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RF Performance in IoT End Devices - Is Good Enough Really Good Enough?

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MATT MAUPIN

SENIOR PRODUCT MARKETING MANAGER

SILICON LABS

CHRIS CALVO

SENIOR STAFF RF DESIGN ENGINEER

SILICON LABS

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Agenda

Key RF Performance Specifications

Link Budget

Coexistence and Blocking Performance

Q&A

Antenna Diversity

Q&A

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Key RF Performance Features

- **Sensitivity**
  - The minimum signal strength a receiver can detect and decode accurately
  - Higher sensitivity improves receiver range and link reliability, especially in low-signal or noisy environments
- **Output Power**
  - The RF signal power transmitted by the device's transmitter
  - Higher output power increases communication range and signal penetration through obstacles
- **Selectivity and Channel Rejection**
  - The receiver's ability to hear a wanted signal in its channel while rejecting nearby-in-frequency interferers
  - These are essential when you have multiple in-band signals being received
- **Blocking**
  - The receiver's ability to maintain performance when strong unwanted signals are present near the desired frequency
  - Strong blocking performance is essential for coexistence in multi-protocol or crowded RF bands (e.g., 2.4 GHz ISM)
- **Antenna Diversity**
  - Using multiple antennas (typically with spatial, polarization, or pattern diversity) to improve signal quality
  - Reduces fading and multipath interference by selecting the best signal among antennas

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Link Budget

Combination of Output Power and Sensitivity

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Why Link Budget Matters?

- **Higher link budget provides better range and reliability – but….**
  - With high output power, increased sensitivity becomes more important in typical mixed vendor networks
  - High output power without improved sensitivity can result in an asymmetric communication link – shouting node syndrome
- **Symmetric Communication is when you have the same link budget on both nodes**
  - Competitor A to Competitor A range = 156.6 meters
  - Silicon Labs to Silicon Labs range = 185.1 meters (18% improvement)
- **Asymmetric Communication is when you have different link budgets on both nodes (typical network)**
  - Competitor A to “Typical” node range = 83.2 meters
  - Silicon Labs to “Typical” node range = 107.1 meters, (29% improvement)
- **Point-to-point range is important even in mesh communication**
  - Reduces the number of routers needed and number of hops required on the network
    - Reduces traffic, latency and improved battery life
- **Higher link budget improves range and reliability, but comes at a cost**
  - Increases current in both receive and transmit modes
  - Increased die area which relates to product cost

- Silicon Labs: Output power +19.5 dBm, Sensitivity – 105.4 dBm
- Competitor A: Output power +20 dBm, Sensitivity -102 dBm
- Range values are calculated based on propagation factor of N=4 (indoor)
- “Typical” node is based on +10 dBm output power and -101 dBm sensitivity

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Coexistence and Blocking Performance

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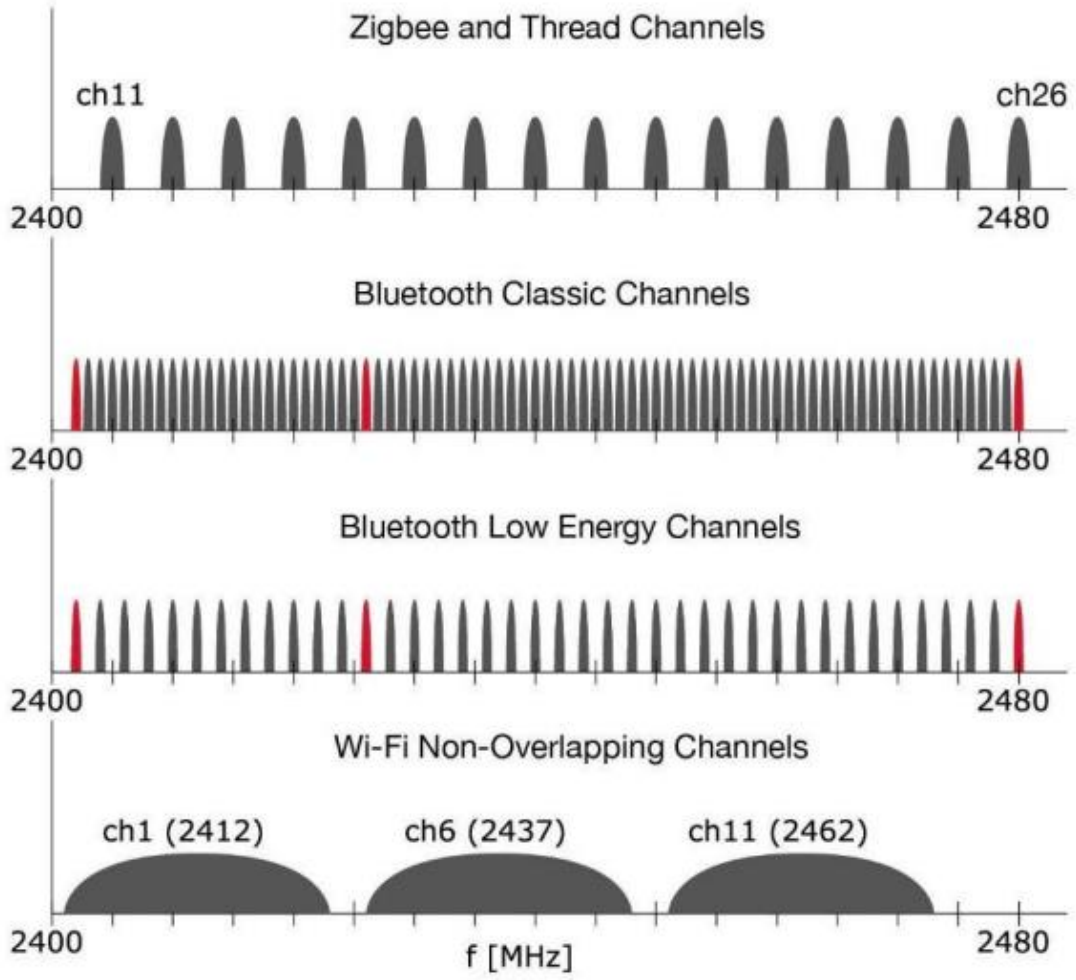
Coexistence Challenges

- **Challenges**
  - Popular Wireless protocols share the 2.4 GHz band
    - BT, Wi-Fi and 802.15.4 (Zigbee, Thread)
  - Protocols have different modulation schemes and can overlap
    - Signals from one protocol looks “noise” to others
  - Noise will impact the ability to receive desired signal
    - Desired signal must be stronger than the noise
- **Trends making it worse**
  - More devices in the home
    - Creating more noise in band
  - Increased Wi-Fi Transmit power and Mesh Networks
    - Increases the level of noise at other, lower output power devices
  - More instances of Streaming
    - Creates more traffic and noise from Wi-Fi
  - Multiple radio integration into a single device
    - Results in significant interference to other radios in the device



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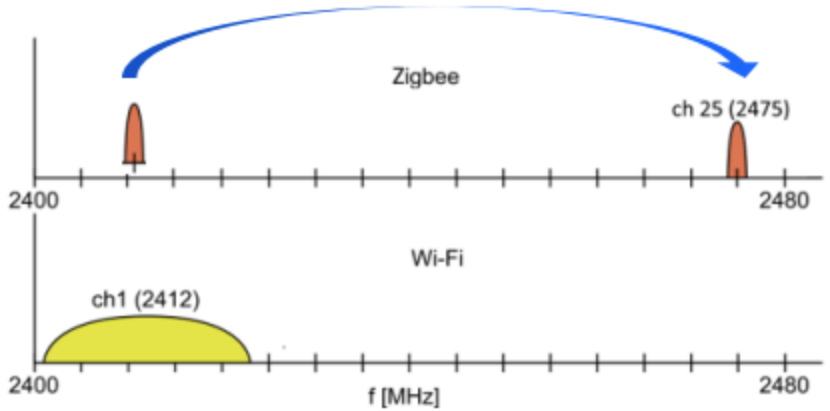
Unmanaged Coexistence

- **Refers to multiple wireless technologies operating in the same environment without any coordination**
  - Each system acts independently, which can lead to interference and degraded performance.
  - No coordination: Devices or radios are unaware of each other
- **Examples:**
  - A Wi-Fi router/AP and a separate Matter over Thread OTBR operating in close proximity
  - Multiple IoT devices using different protocols (e.g., Zigbee and proprietary 2.4 GHz) without coordination
- **Techniques Used:**
  - Separate the radios spatially
    - Moving wireless devices apart, equivalently increase the RF isolation between radios
    - Increase antenna isolation in multi-radio (co-located radio) devices
  - Separate the radios in frequency
    - Choose a low channel for Wi-Fi and a high channel for Zigbee
    - Operating 2.4 GHz-Wi-Fi with 20MHz Bandwidth
  - Protocol
    - MAC layer CCA timeouts
    - Extended MAC retries
    - Application layer retries
    - Frequency Hopping
    - Frequency Agility
  - Radio performance
    - Selectivity – how well the receiver rejects interferers on neighboring channels
    - Channel rejection – a measurement on how strong an interfere can be on an adjacent channel
    - Blocking - how well the receiver survives very strong interferers



Separate the radios in frequency

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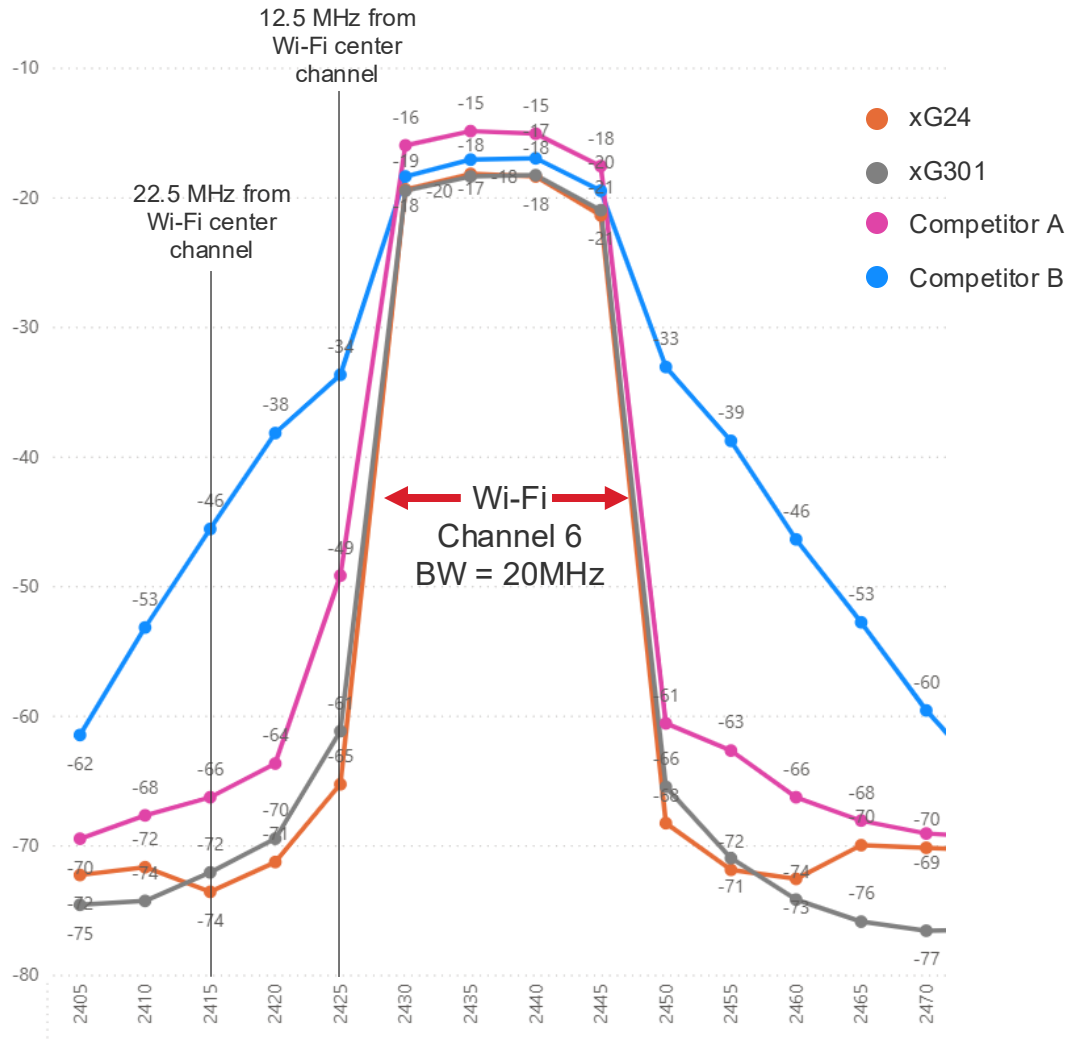
802.11n Blocker Impact on 802.15.4 (-10 dBm Blocker)

- **Strong blockers can significantly impact 802.15.4**
  - Impacts reception far from center of Wi-Fi channel
    - 802.15.4 can be 13 MHz from Wi-Fi with non overlapping channels
    - Typical channel separation may be 20 to 30 MHz
- **-10 dBm blocker**
  - Requires Wi-Fi source to be very close (1-2 feet)
    - Wearables or collocated devices
  - 802.15.4 sensitivity outside of Wi-Fi channel can be degraded
    - Silicon Labs has better sensitivity in presence of blocker
    - Competitor A is severely impacted with strong blocker

	Sensitivity at -12.5 MHz from blocker	Delta* (dB)	Sensitivity at -22.5 MHz from blocker	Delta* (dB)
xG24	-65.3 dBm	Baseline	-73.6 dBm	Baseline
xG301	-61.2 dBm	4.1 dB	-72.1 dBm	1.5 dB
Competitor A	-33.7 dBm	31.6 dB	-45.6 dBm	28.0 dB
Competitor B	-49.2 dBm	16.1 dB	-66.3 dBm	7.3 dB

*Delta represents signal increase needed over Baseline device for similar packet reception



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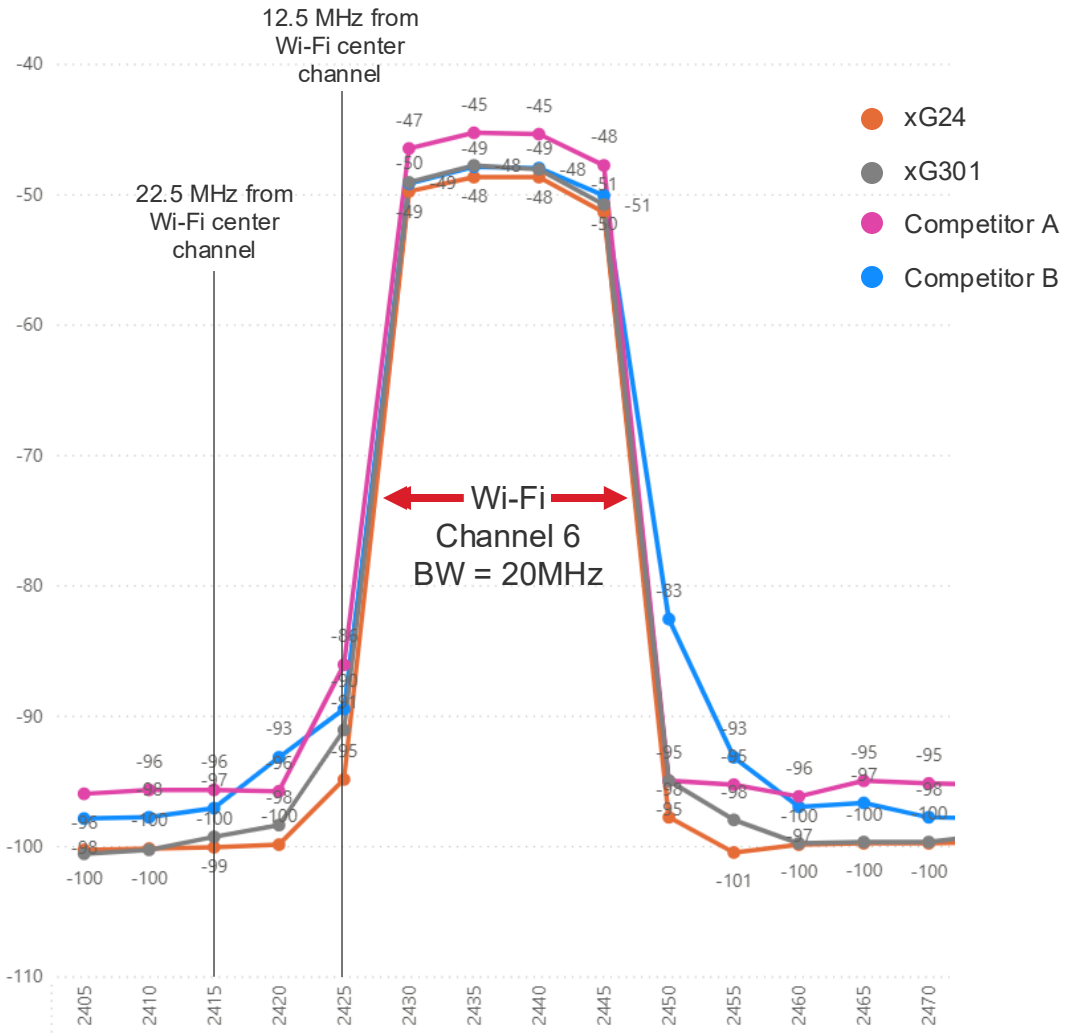
802.11n Blocker on 802.15.4 (-40 dBm Blocker)

- **Lower power blockers still impact 802.15.4**
  - Most impact is near center frequency
  - Less impact to 802.15.4 sensitivity >15 MHz
- **-40 dBm blocker**
  - Slight sensitivity degradation beyond 15 MHz
    - Blocking performance can still have some effect
  - -50 dBm Wi-Fi is considered a good signal
    - Has little effect on 802.15.4 when channels are beyond 15 MHz

	Sensitivity at -12.5 MHz from blocker	Delta* (dB)	Sensitivity at -22.5 MHz from blocker	Delta* (dB)
xG24	-94.9 dBm	Baseline	-100.1 dBm	Baseline
xG301	-91.1 dBm	3.8 dB	-99.3 dBm	0.8 dB
Competitor A	-89.5 dBm	5.4 dB	-97.1 dBm	3.0 dB
Competitor B	-86.1 dBm	8.8 dB	-95.7 dBm	4.4 dB

*Delta represents signal increase needed over Baseline device for similar packet reception



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Selectivity, Channel Rejection and Blocking

- **Selectivity impacts channel rejection and blocking**
  - Higher selectivity provides better rejection and blocking performance
  - Provides better sensitivity and more margin/robustness for variation in a signals power level

- **Selectivity tradeoffs in the IC design - a delicate balance needs to be struck**
  - Area/Cost
    - More selectivity and blocking performance is gained adding more filtering stages
    - Adds area and increases die cost and product cost
  - Current
    - More stages of filtering at the channel level need to be active, tunable, and linear
    - Increases current consumption for receive, reducing battery life

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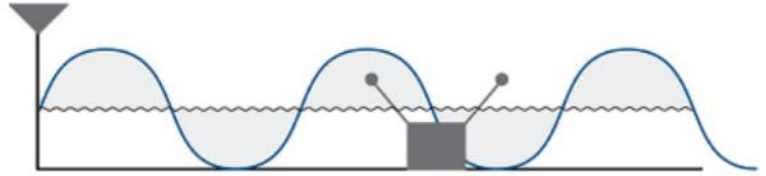
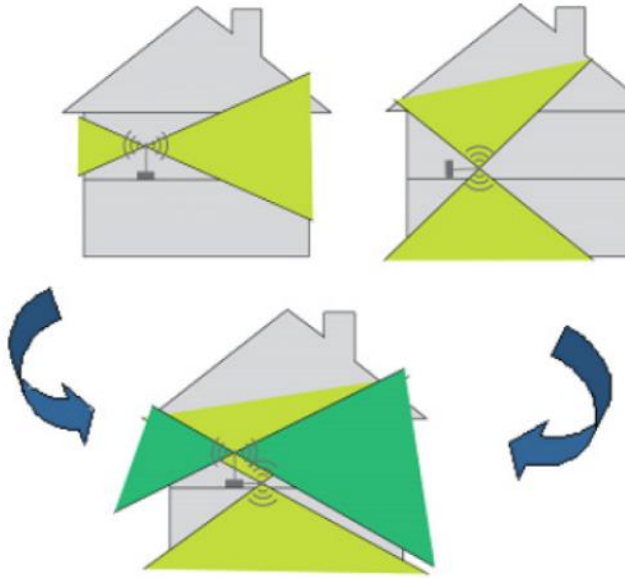
Antenna Diversity

How Antenna Diversity can Improve Performance

- **Improves performance during blocking and multipath fading conditions**
  - Spatial diversity
  - Separation of the antenna by at least ¼ wave
  - Allows one antenna to be out of the null providing better SNR and RSSI
  - Monitors both antennas during preamble and selects antenna
  - Improves the performance in multipath environments by about a 6 dB



- **Polarization can be used to provide better antenna coverage**
  - Most antennas have some type of polarization
  - Antennas are placed at 90 degrees to compensate for polarization
  - Provides better coverage vs same plane
  - May not be as big of an issue in buildings due to the multpath



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Why Does the Chip Design Matter for Antenna Diversity?

- **How quick can it switch antennas**
  - Antenna switch time + control latency
- **How quick does the RF settle**
  - Front-end settling time after a switch
- **How quick can it can detect a preamble**
  - Preamble/access-address detect latency
- **How reliable does it measure the packet quality**
  - Quality metric reliability & decision confidence
- **What is the insertion loss of the switch**
  - Loss can vary based on an internal or external switch

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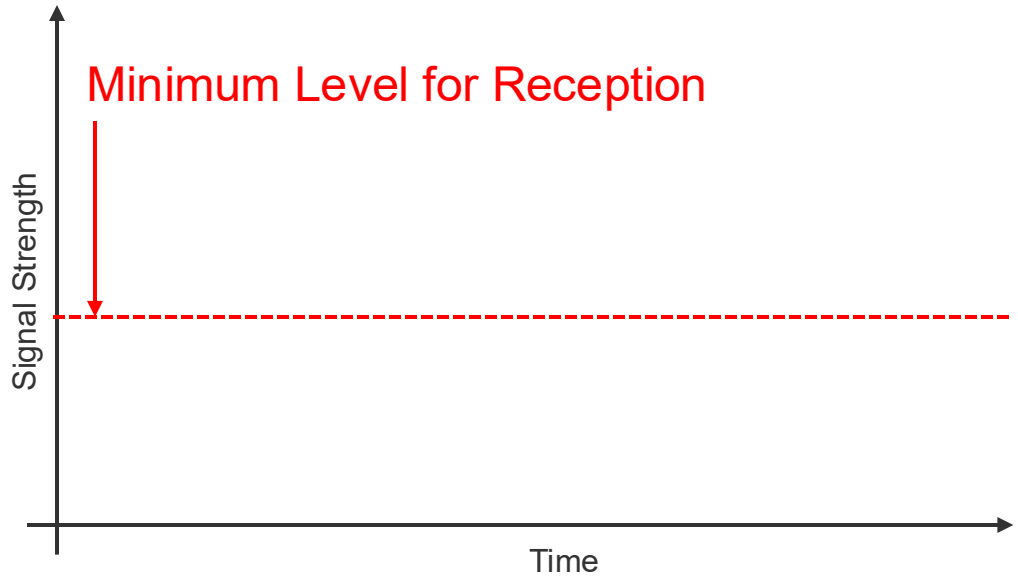
Antenna Diversity Results – Antenna 1

- **Red line represents the minimum signal level for reception**



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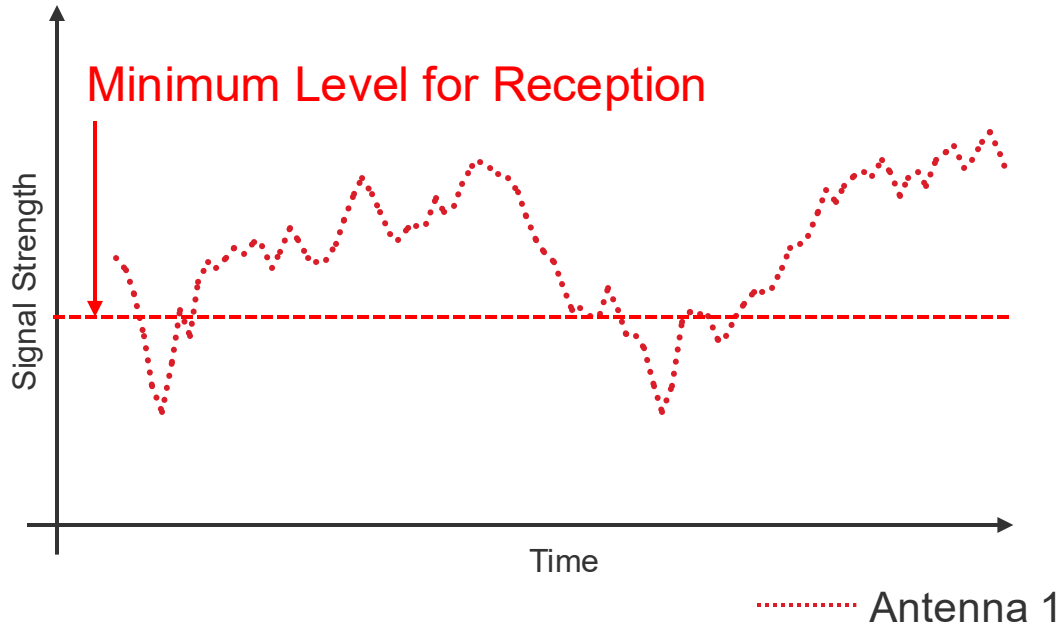
Antenna Diversity Results – Antenna 1

- Red line represents the minimum signal level for reception
- **Signal levels received vary, due to reflections and movements of people or objects in the environment**



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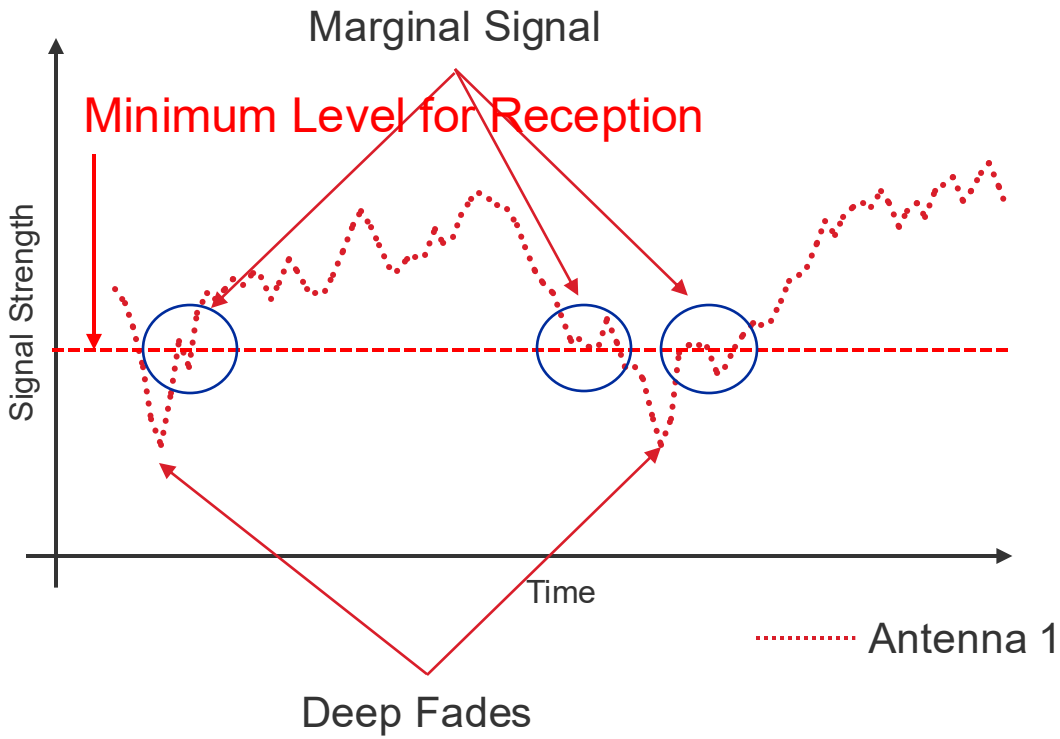
Antenna Diversity Results – Antenna 1

- Red line represents the minimum signal level for reception
- Signal levels received vary, due to reflections and movements of people or objects in the environment
- **Without diversity, some packets will not be received**
  - Results in loss of data or source needs to retransmit



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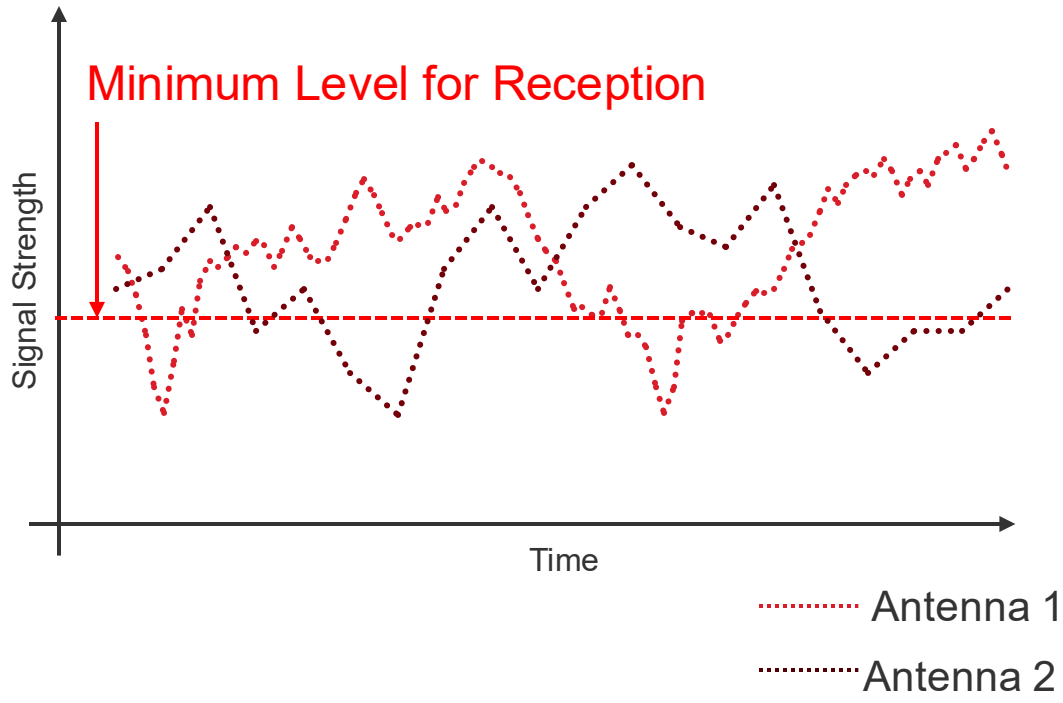
Antenna Diversity Results – Antenna 1 + Antenna 2

- Red line represents the minimum signal level for reception
- Signal levels received vary, due to reflections and movements of people or objects in the environment
- Without diversity, some packets will not be received
  - Results in loss of date or source needs to retransmit
- **Antenna Diversity enables a second antenna**



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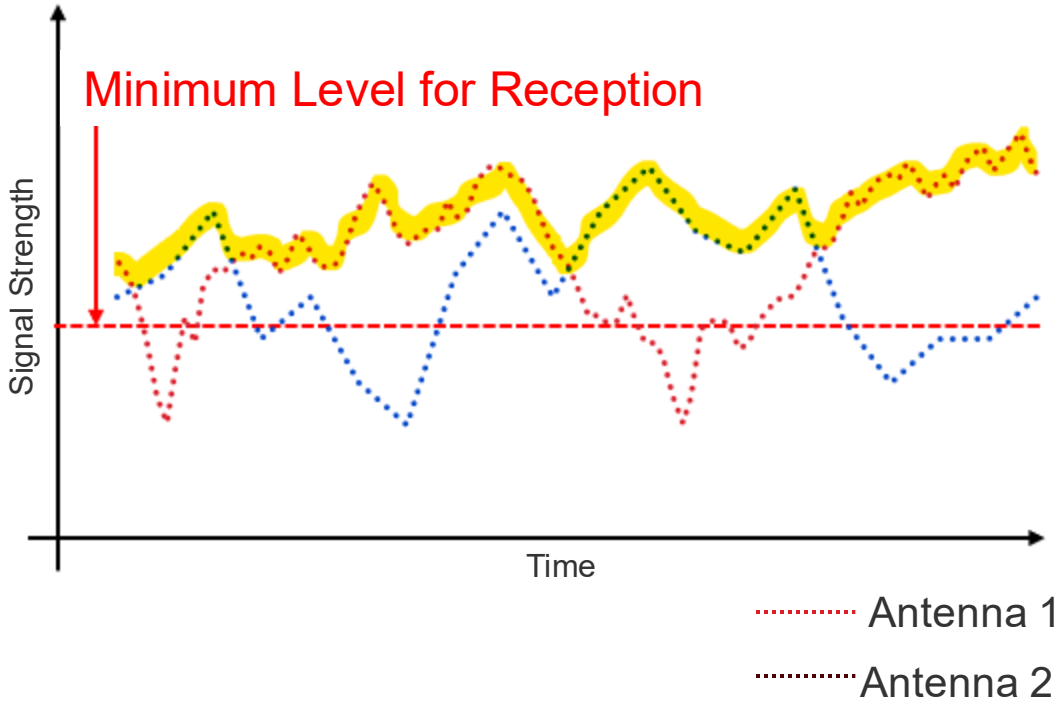
Antenna Diversity Results – Select Best Antenna

- Red line represents the minimum signal level for reception
- Signal levels received vary, due to reflections and movements of people or objects in the environment
- Without diversity, some packets will not be received
  - Results in loss of date or source needs to retransmit
- Antenna Diversity enables a second antenna
- **Selects the better signal between the 2 antenna**
  - Reduces or eliminates nulls and marginal signals



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Silicon Labs Antenna Diversity Support

- **Select First Good**
  - Selects the first antenna that is able to receive a valid preamble
    - May not be the “best” signal
- **Select Best**
  - Monitors both antenna and selects the antenna with a better signal during the preamble
    - Choose RSSI-based diversity if:
      - You need to minimize the receiver's on-time and power consumption.
      - Your application can tolerate a slightly less reliable antenna choice in exchange for speed.
    - Choose Correlation-based (CORR) diversity if:
      - You are operating in a noisy or interference-heavy environment and require a more stable, robust connection.
      - Your application prioritizes reliability and performance over minimizing the preamble length and power consumption.

Device	Diversity Support	Sub-GHz	2.4 GHz	Antenna Diversity Selection	Antenna Diversity Mode	Antenna Switch
EFR32xG21	Yes	N/A	802.15.4	Select First	RSSI	Internal
EFR32xG23	Yes	Proprietary	N/A	Select Best	RSSI or Correlation	Internal
EFR32xG24	Yes	N/A	802.15.4	Select Best	RSSI or Correlation	External
EFR32xG25	Yes	Proprietary, Wi-Sun	N/A	Select Best	RSSI or Correlation	External
EFR32xG26	Yes	N/A	802.15.4	Select Best	RSSI or Correlation	External
EFR32xG28	Yes	Proprietary, Wi-Sun	N/A	Select Best	RSSI or Correlation	Internal

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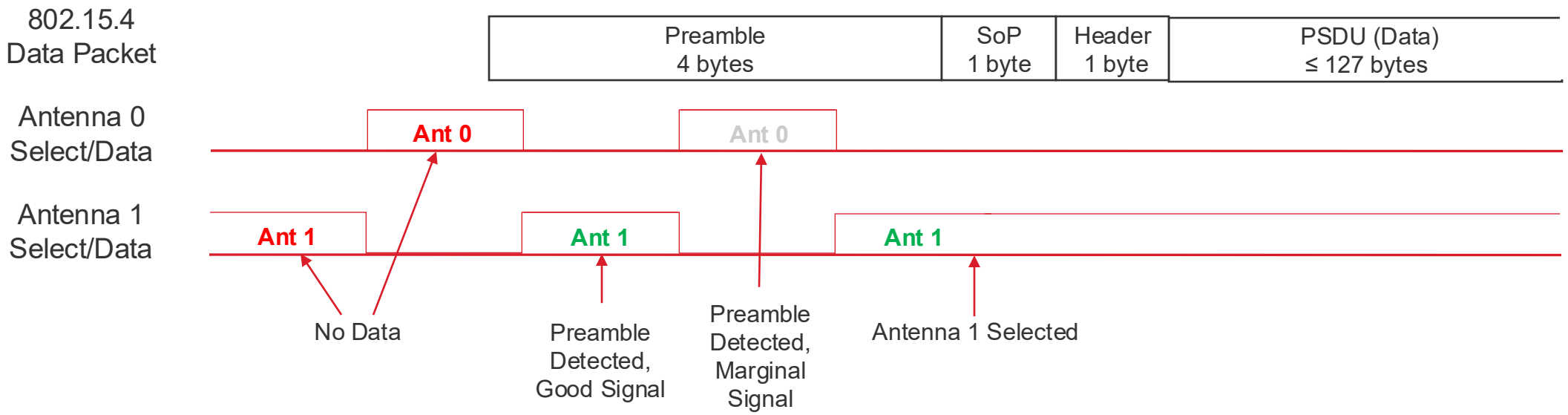
802.15.4 Diversity Example – Select Best



- **Device switches between antenna while in receive mode**
- **During preamble, measures RSSI, correlation, etc.**
  - Shorter duration on one antenna provides less time to detect timing and lock on frequency
    - Results in lower sensitivity vs single antenna implementation
- **Compares information from both antenna**
- **Selects best antenna**
  - TX is generally on the same antenna selected for RX

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What are the Implications and Tradeoffs

- **BOM cost and product size**
  - IC design complexity
  - Additional components needed for diversity
    - Additional matching components on devices
    - External switch or FEM for devices without internal switch
  - Larger product size due to required antenna separation (1/4 wave)
    - 2.4 GHz => ¼ wave of 3.125 cm or 1.23 inches
    - 915 MHz => ¼ wave of 8.2 cm or 3.22 inches
- **Limited to protocols with longer preambles**
  - Depends on preamble length and timing
  - May also limit ability to do Select Best vs Select First Good
- **Potential for reduced baseline sensitivity due to shorter time on preamble**
  - Shorter duration on one antenna provides less time to detect timing and lock on frequency
  - Any loss depends on length of preamble
  - Reduction is offset by reducing multipath fading
- **Antenna Diversity needs can be mitigated by other options to provide “good enough” performance**
  - Mesh provides multiple paths for a packet to make it to the destination vs a single point to point link
  - Frequency hopping provides “frequency diversity” over time by mitigating frequency specific fading
  - Forward Error Correction (FEC) adds redundant bits to allow receivers to detect and correct bit errors
  - Protocol retries may provide an acceptable level of performance by retrying missed packets

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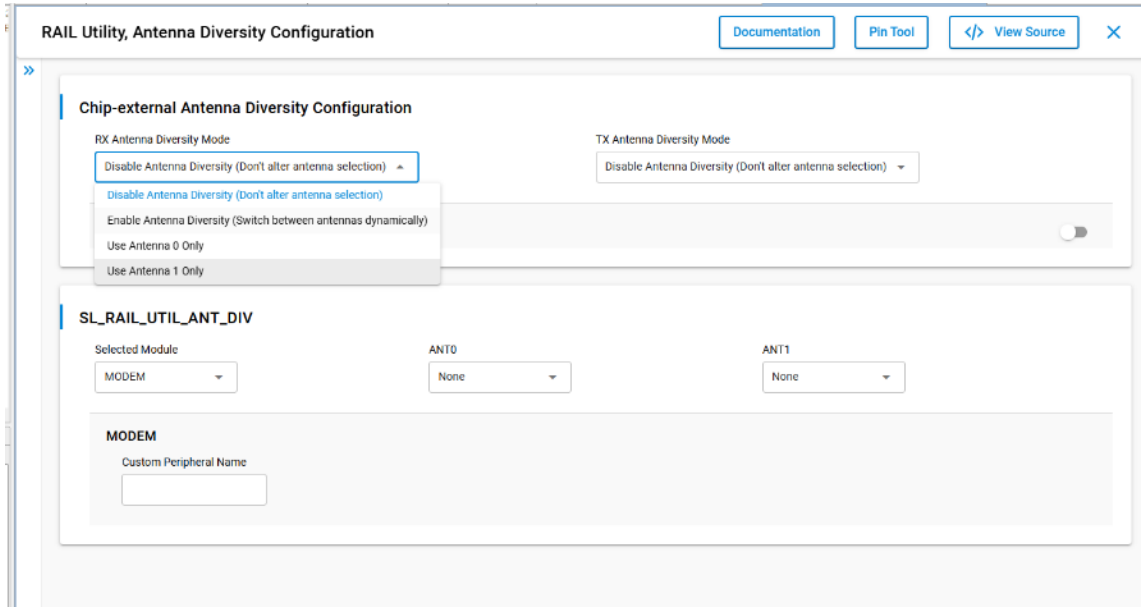
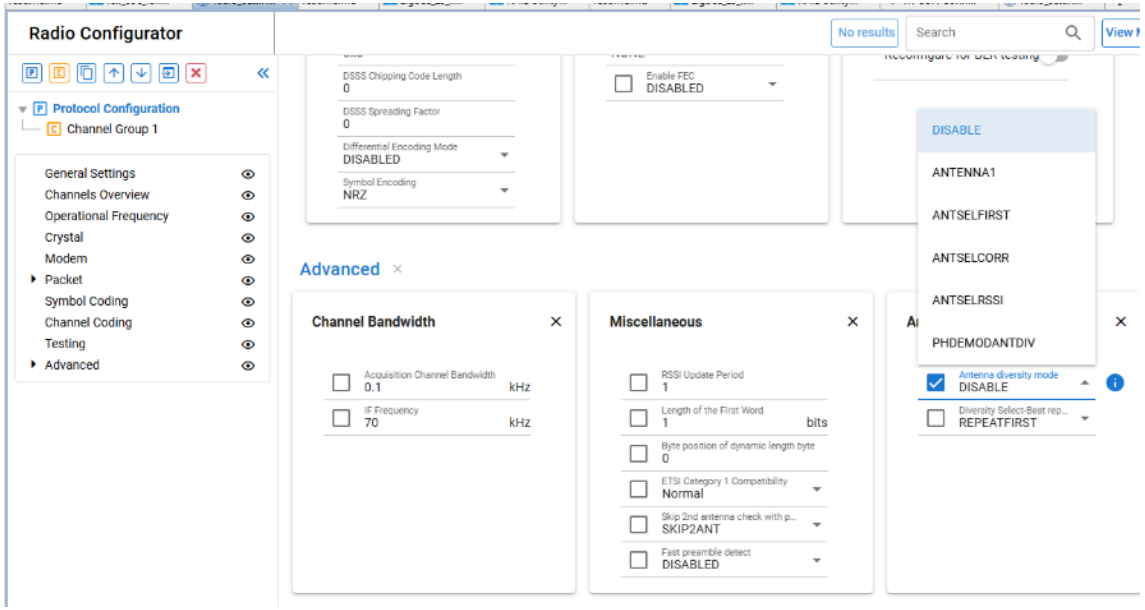
Enabling Antenna Diversity in Studio

- **802.15.4 (Zigbee, Thread, Matter over Thread)**
  - Go to Radio under Software Components



- **Sub-GHz**
  - Use Radio Configurator for Sub-GHz



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Antenna Diversity Summary

- **Antenna diversity can provide a better link and performance vs single antenna**
  - Provide ~6 dB improvement on average
    - Deep fades can be as much as 30 dB
  - More important in areas with strong multi-path
    - Commercial and industrial settings
- **Adds size and cost to the product**
  - Additional components needed for diversity
  - Larger product size due to required antenna separation (1/4 wave)
    - 2.4 GHz = 3.125 cm or 1.23 inches
    - 915 MHz -= 8.2 cm or 3.22 inches
- **Limited to protocols with longer preambles**
  - 4-byte preamble is often the lower limit
    - 802.15. is 4-byte preamble
    - Proprietary protocols often have longer preambles
  - BLE is not typically not supported due to short preambles (1 to 2 bytes)
- **Product developers need to understand the cost/benefit of implementing antenna diversity**
  - If antenna diversity was “free” everybody would have it

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