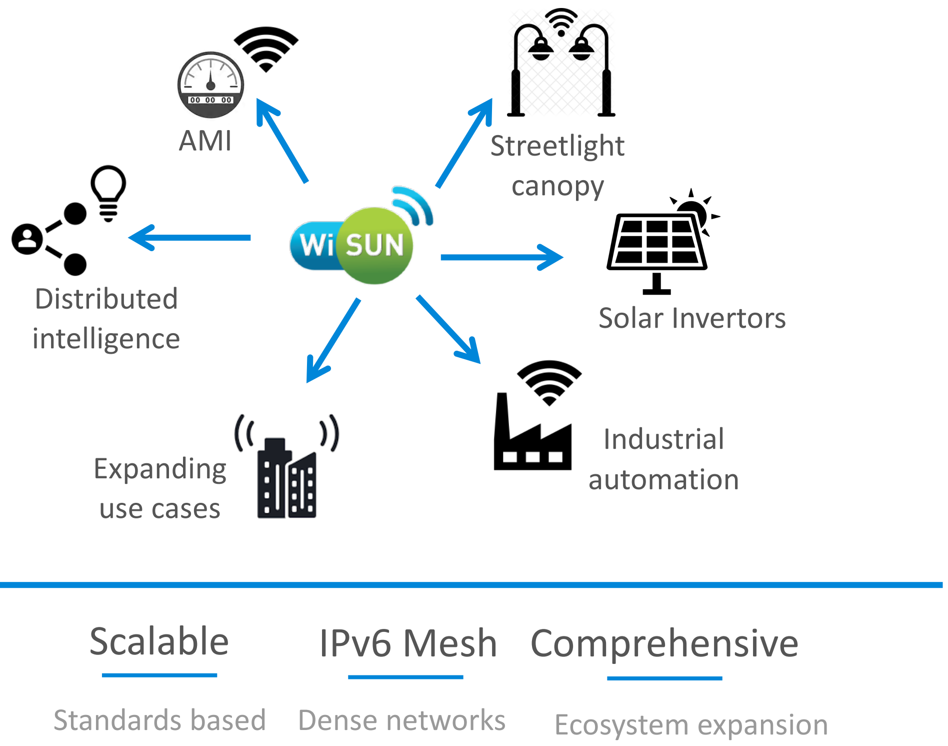


Radio boards
Simplicity Studio
Wireless Starter Kits

A Common Platform

	Bluetooth	THREAD	zigbee	FLEX SDK Proprietary	
Application	Customer Application	Customer Application	Customer Application	Customer Application	
Application	GATT (profiles / services); Mesh Models (e.g. lighting)	Application Layer (e.g. dotdot, CoAP)	Application Profile (e.g HA1.2, ZLL, dotdot)	Customer Application	
Network / Transport	Bluetooth LE Core; Bluetooth Mesh Core	UDP; IPv6, Mesh Routing; 6LoWPAN	zigbee Core Stack	Connect Stack	Customer Proprietary Stack
Link	Bluetooth Link Layer	IEEE 802.15.4 MAC	IEEE 802.15.4 MAC	IEEE 802.15.4 like MAC	Customer Proprietary Stack
Physical	Bluetooth PHY (2.4 GHz)	IEEE 802.15.4 PHY (2.4 GHz)	IEEE 802.15.4 PHY (2.4 GHz)	Proprietary PHY (2.4 GHz or Sub-GHz)	
Platform	RAIL	RAIL	RAIL	RAIL	
Platform	Common Bootloader	Common Bootloader	Common Bootloader	Common Bootloader	

Wi-SUN – Wireless Smart Ubiquitous Networks



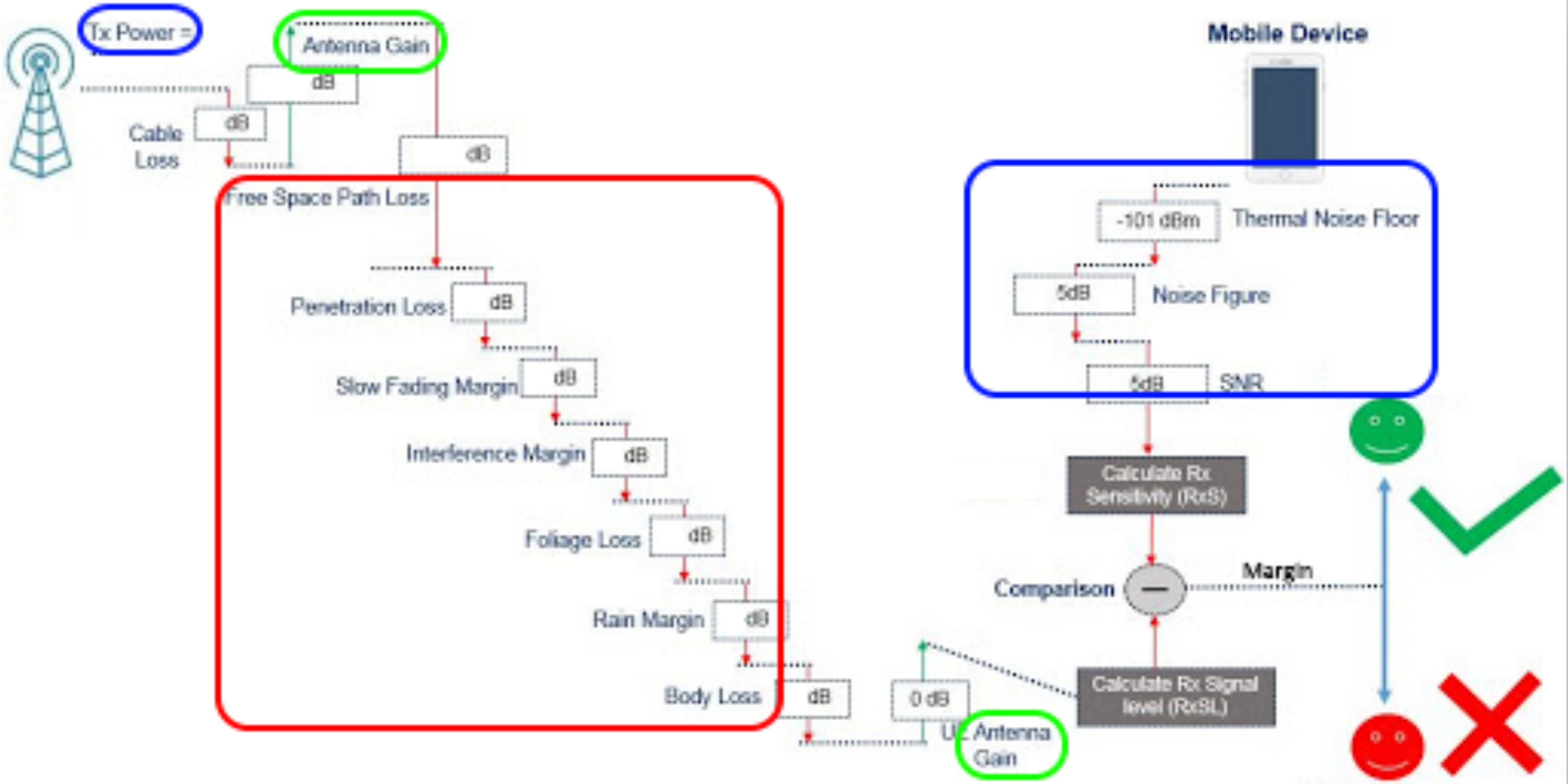
- Why Wi-SUN?
  - Drive towards **standards-based** technology
  - Need for **IPv6** for unified convergence
  - Multi-mode robust **subGHz mesh** solution
- Silicon Labs joins the Wi-SUN board
  - Massive push towards Wi-SUN
- Target markets
  - Proprietary networks
  - Wi-SUN standard (FAN 1.0) networks
- Silicon Labs Wi-SUN offering
  - Competitive hardware roadmap
  - Stack Based on open-source implementation from Arm
    - Alpha program - Q42020
    - GA – 2H2021
  - Contact your Silicon Labs representative for more details

WI-SUN LEADING IPv6 MESH STANDARD IN SMART INFRASTRUCTURE

Long Range: How long is “Long”, and how to approach ?

Base Parameters Impacting Achievable Range

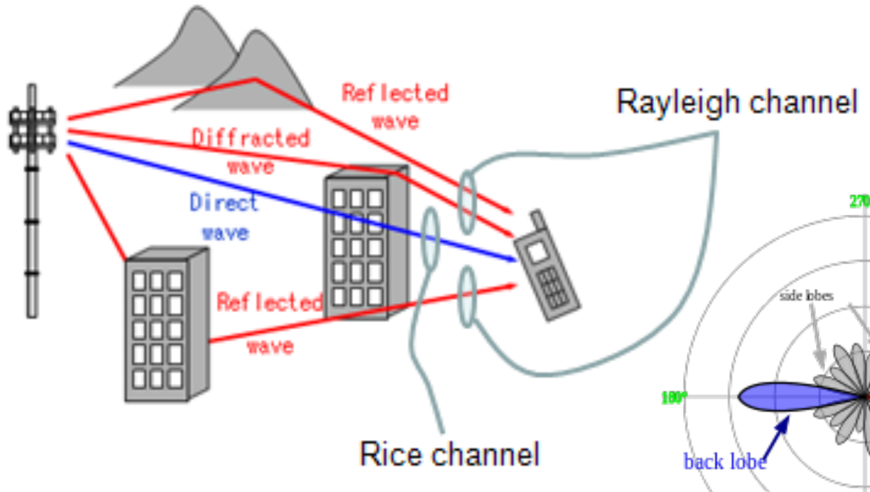
- Long Range (LR) generally implies a TX to RX distance > 1 km
- Calculate available Link Budget
  - TX power and RX sensitivity
  - Antenna Gain (TX, RX)
- Apply Propagation Loss
  - signal energy loss experienced on the path from TX to RX nodes
  - free space loss dominates, but
  - depends on many factors, details later
  - summary KBA is available here
  - consider “real life” conditions
    - urban or rural terrain
    - absence of line-of-sight (LOS)
    - interference, fading, weather
- Check the criteria for a stable RF link:
  - Link budget > Propagation loss + Margin (rec. 5-10 dB)
  - Margin is to cover changes in channel conditions during operation
    - fading issues and/or worse conditions, e.g. Reflections, Multi-path propagation, LOS or Fresnel-zone disruption, weather conditions, etc.

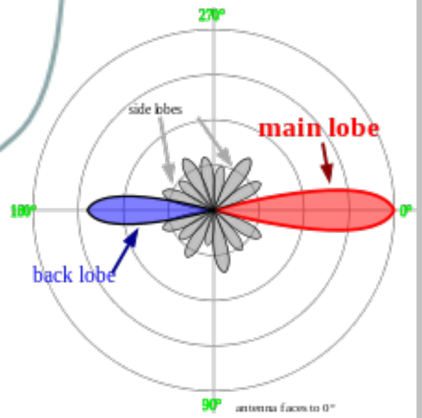


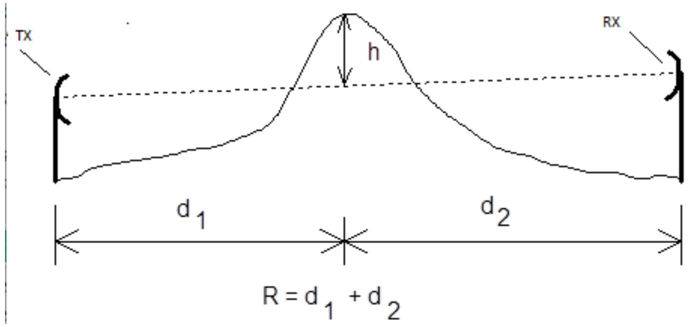
What affects the RF range besides the conducted link budget and antenna gains?

- Frequency: This dependency comes from the effective aperture/area of antennas. **The higher the operating frequency is, the higher the propagation loss will be.**
  - However, especially for small modules, antenna gain is better at higher frequencies - this means that with small modules better range can be achieved at higher frequency.
  - If board size > lambda/2, then the range is better at lower frequencies.
- Antenna radiation pattern: most applications do not have omnidirectional antennas, so it is recommended to perform range testing along the antenna's main radiation direction/lobe.
- Interference and noise: most crucial in an urban area where multiple systems' transmitters (not just ISM but GSM, LTE) are also operating
- Frequency offset: can be critical for narrowband applications by missing out part of the incoming signal energy.
- Final product placement and enclosure: ensure proper antenna clearance and placement, as suggested by the antenna manufacturer.
- Environment: best range can be achieved with a clear LOS in , while urban or office (indoor) multi-path environments with obstrutions can have severe negative impacts on range.
- TX and RX node heights, diffraction: Ensure clear and free Fresnel-ellipsoid between TX and RX nodes for the best range. If the first Fresnel zone (radius: r1) is free then ~96% of power goes through (not considering other impacts).
  - The higher the nodes are without any obstacles (hill, building) between them, the better RF range is expected (e.g. avoid ground effect and thus avoid multipath propagation).

$$A_e = \frac{c^2}{f^2} \times \frac{10^{\frac{G\,(dB)}{10}}}{4\pi}$$







$$r_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}$$

Calculating Link Budget and RF Range

- TX power
  - Up to +20 dBm
- Receiver Sensitivity
  - Ideal value is the sum of
    - Background noise floor
      - k*T*B = -174dBm + 10*log10(BW_in_Hz)
    - LNA noise figure
      - 8 dB on Gen1 and 4 dB on Ocelot
    - demod's Signal-to-Noise-Ratio requirement for given Bit-Error-Rate
      - 2FSK with H=1 → 10 dB
      - OQPSK + DSSS SF=8 → 3 dB
  - Depends on
    - actual implementation (chip generation and manufacturing process)
    - modulation parameters
    - radio configuration
- Antenna Gain
  - Depends on size of GND plane presented to the stick antenna
  - 490MHz WSTK : ~ -2 dBi
  - 915MHz WSTK : ~ 0 dBi
- Propagation loss
  - Depends on many factors as shown on the previous slide
- How to estimate the achievable RF range?
  - See Range Calculator for reference here

- Friis formula for range estimation

$$P_R = P_T + G_T + G_R - 20\log_{10}d - 20\log_{10}f + 20\log_{10}\frac{c}{4\pi}$$

- Ideal RF range, e.g. with clear LOS, no obstacles, no GND effect, and zero interference (in this case, propagation exponent n=2)

$$\boxed{r_{id}[m] = \sqrt{\frac{120\pi \cdot EIRP}{4\pi \cdot E_{RXSens}^2}} = \frac{\sqrt{30 \cdot EIRP}}{E_{RXSens}} = 1000 \cdot \frac{\sqrt{30 \cdot EIRP[W]}}{E_{RXSens}\left[\frac{mV}{m}\right]}}$$

- Real RF range in different example environments (the propagation exponent has a severe impact on the achievable RF range)

$$\boxed{r_{real} = r_{id}^{\frac{2}{n}} \cdot 2^{\frac{n-2}{n}}}$$

Environment	Propagation Exponent, *n*
Free space	2
Urban area cellular radio	2.7 ... 3.5
Outdoor	2.8 ... 4
Obstructed in building	4 ... 6
Obstructed in factories	2 ... 3

RF Range Estimation Rules Of Thumb

- When link budget and environmental conditions are known, what is the achievable RF range?
- How is the RF range impacted if we back-off (or boost) the power/sensitivity, i.e. modify the link budget, in the same environment?
  - Gain insight on these questions by using the RF range calculator – some example results are shown below.
  - For a given link budget, longer range can be expected at lower frequencies – however, for relatively small modules the antenna gain is less at lower frequencies, so for some HW it may be harder to achieve the same link budget (incl. antenna gains) at a lower frequency.
  - A specific link budget improvement will achieve more range extension in a better environment than in one with unfavorable conditions.

Environment	Propagation Exponent, n	Frequency [MHz]	RF Range /w different Link Budgets			
			120 dB	126 dB	130 dB	140 dB
Outdoor suburban area with clear LOS	~2.7	434	3.8 km	6.4 km	9.1 km	21.3 km
		868	2.3 km	3.8 km	5.4 km	12.8 km
Outdoor urban area without LOS	~3.2	434	1.1 km	1.8 km	2.4 km	5 km
		868	770 m	1.1 km	1.5 km	3.2 km
Indoor factory area with LOS	~3.8	434	430 m	620 m	790 m	1.4 km
		868	300 m	430 m	550 m	1 km
Indoor office area without LOS, obstructed with walls	~5.2	434	100 m	130 m	150 m	240 m
		868	70 m	100 m	120 m	190 m

Using DSSS to Build a Long Range PHY

How to Improve RX Sensitivity for any Modulation Format?

The only non-physical parameter we have control over for every design and device is PHY sensitivity

The fundamental approach: decrease channel bandwidth to increase Signal-to-Noise-Ratio (SNR)

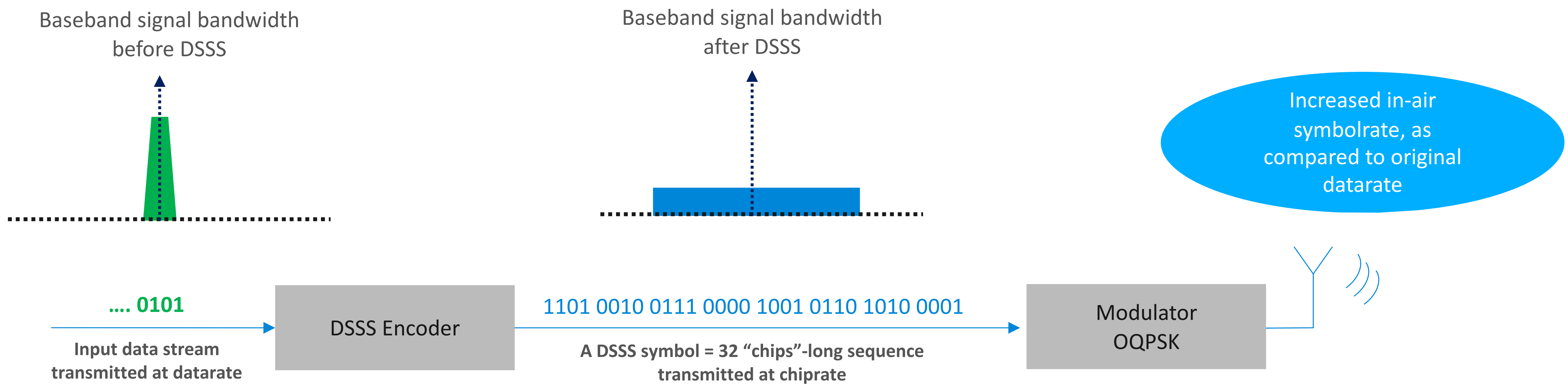
- Half BW -> alters noise power by -3 dB -> SNR by +3 dB
- BW/10 -> alters noise power by -10 dB -> SNR by +10 dB

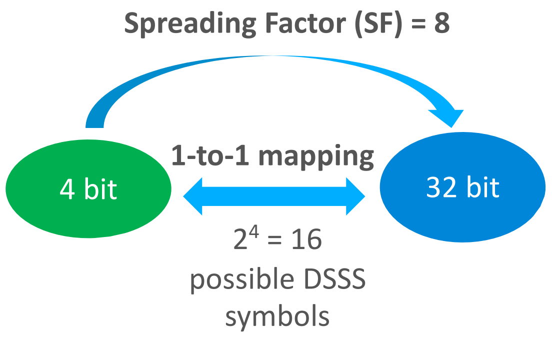
Bandwidth reduction can be achieved:

- by decreasing the datarate
  - example: RX sensitivity of 2FSK H=1 where BW ~ 2*Dev+DR and Dev=DR/2
    - 100 kbps ~ -103 dBm
    - 50 kbps ~ -106 dBm
    - 10 kbps ~ -113 dBm
    - 1kbps ~ -123 dBm
- while sacrificing frequency offset tolerance
  - tolerance depends on RX BW and correlates with deviation
  - example: 2FSK H=1 where BW ~ 2*Dev+DR and Dev=DR/2
    - tolerance ~ deviation
    - for 1 kbps a BW of 2 kHz results in +/- 0.5 kHz offset tolerance
  - kHz vs ppm mapping: for 1GHz, 1 kHz = 1 ppm
  - Narrow band requires a very accurate and stable clock reference like TCXO in ppm range
    - Cost implications
- with effect on RF Immunity
  + Super narrow filters have excellent Adjacent Channel Selectivity and Blocking
  — Low Data Rate -> long packet time -> longer exposure to co-channel interferers

Consider using DSSS
if available

EFR32 DSSS Theory: Zigbee PHY Example – TX Side





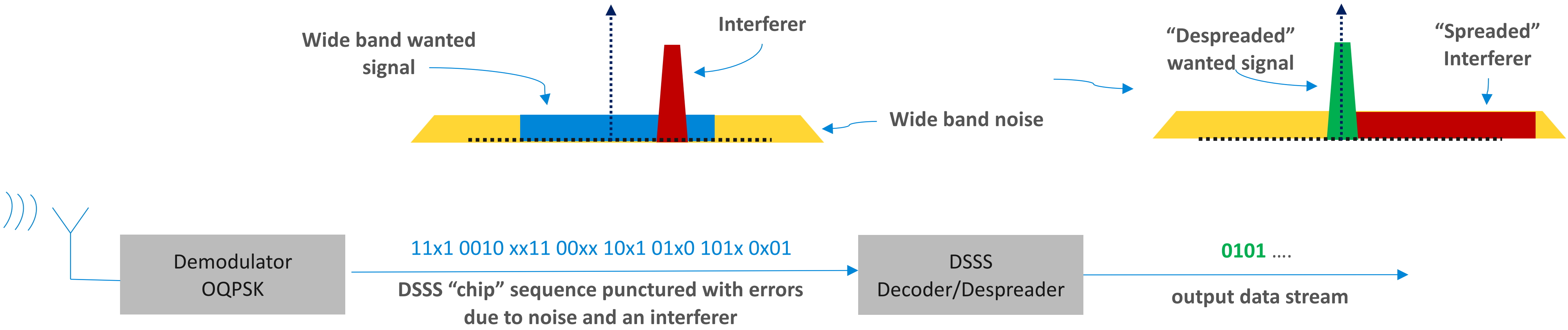
Example:

- Zigbee 15.4 PHY
  - 250kbps OQPSK- DSSS
  - SF=8
  - 2Mcps chip rate

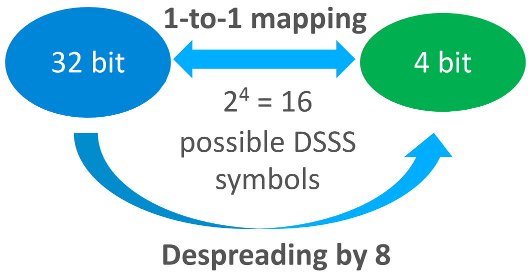
Key takeaways:

- Encoder replaces each bit group by a "chip" sequence
  - 4 with 32 in this LR example
- Chip rate = Datarate x SF
  - spreads the signal spectrum
  - higher Occupied Bandwidth
  - lower Power Spectral Density
- Good for passing Tx regulations for low net datarate links

EFR32 DSSS Theory: Zigbee PHY Example – RX Side



Key takeaways:



- Decoder
  - increases SNR via despreading
  - selects the closest valid “chip” sequence to the received one
    - buit-in error tolerance
  - decodes a bit group by the “chip” sequence
- If implemented correctly, DSSS retains the low datarate sensitivity, but with
  - higher frequency offset tolerance, and
  - higher immunity against co-channel interferers
  - (both benefits due to increased bandwidth)
- EFR32 Series 1 supports SF up to 32, but at reduced sensitivity above SF=8. BPSK/(G)FSK/MSK/OQPSK supported.

Zigbee 2.4GHz 250 kbps OQPSK-DSSS PHY Details

- Coherent detector for OQPSK available on xG12 and later devices
  - 3 to 4 dB sensitivity increase compared to FSK
- So-called *half-sine shaped* OQPSK
  - functional equivalent to rectangular shaped MSK
  - EFR32 has no I/Q modulator → implementation is done via MSK
- DSSS symbol configuration
  - base chipping sequence = 0x744AC39B
  - DSSS symbol length= 32
  - spreading factor = 8
  - 16 different DSSS symbols
- Detection parameters
  - number of DSSS symbols transmitted as preamble = 8
  - all preamble symbols are identical and reflect the chipping sequence
  - preamble detect occurs upon RX of 3 successive DSSS symbols
  - In DSSS, sync word is coded on TX and detected after decoding at the RX side

- Further reference in sections 3.4.3 "Packet Graphical UI" and 3.5 "Symbol Coding" of AN971

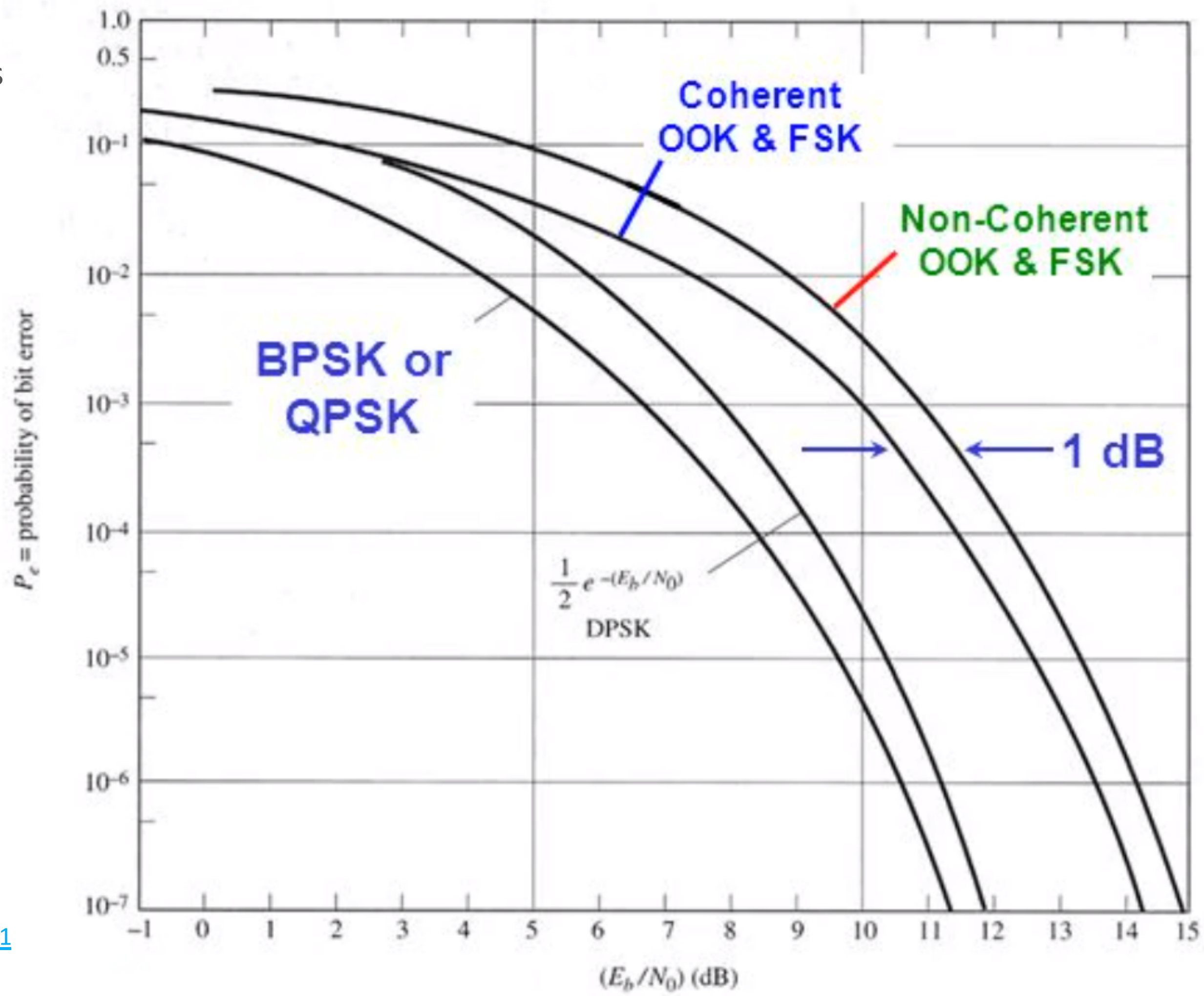


Figure 7–14 Comparison of the probability of bit error for several digital signaling schemes.

Long Range PHY Capabilites and Requirements

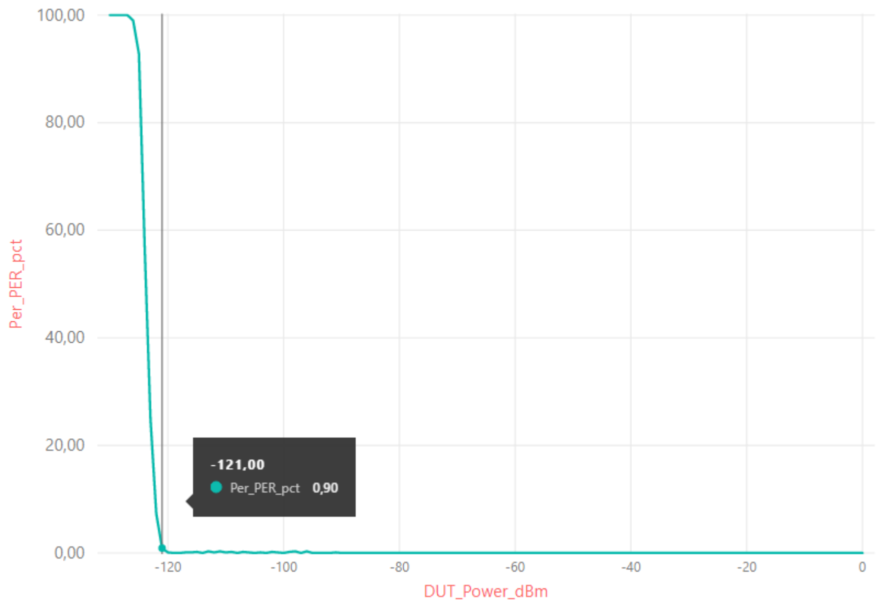
Scaling the 15.4 PHY

- Data rate and BW scaled down
- Coding scheme inherited
  - OQPSK, DSSS SF=8, 32bit symbol length with 4bit symbol map
  - ½ rate FEC option available
- 2x DR results in 3dB sensitivity drop, but only requires half as accurate XO
- XO accuracy value should be SPLIT between TX and RX
  - Cost savings option on nodes vs stations
- Currently available for xG14 ONLY
  - xG12/13 support estimate is Q3
- 38.4 and 80 kbps PHYs have also been created (passing FCC's 500 kHz limit), release targeted for Q4
- Handle TCXO aging
  - Example code will be available in Q3/Q4 for
    - Calibrating initial frequency offset upon application start
    - Cancelling frequency offset accumulated over time

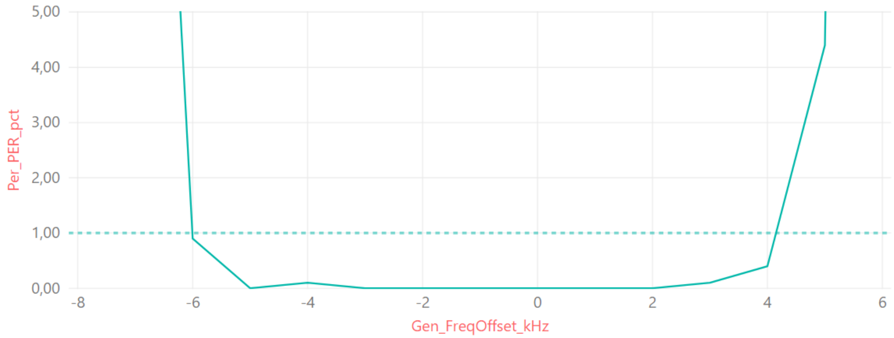
Frequency band	Data rate	MEASURED Sensitivity	TX + RX XO accuracy +/-
434/490 MHz	1.2 kbps	-128 dBm	2.5 ppm
434/490 MHz	2.4 kbps	-124.5 dBm	5 ppm
434/490 MHz	4.8 kbps	-122.5 dBm	10 ppm
434/490 MHz	9.6 kbps	-120.5 dBm	20 ppm
434/490 MHz	19.2 kbps	-117 dBm	40 ppm
868/915 MHz	1.2 kbps	-128 dBm	1.25 ppm
868/915 MHz	4.8 kbps	-120.5 dBm	5 ppm
868/915 MHz	9.6 kbps	-118 dBm	10 ppm
868/915 MHz	19.2 kbps	-115 dBm	20 ppm

Conducted Performance

PER curve:



Frequency offset tolerance curve:



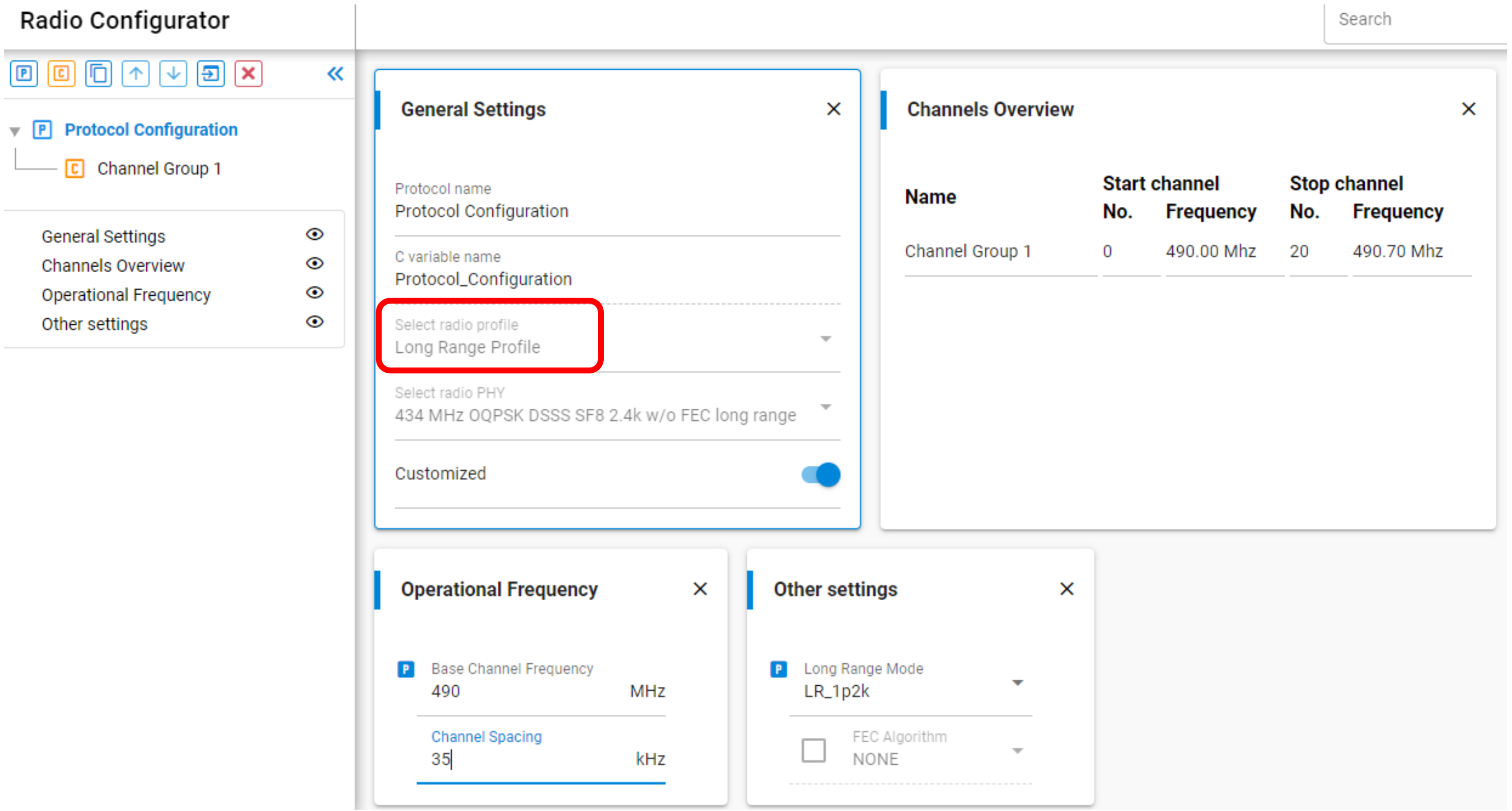
915 MHz 4.8 kbps DSSS-OQPSK SF=8 PHY Summary:

- 1% PER Sensitivity on 19 byte payload is -121 dBm
- Frequency offset tolerance:
  - +/- 4,5kHz on Rx side -> 5 ppm on the entire link on 915 MHz
  - Required TCXO is 2.5 ppm on both TX and RX side of the link
- Blocking (measured 3 dB above sensitivity level):
  - Co-channel rejection: -3 dB (-10dB w/o DSSS)
  - Adjacent channel selectivity: 40 dB
  - Blocking +/- 1 MHz: 71 dB
  - Blocking +/- 2 MHz: 77 dB
  - Blocking +/- 10 MHz: 97 dB
  - LTE Band 5 DL Blocking: -47 dBm
    - f_LTE = 889 MHz; BW_LTE = 10 MHz; f_Desired
    - LTE optimized PHYs in Q3

Long Range PHY Availability & Access

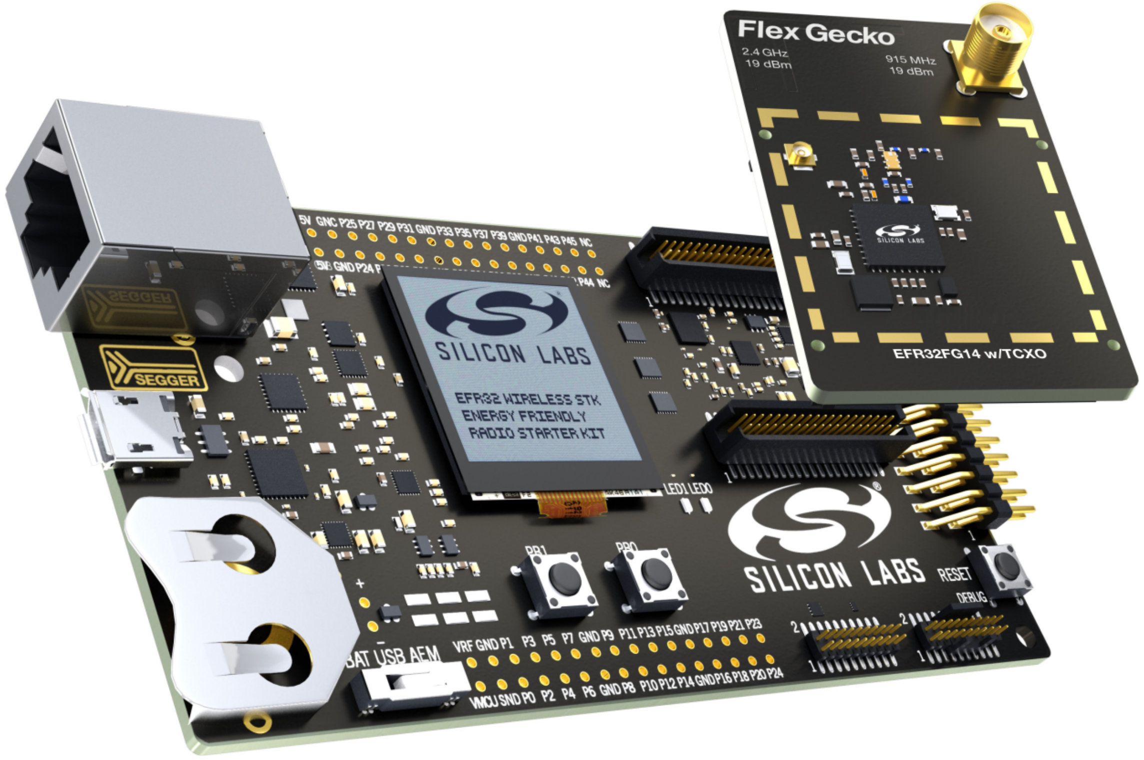
Long Range Profile in Simplicity Studio v5

- New profile in Radio Configurator GUI
- Supported parts xG12/xG13/xG14
- PHYs can be used with Connect as well
  - Without FEC only, as Connect does not support it



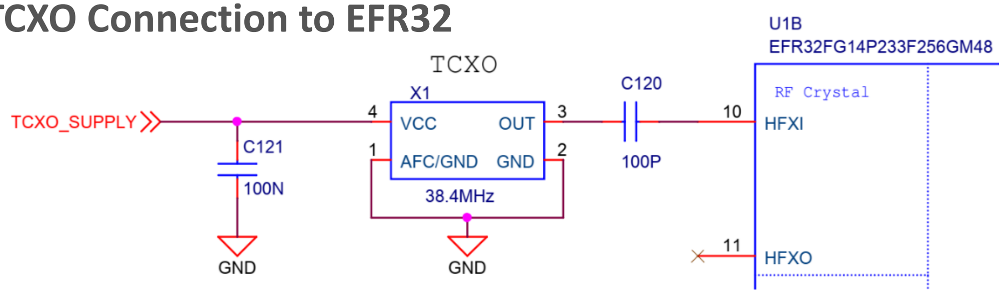
Boards available from Q4 2020

- EFR32FG14 2400/490 MHz 19 dBm
- EFR32FG14 2400/915 MHz 19 dBm
- EFR32FG14 2400/868 MHz 13 dBm

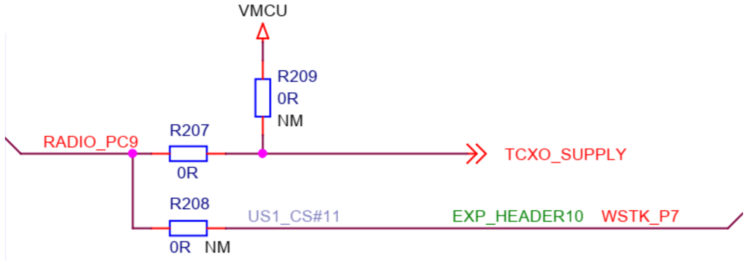


- Boards equipped with +/- 0.5 ppm TCXO
  - Supply is filtered for 38.4MHz
  - Pin PC9 is used to control TCXO supply

TCXO Connection to EFR32



TCXO Power supply



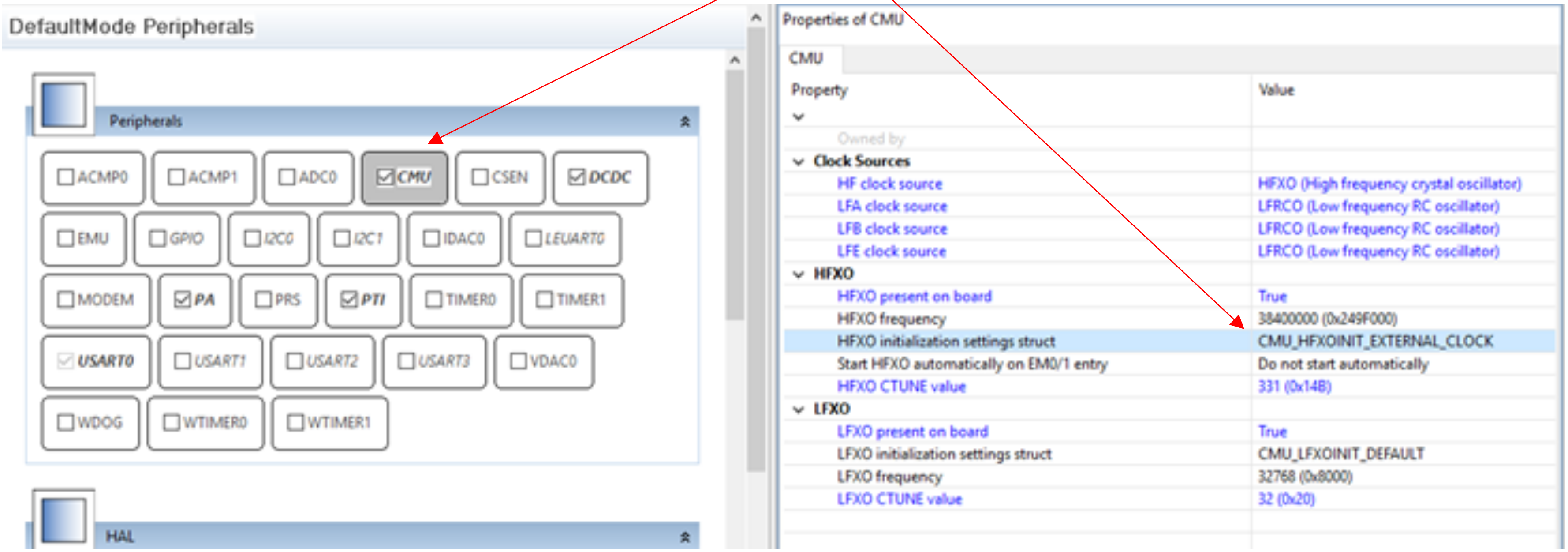
TCXO Usage in Simplicity Studio v4

- Just 4 steps
  1. HW Configurator change

     CMU_HFXOINIT_DEFAULT to **CMU_HFXOINIT_EXTERNAL_CLOCK**
  2. Enable the GPIO Clock
  3. Drive the GPIO pin supplying power to the TCXO to logic 1 (PC9)
  4. Enforce the required TCXO start-up time: issue a delay function before proceeding (HFRCO to HFXO switch performed later by clock init)

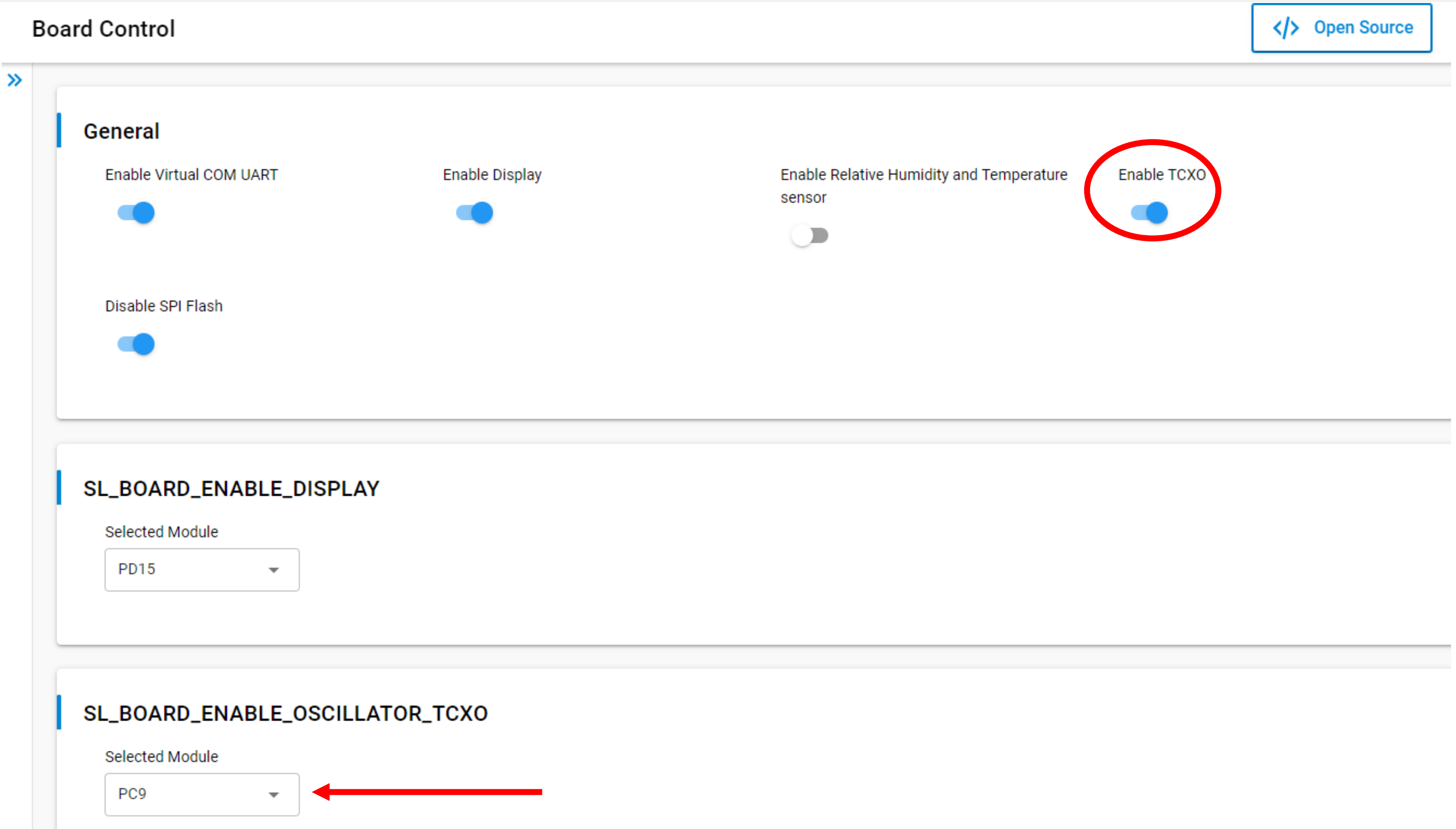
- Code snippet – place at the start of “main()”:

CMU_ClockEnable(*cmuClock_GPIO*, true);
GPIO_PinModeSet(*gpioPortC*, 9, *gpioModePushPull*, 1);
UDELAY_Delay(1000);



TCXO Usage in Simplicity Studio v5

- **Studio V5 recognizes boards equipped with TCXO**
  - Check the **Board Control** component
    - **Enable TCXO** slider is active
    - **SL_BOARD_ENABLE_OSCILLATOR_TCXO** defines the PC9 pin
  - Check the **Device Init: HFXO** component
    - **Mode** set to **External digital clock**



- TCXO enabled automatically by *sl_platform_init function()* at startup
  - *sl_board_preinit()* pulls up the PC9 pin to supply the TCXO
  - *sl_device_init_hfxo()* enables the HFXO clock
  - *sl_device_init_clocks()* selects HFXO as the HF clock once the TCXO started (it waits for the TCXO's startup, so there is no need for additional delay)

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