Tech Talks LIVE Schedule – Presentation will begin shortly
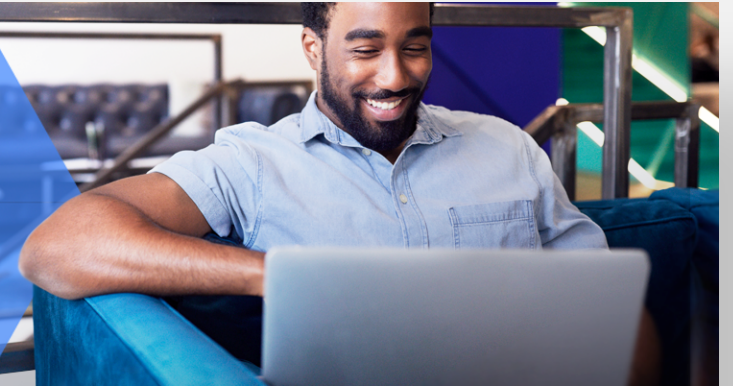
Tuesday, June 8	**Implement a Bluetooth AoX Solution with BG22**
Tuesday, June 22	Understand the Benefits of Wi-SUN for Long Range Industrial Applications
Tuesday, July 13	Learn to use Machine Learning for Predictive Maintenance
Tuesday, July 27	Simplify your Bluetooth Designs using Python Scripts
Tuesday, August 10	Quick Start your Bluetooth Designs for Pulse Oximetry and Electric Shelf Labels
Tuesday, August 24	Works With: Make the Most of WW 2021

Respond to the poll to enter to win a BG22 Thunderboard

Recording and slides will be posted to: www.silabs.com/training

We will begin in 0:00

WELCOME

Implementation of an AoA
Solution using BG22

Jake Johnson - Host
Rich Lysaght - Presenter

Agenda

- Review How Angle of Arrival Works

- AoA System Level Description

- Using BG22 in AoA Designs

- Example Asset Design

- Antenna Array Evaluation Kit

- AoA Asset Tags

- AoA Locators

- AoA Multi-Locator

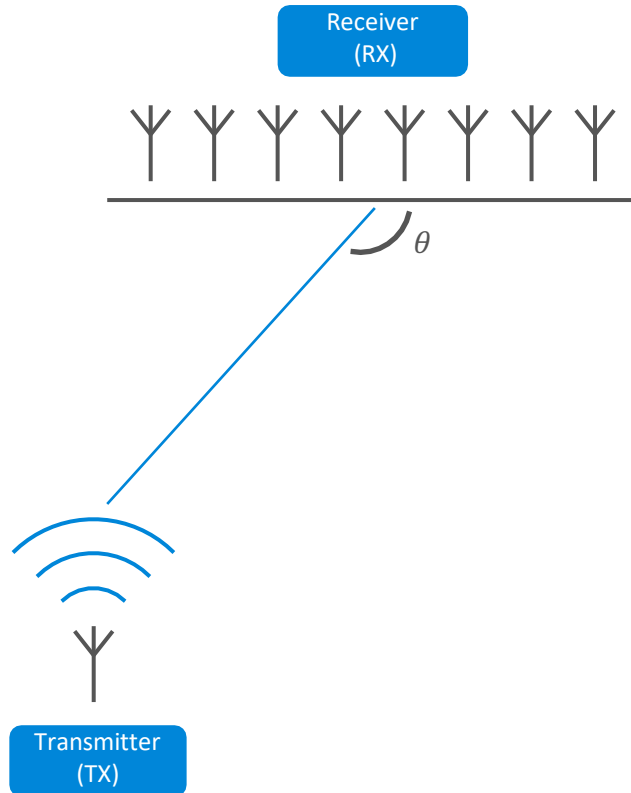- AoA Antenna Array (Locator) Recommendations

- Demonstration

AoA Overview

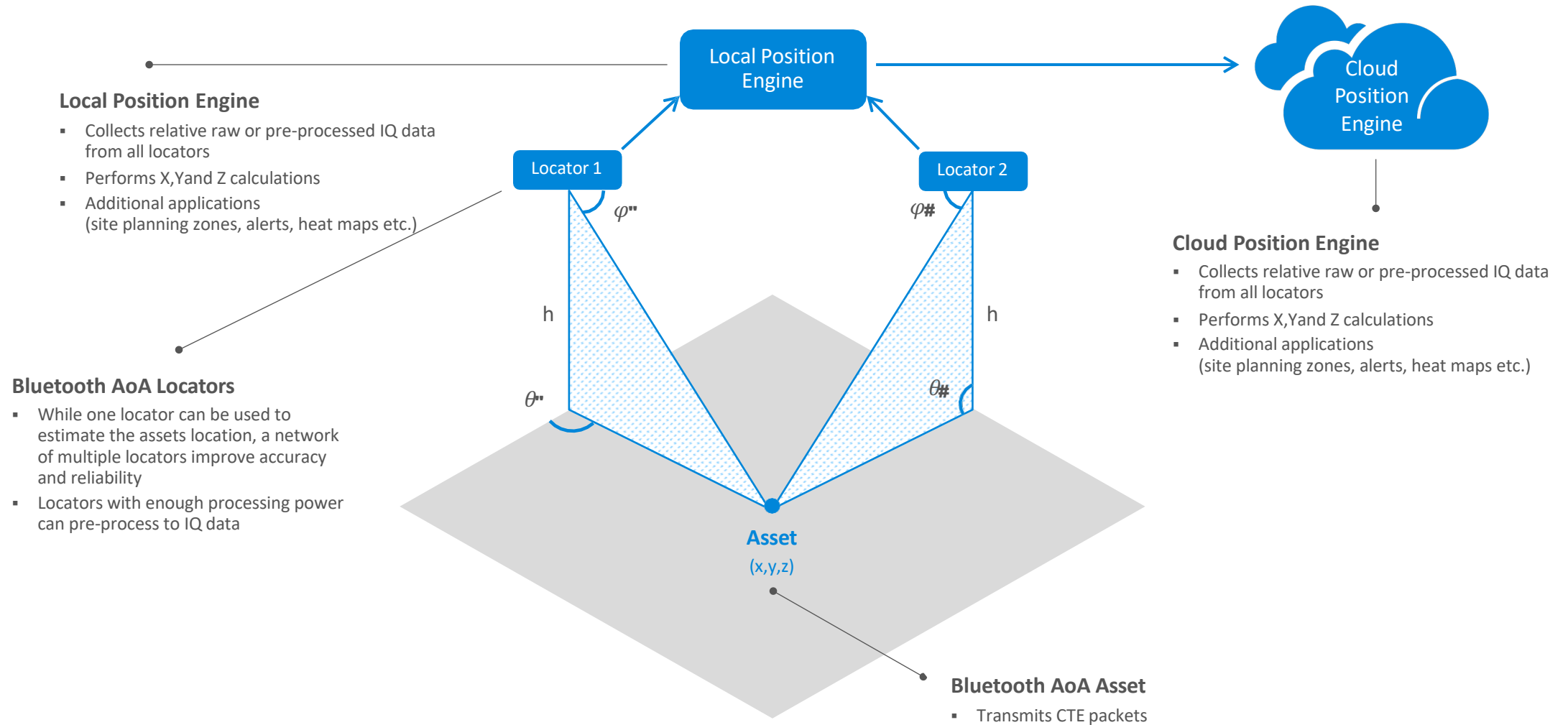JUNE 2021

How Angle-of-Arrival (AoA) Works?

An asset wants to broadcast its location

- Continuous tone extension (CTE) is added to the end of a Bluetooth advertisement or connection packet
- Asset can support other Bluetooth functions while being tracked as CTE does not use the payload

A locator wants to find the asset

- A locator needs to have multiple antennas, as antenna is switched during the CTE reception
- A locator listens for CTE packets and measures IQ data from the CTE payload
- Can perform spherical azimuth and elevation calculation, or pass the IQ data forward to back-end processing

How AoA Works at a System Level?

Local Position Engine
- Collects relative raw or pre-processed IQ data from all locators
- Performs X,Y and Z calculations
- Additional applications (site planning zones, alerts, heat maps etc.)

Bluetooth AoA Locators
- While one locator can be used to estimate the assets location, a network of multiple locators improve accuracy and reliability
- Locators with enough processing power can pre-process to IQ data

Cloud Position Engine
- Collects relative raw or pre-processed IQ data from all locators
- Performs X,Y and Z calculations
- Additional applications (site planning zones, alerts, heat maps etc.)

Bluetooth AoA Asset
- Transmits CTE packets

Local Position Engine

Cloud Position Engine

Locator 1

Locator 2

φ''

$\varphi\#$

h

h

θ''

$\theta\#$

Asset
(x,y,z)

BG22: Optimized for Asset Tags

Optimized

Secure Bluetooth 5.2 SoCs for High-Volume Products

Radio
Bluetooth 5.2
+6 dBm TX
AoA & AoD

Ultra-Low Power
3.6mA Radio TX
2.6mA Radio RX
1.4uA EM2 with 32kB RAM
0.54uA in EM4
RTC in EM4

World Class Software
Bluetooth 5.2
Bluetooth mesh LPN
Direction Finding

Compact Size
5x5 QFN40 (26 GPIO)
4x4 QFN32 (18 GPIO)
4x4 TQFN32 (18 GPIO)

ARM Cortex-M33 with TrustZone
76.8 MHz with FPU and DSP
352/512kB of flash
32kB RAM

Peripherals Fit for Purpose
2x USART, 2x I2C, 2x PDM and GPIO
12-bit ADC (16 channels)
Built-in temperature sensor with +/- 1.5°C
32kHz, 500ppm PLFRCO

Security
AES128/256, SHA-1, SHA-2 (256-bit)
ECC (up to 256-bit), ECDSA and ECDH
True Random Number Generator (TRNG)
Secure boot with RTSL
Secure debug with lock/unlock

Extending Battery Life in Bluetooth Applications

10+ years on a coin cell battery

SILICON LABS BG22
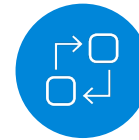
Data Transfer	Location Services
Connected to a phone at 2000ms interval	Advertising 10 bytes every 1000ms
Using 2M PHY and transmitting 10 Byte / packet	TX at 0dBm and using 1 channel
Average current: 4.2µA	Average current: 3.7µA

5+ years on CR2032
10+ years on a CR2354

BG22 Example Tag Design
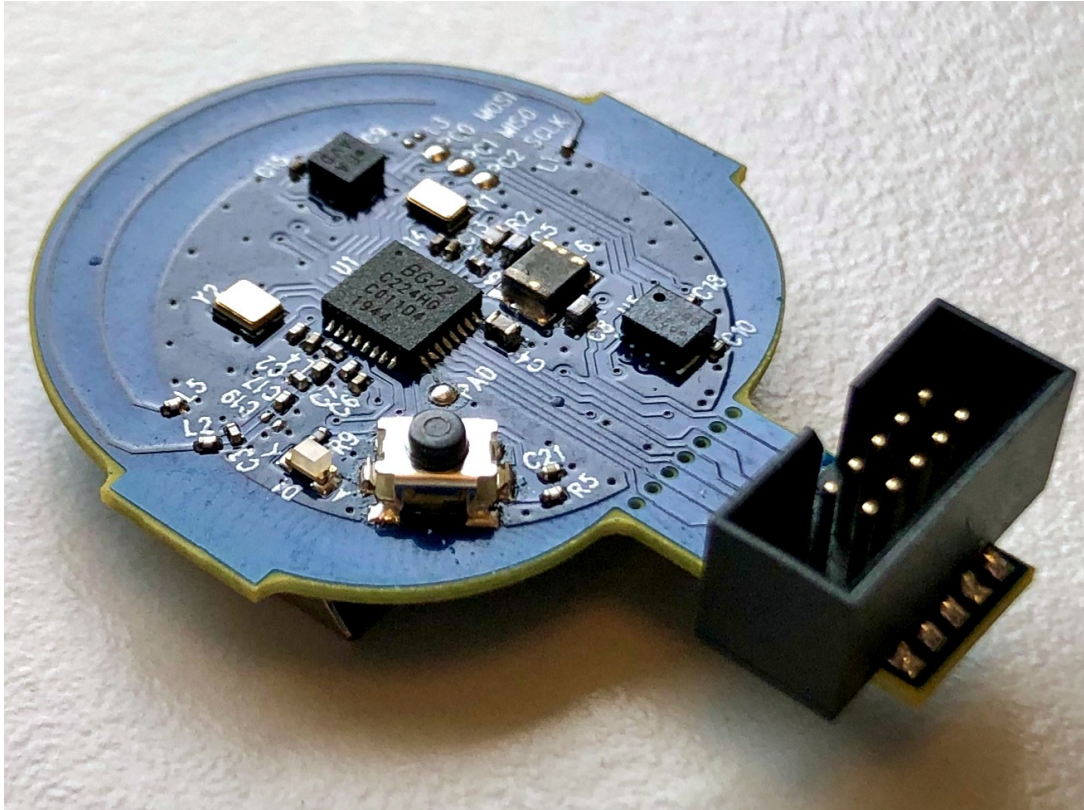
BG22 Based Tag Reference

- EFR32BG22C112 4x4 QFN32
- Built in PCB antenna
- 1 or 2x XTALs
- Accelerometer for wake-on motion
- RFSENSE for wake-on radio
- Button for wake-on by user
- Barometer for height detection
- CR2032 battery holder
- Mini Simplicity debug connector
- Slightly larger than CR2032

BG22 benefits for tags

- Extremely low power
- EM4 wake-ups from via I/O or with RTC
- RFSENSE wake-on radio for RF wake-ups (commissioning, proximity wake-up etc.)
- Possibility to use 1x HF XTAL
- Built-in temperature sensor
- AoA, AoD and Quuppa compatible

Bluetooth Direction Finding for Locators and Gateways
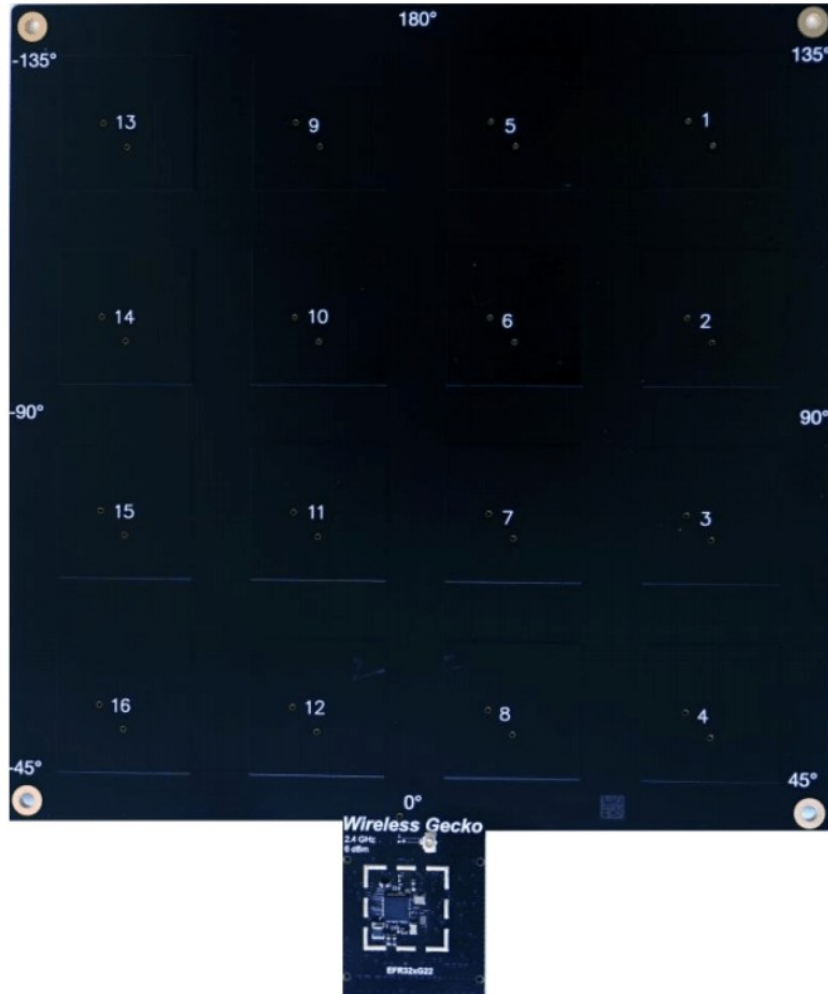
BG22 SoC Provides Best AoA Performance

- 1 degree accuracy with the SoC
- Both 1M and 2M PHY support
- Extremely good sensitivity

4x4 antenna array for best performance

- 4x4 for best accuracy and robustness
  - <5 degrees of accuracy
- 5x 1-to-4 Skyworks' RF switches (~$1)
- PCB patch antennas with circular polarization
- Half dome radiation pattern
- 4-layer PCB

AoA Application Development – RTL (Run Time Library)

AoA Asset Tags
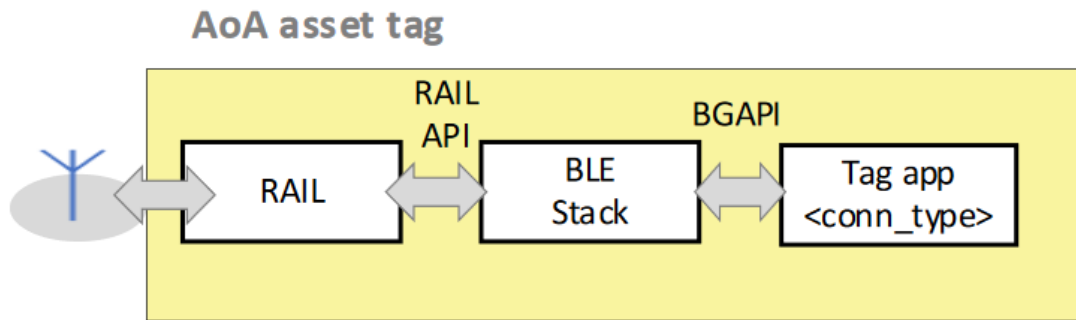
Figure 2-1. Bluetooth – SoC Asset Tag

AoA Asset Tags – CTE Transmitters

- Bluetooth 5.1 **Connection Based** AoA Asset Tag
  - Sends CTE responses on a connection when a CTE request is received
- Bluetooth 5.1 **Connectionless** AoA Asset Tag
  - Sends CTE in periodic advertisements
- **Silicon Labs Enhanced** AoA Asset Tag
  - Sends CTE in extended advertisements

Creating an AoA Asset Tag Application
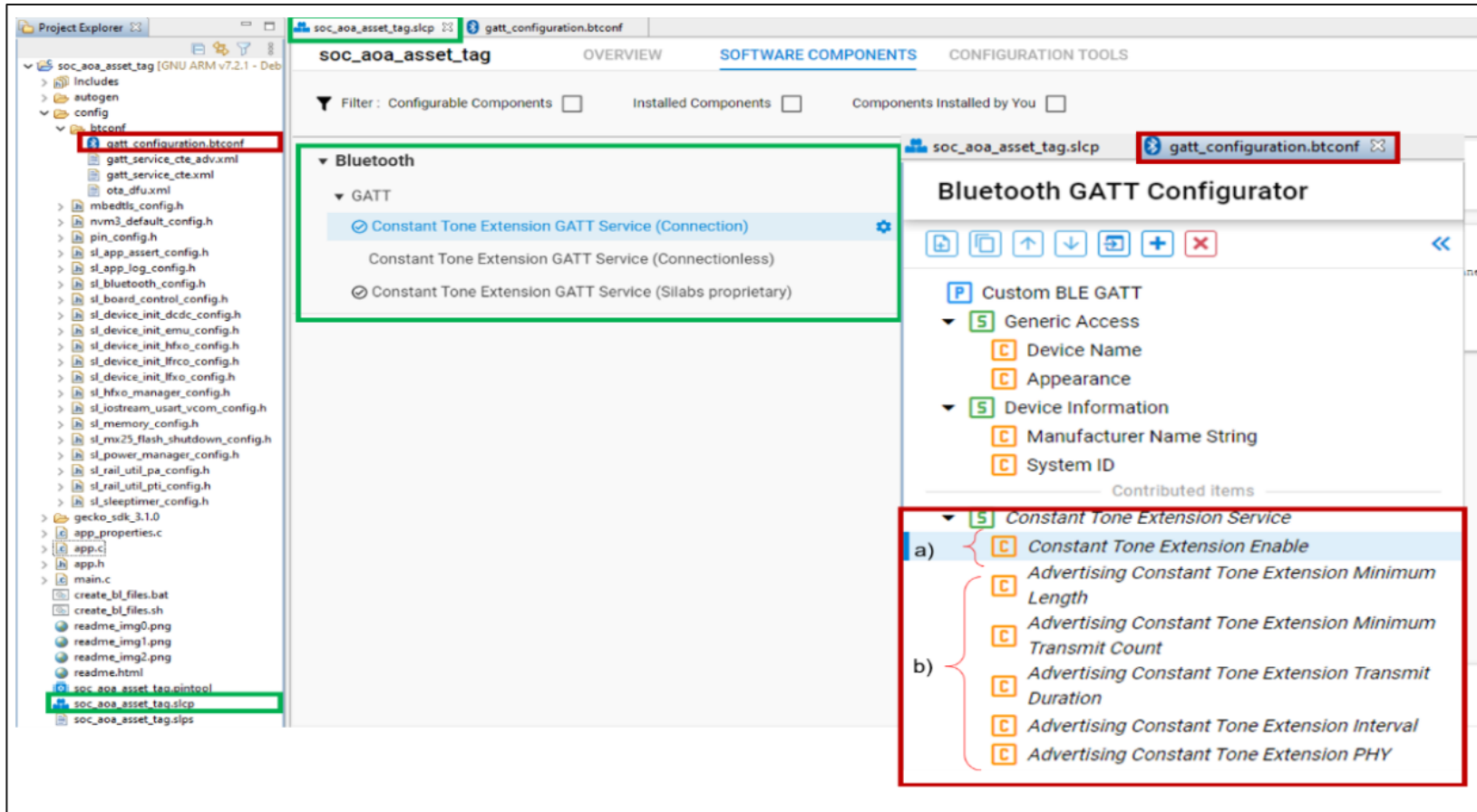
GATT Configuration
- Add CTE Service to BLE GATT
- Characteristics Control
    - Length
    - Transmit Count
    - Transmit Duration
    - Interval
    - PHY

AoA Locators

AoA Locator
- Much more complicated than asset tags
- Need to precisely sample incoming signal and calculate the angle and position estimations from received signal
- Because of processing constraints, example applications work in an NCP (Network Co-processor Mode)
  - Bluetooth Stack runs on EFR32
  - Application runs on a host processor or PC
- Windows, Linux & Raspberry Pi Sample Applications available.

Figure 3-1. AoA Locator
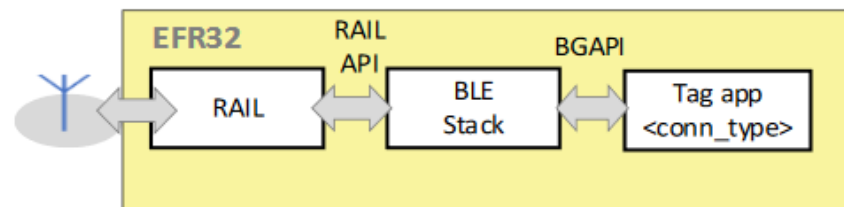
AoA Multi-Locator Sample Application
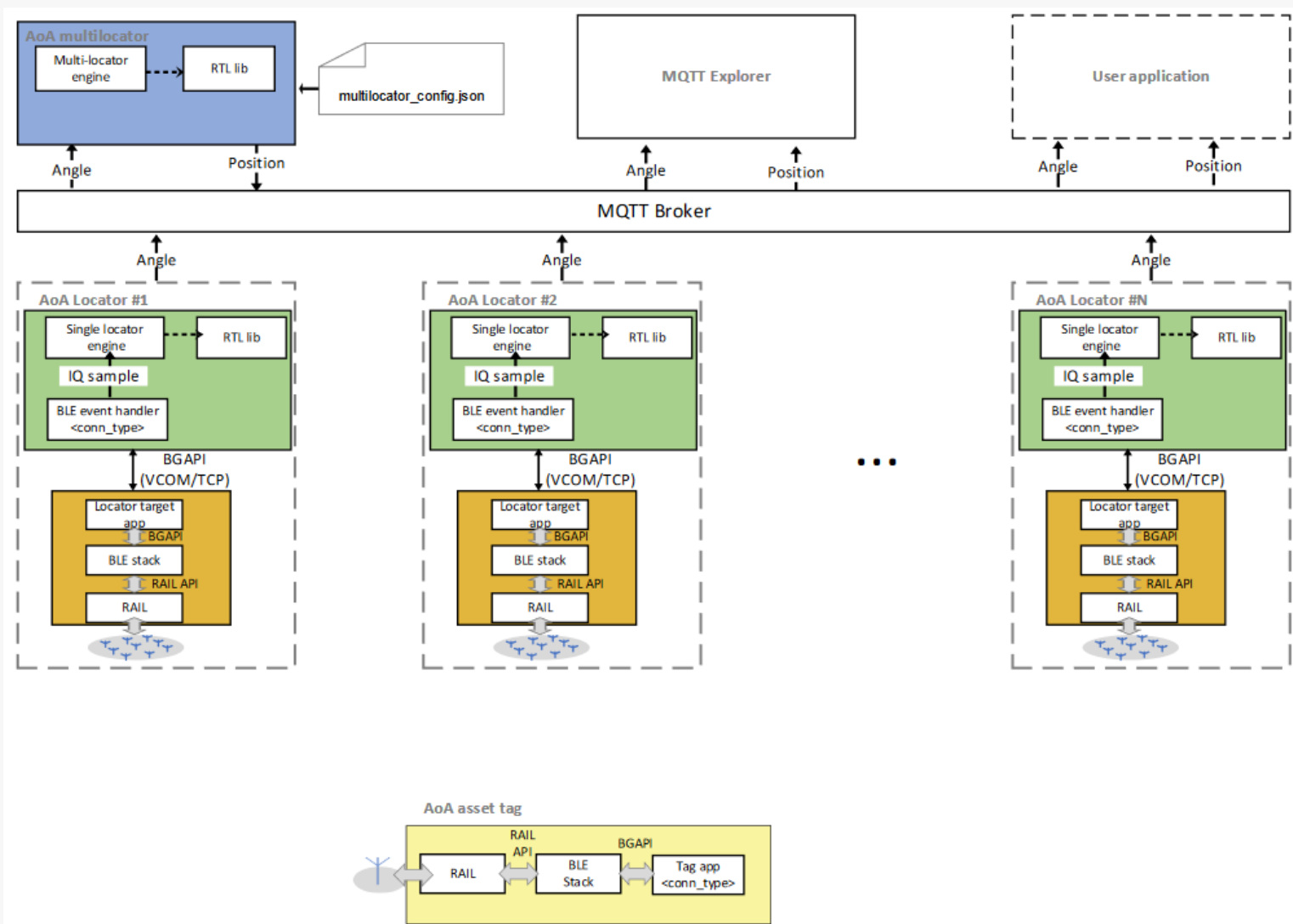
Figure 4-1. Multi-Locator AoA Architecture

AoA Multi-Locator

- Only rough estimation of position can be determined from a single AoA Locator
- To determine more accurate location with need to use multiple locators.
- Triangulation is used to determine position of Asset Tag

# AoA - Antenna Array Design

General Antenna Recommendations
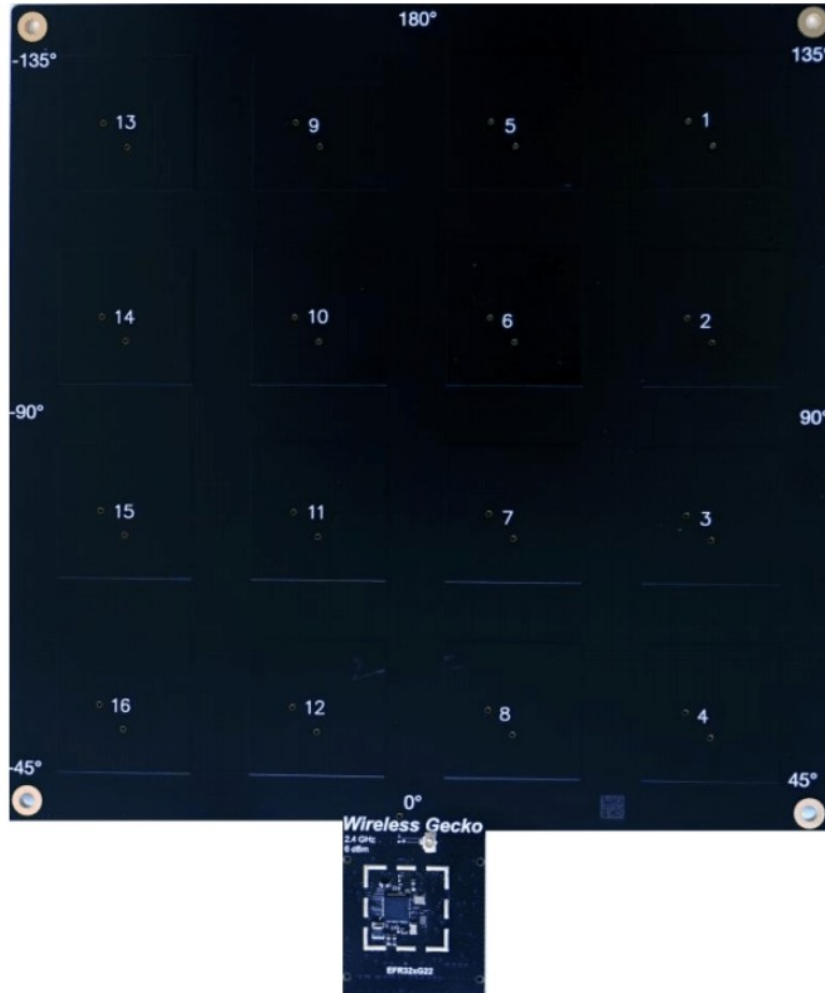
Silicon Labs recommends copying the antenna array structure from the reference design as-is to minimize any issues caused by improper antenna design

Key Antenna Parameters
- Single Antenna Dimensions
- Distance Between Single Antennas
- Position of Antenna Feed Points
- Hybrid Coupler Dimensions
- Trace Lengths, and Widths Between the Couplers and the Switches
- PCB Dimensions (length, width, thickness)
- PCB Layer Stack-Up

Antenna Array Design

ANTENNA ARRAY TYPE
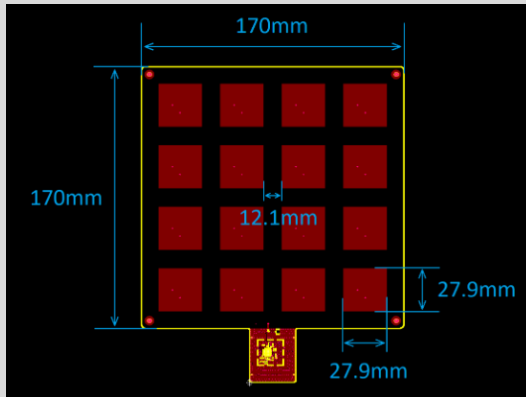
Array Type: Patch Antenna
Phased based angle estimation is dependent on slightly differing path lengths from antenna to antenna
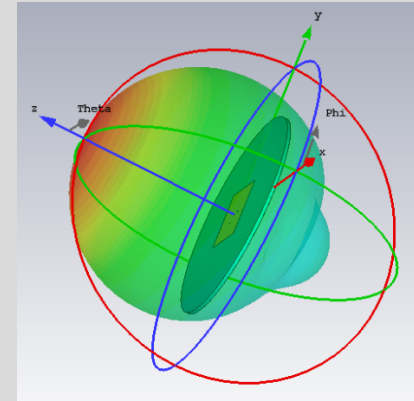
RECTANGULAR PATCH
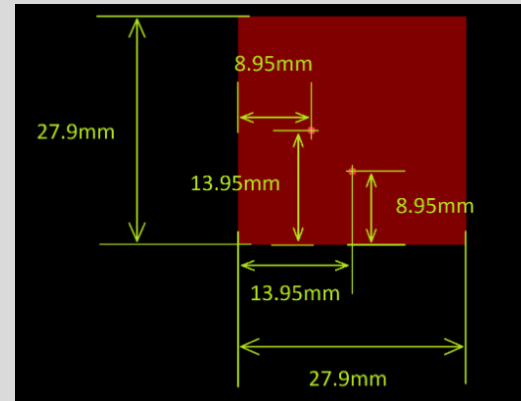
Rectangular Shape Patches:
Array utilizes a 4x4 matrix of patch antennas with 2 feed points. Monopole or chip do not work well for AoA
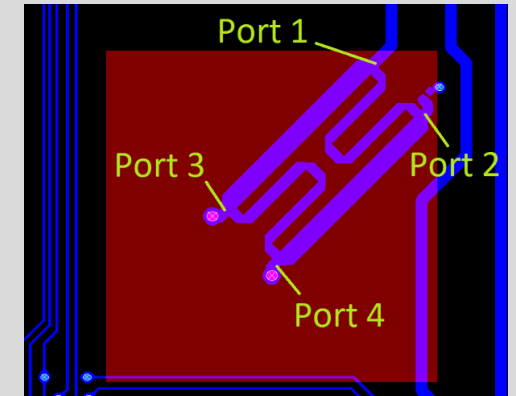
POLARIZATION

Polarization: Circular Pattern
Circular polarization is needed so that antenna is not sensitive to the polarization of incoming signal.
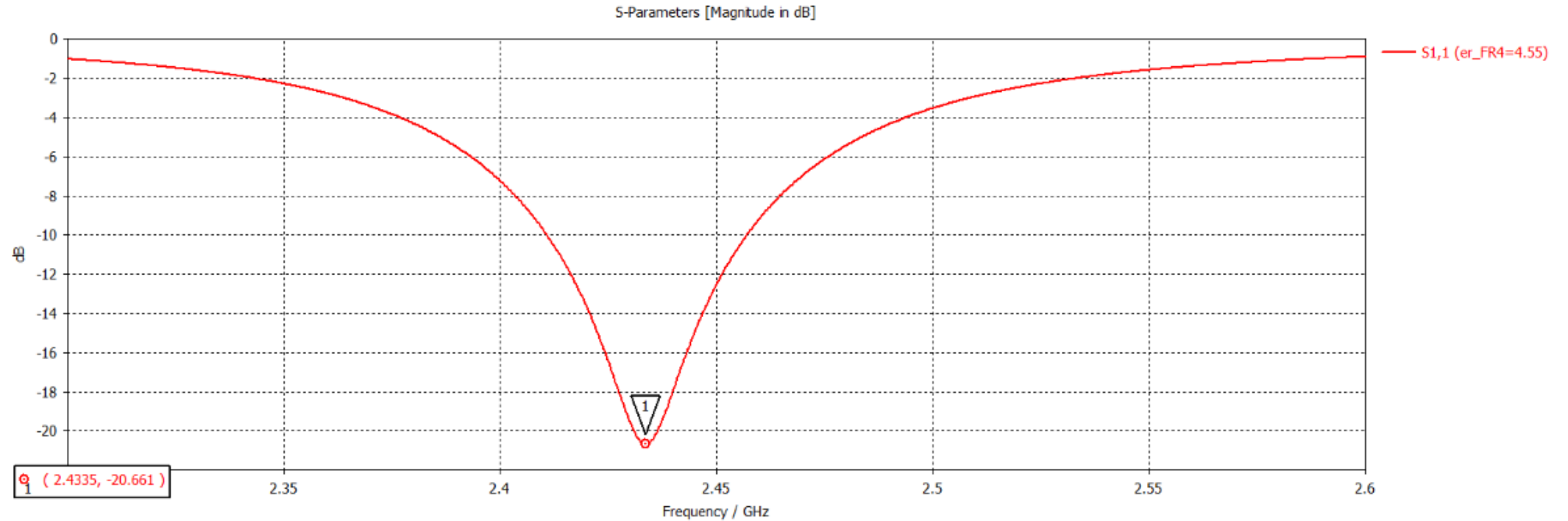
HYBRID COUPLER

Port 1: RF Switch
Port 2: Terminated to GND by 50 ohm resistor
Port 3 & 4: Connected to antenna feed points
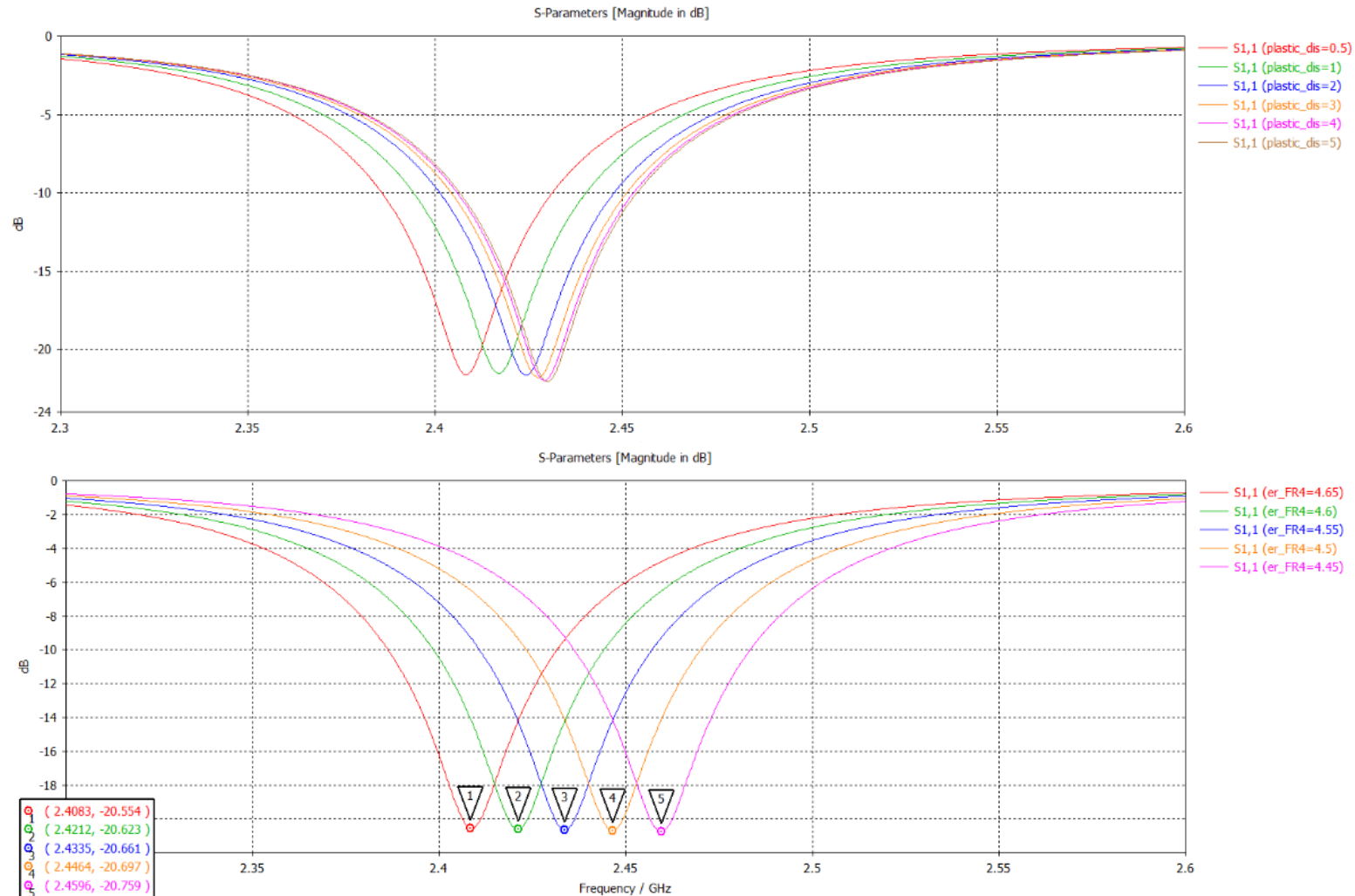
Antenna Resonance

S-Parameters [Magnitude in dB]

1 (2.4335, -20.661)

Antenna Resonance

- Antenna impedance is optimized so that its resonance is in the middle of the Bluetooth band(2.402-2.48GHz)
- Individual antennas of the array are expected to be similar in terms of impedance and return loss

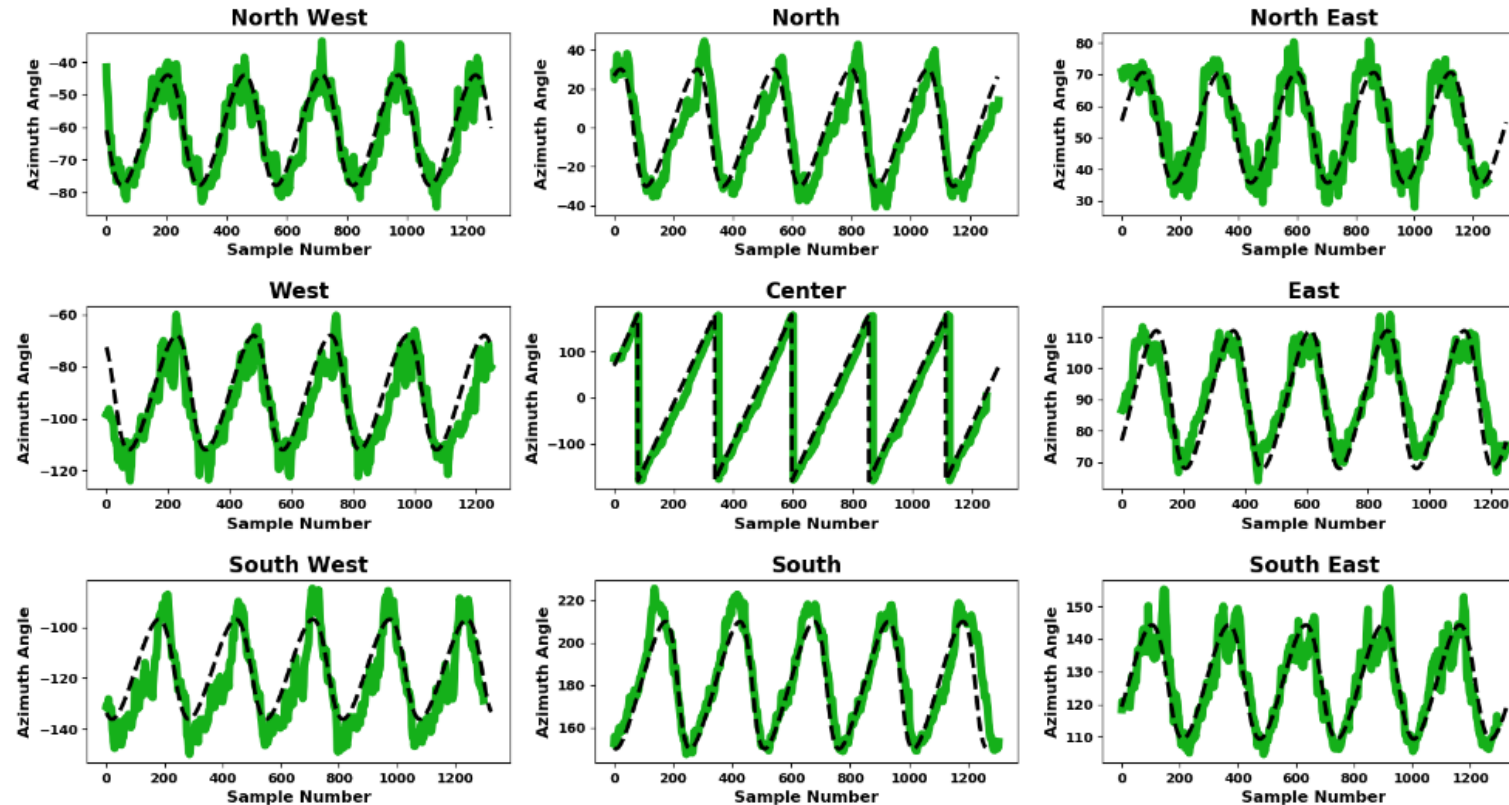# PCB Stack Up and Plastic Enclosure Effects:

Effects of Plastic Case

The distance of plastic case from top of antenna layer can influence antenna impedance and radiation pattern.

PCB FR4 Dielectric Effect

PCB Dielectric Constant has a direct effect on the antenna resonance frequency.

Azimuth Angle Measurement Results:

Azimuth Angle Test
- Indoor, Open Space
- Locator Height 2.7m
- Tag Height 0.5m
- 9 Locations Tested on Turntable
- Tag rotated with turntable in all 9 locations.
- Locator Position Fixed at Center

- **Black Dotted Line:** Expected Ideal Angle
- **Green Line:** Measured Azimuth Angle

AoA Demo

References:

Application Notes

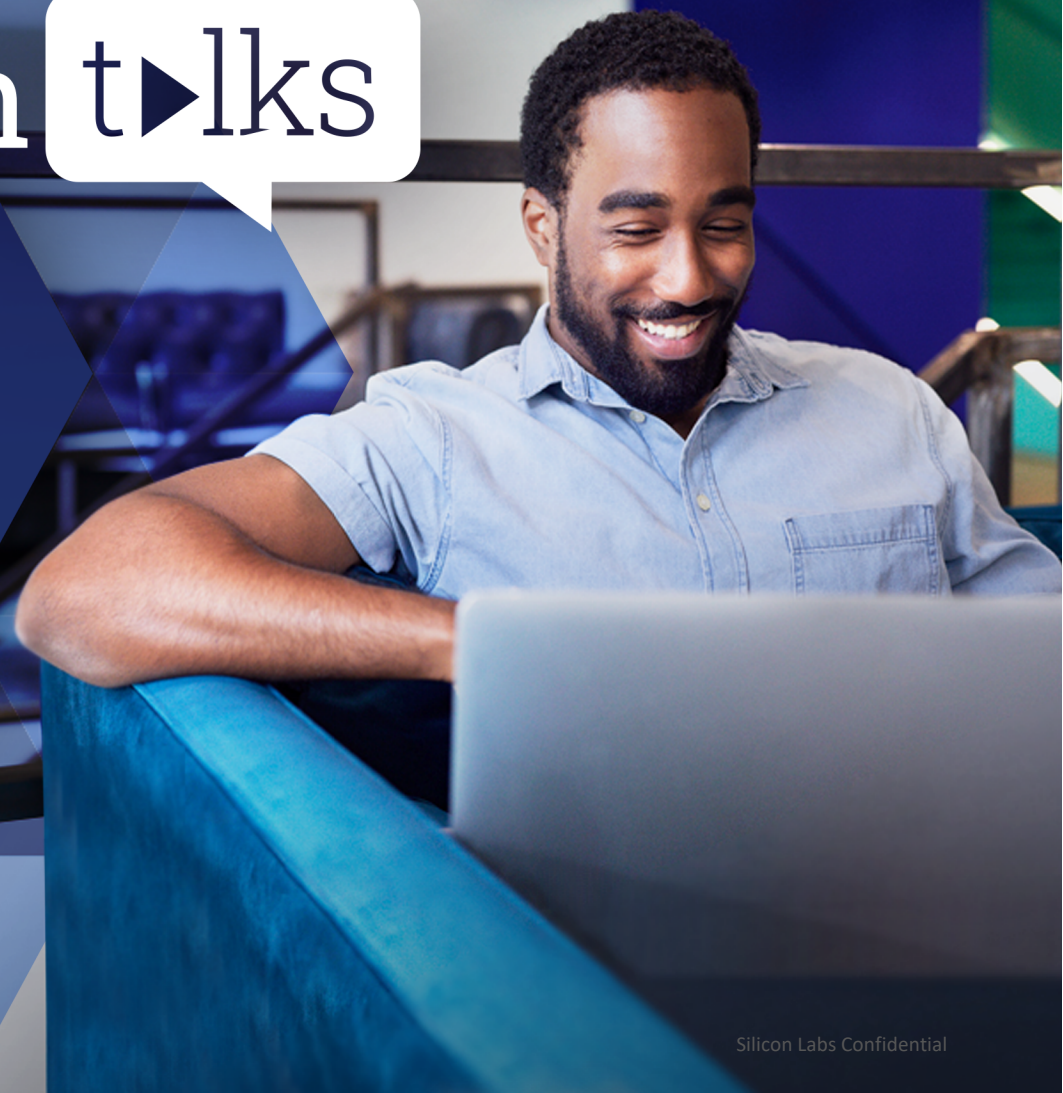- AoA Application Development:
    - https://www.silabs.com/documents/public/application-notes/an1296-application-development-with-rtl-library.pdf
- AoA Antenna Array
    - https://www.silabs.com/documents/public/application-notes/an1195-antenna-array-direction-finding.pdf

AoX Tech Talk – April 2020

- Bluetooth AoX Tech Talk:
    - https://www.silabs.com/support/training/bluetooth-aox-solutions

THANK YOU

Q&A

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