Bluetooth Direction Finding

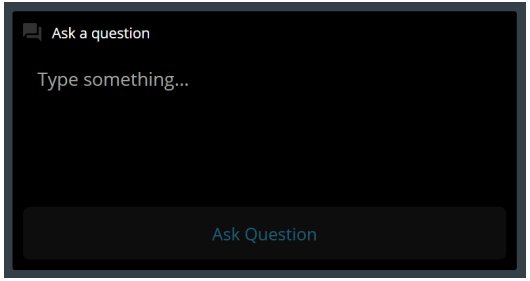
Nordic offering

Paal Kastnes

December 2022

Practicalities

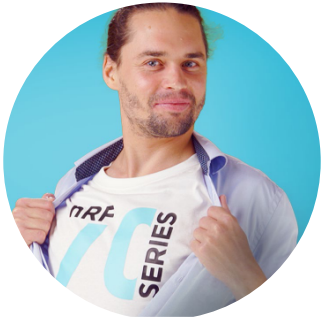
- Duration: about 60 minutes
- Questions are encouraged!
  - Please type questions in the top of the right sidebar
  - All questions are anonymous
  - Try to keep them relevant to the topic
  - We will answer towards the end
- The chat is not anonymous, and do not use for questions
- Go to DevZone if you have more questions
- A recording of the webinar will be available together with the presentation at webinars.nordicsemi.com



{ DevZone

Today's Speakers

Finn Boetius



Product Marketing Engineer

Host

Paal Kastnes

Technical Marketing Manager

Speaker

Bluetooth AoA/AoD

Nordic offering

Paal Kastnes

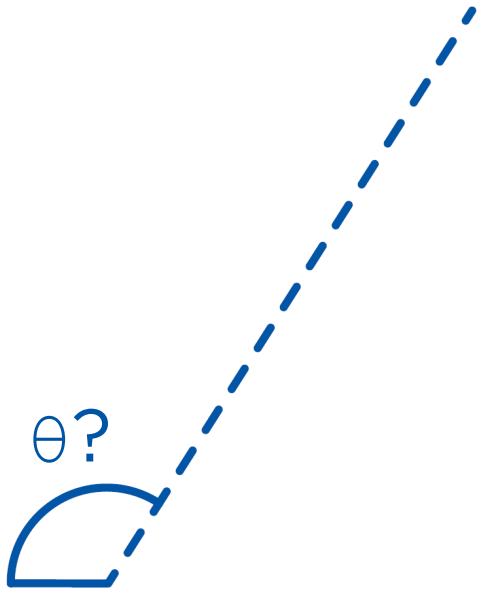
December 2022

Agenda

- Introduction
- AoA vs AoD
- The physics involved in direction finding
- IQ samples and how to use them
- Scope of Bluetooth specification for Direction Finding
- Bluetooth standard data formats
- Connected vs. connectionless
- Periodic Advertising
- nRF Connect SDK samples
- Supported hardware tools
- Partner support
- QA

Introduction to direction finding

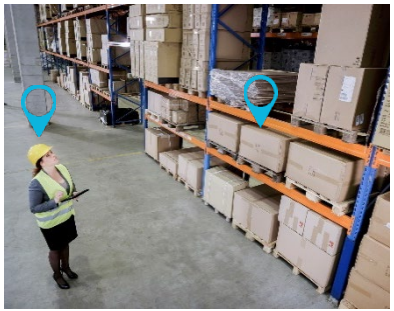
Direction Finding



- Hallmark feature of Bluetooth 5.1 Core Specification
- Requires additional HW radio support
- Optional feature
- Enables positioning solutions based on direction of a signal using phase detection
- First Bluetooth standard to support real life positioning solutions
- Enables cost efficient, ultra low power tags

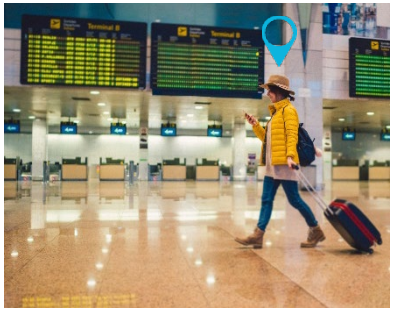
Direction Finding – use cases

Asset tracking



Real-Time Locationing Systems (RTLS)

Wayfinding

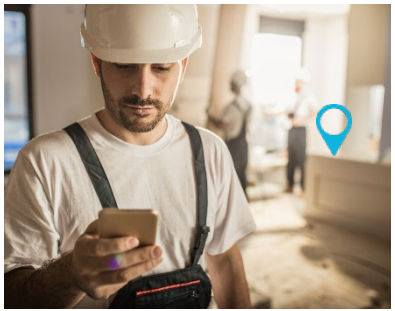


Indoor positioning

Point of interest

Proximity marketing

Item finding



More advanced item finding solutions

Positioning systems

Proximity solutions

Bluetooth qualification

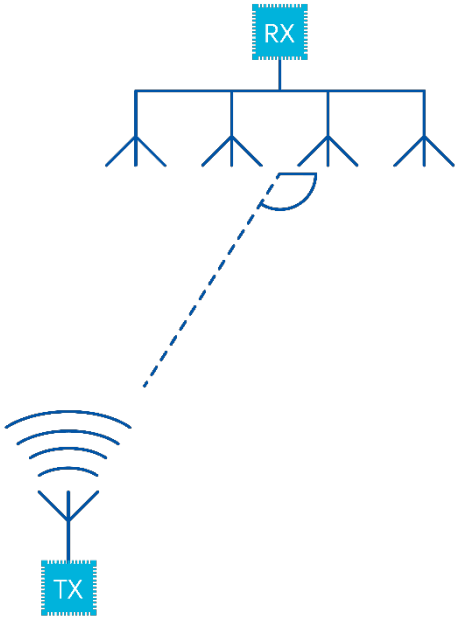
- nRF Connect Bluetooth Host qualified with Direction Finding support for tag 2.1.0
  - Bluetooth Host QDID
- SoftDevice Controller subsystem qualified for AoA transmitter since tag 2.0.0
  - SoftDevice QDID
- Zephyr Controller Subsystem qualified for Direction Finding for tag 2.1.0
  - Zephyr Controller QDID

nRF Connect SDK	Host subsystem		SoftDevice[1] Controller subsystem		Bluetooth mesh	
	QDID	Core spec.	QDID	Core spec.	QDID	Mesh spec.
1.3.1	151074	5.1	154563	5.2	Not planned	-
1.3.2						
1.4.0	Not planned	-	Not planned	-		
1.4.1	157450	5.2	154563	5.2		
1.4.2						
1.5.0						
1.5.1						
1.6.0			170216			
1.6.1						
1.7.0	176697	5.3			178269	1.0.1
1.7.1						
1.8.0						
1.9.0	Not planned		183689			
1.9.1	182626					
1.9.2						
2.0.0	187856		188441 188443[2]	5.3		
2.0.1						
2.0.2						
2.1.0	195971					
2.1.1						
2.1.2						

Table 1. nRF52833 nRF Connect SDK QDIDs

Angle of Arrival (AoA) and Angle of Departure (AoD)

Angle of Arrival (AoA)



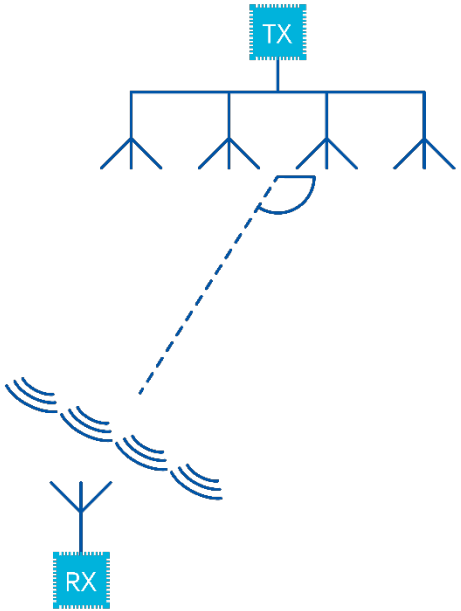
Transmitter

- Simple beacon
- Single antenna required
- No I/Q calculations needed
- Low cost, low power consumption device possible

Receiver

- Antenna array and RF switches required
- I/Q data needed for angle estimation
- Processing power to calculate angles/connection to offload data required
- Higher cost, higher power consumption device

Angle of Departure (AoD)



Transmitter

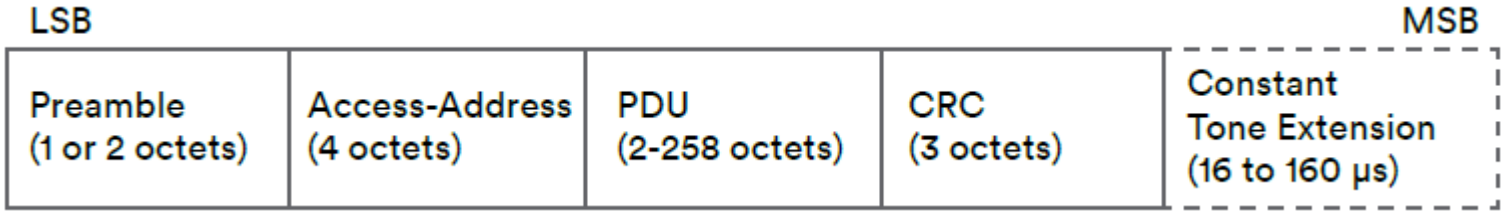
- Advanced beacon
- Antenna array and RF switches required
- No I/Q calculations needed
- Medium cost, low power consumption device

Receiver

- Single antenna
- I/Q data needed for angle estimation
- Processing power to calculate angles/connection to offload data required. Access to antenna design data
- Higher cost, higher power consumption device

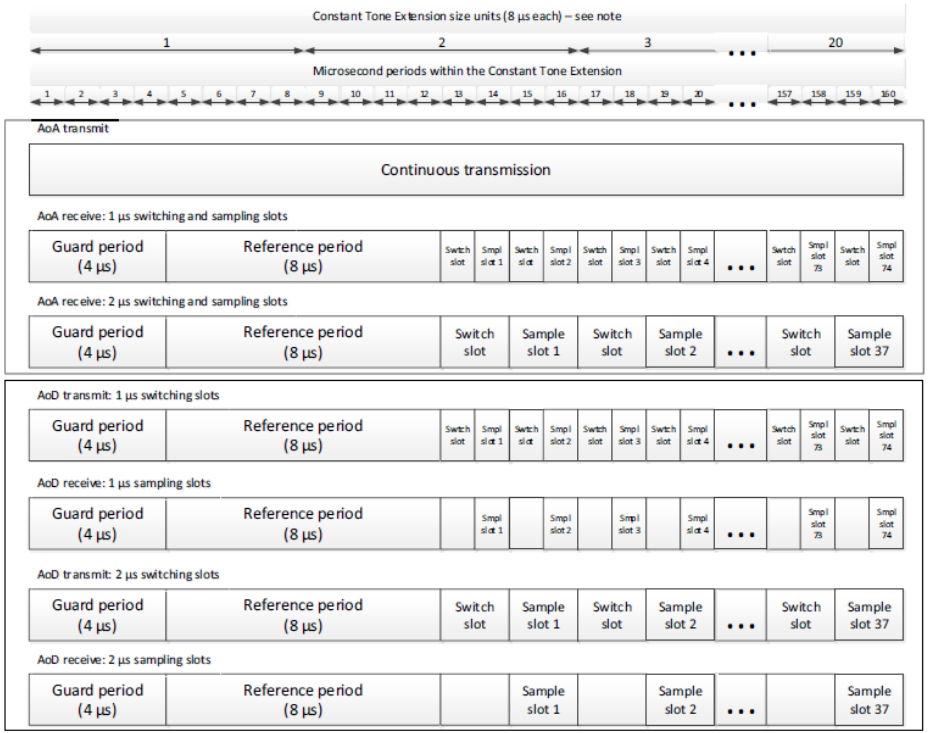
The physics behind direction finding

Constant Tone Extension (CTE)



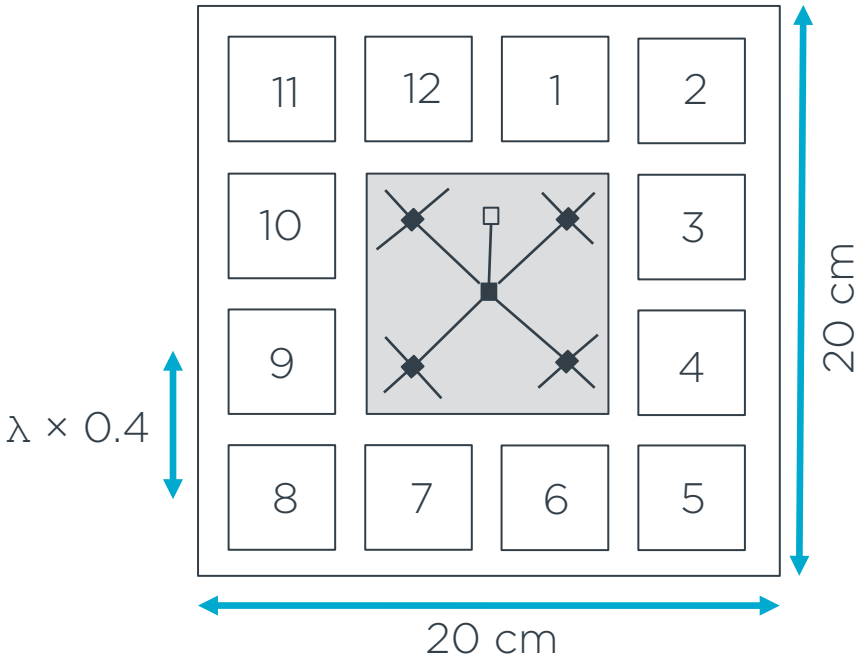
- CTE provides constant frequency signal for IQ sampling
- Unwhitened sequence of 1s (Tone) and is appended after CRC
- Connectionless and connection-oriented modes
- In connectionless, periodic advertising is required (deterministic timing)
- Supported for 1 Mbit and 2 Mbit PHYs

Constant Tone Extension and I/Q sampling



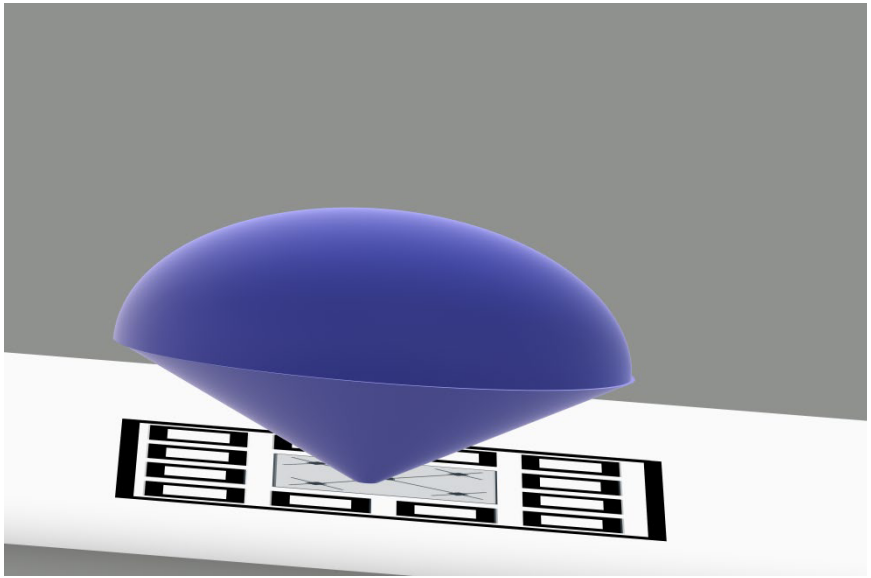
- CTE range: 16 us to 160 us
- Minimum 2 antennas, maximum 38/75 antennas (switch and slot length dependent)
- Guard Period – antenna may switch
- Reference Period – 8 reference I/Q samples
- Switch/Sample slots are 2us or 1us:
  - Switch Slot: Antenna switching period
  - Sample Slot: I/Q sampling period

Antenna array example – patch antennas



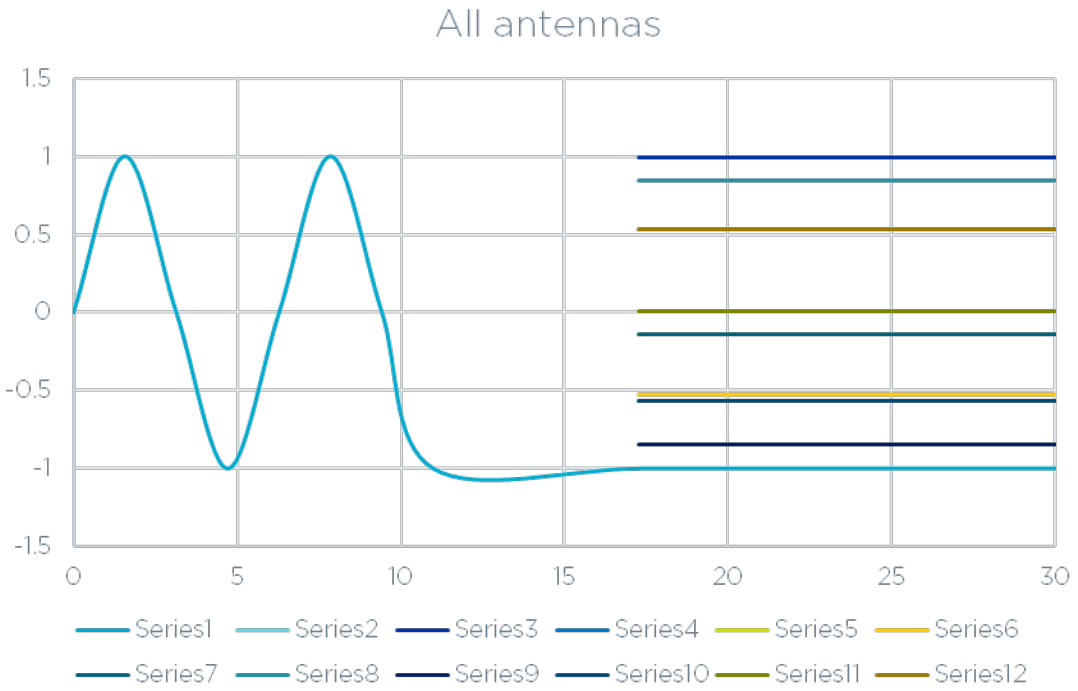
- 12 patch antennas
  - High-performance RF switches
- HW will scan through antennas in pre-defined patterns
  - one antenna set as a reference
- Array design will give 2 angles
  - “Line” antenna design will give 1 angle
- Design files available
  - HW can be purchased from InsightSiP as ISP1907-AOA-DK

Antenna array –Area of coverage



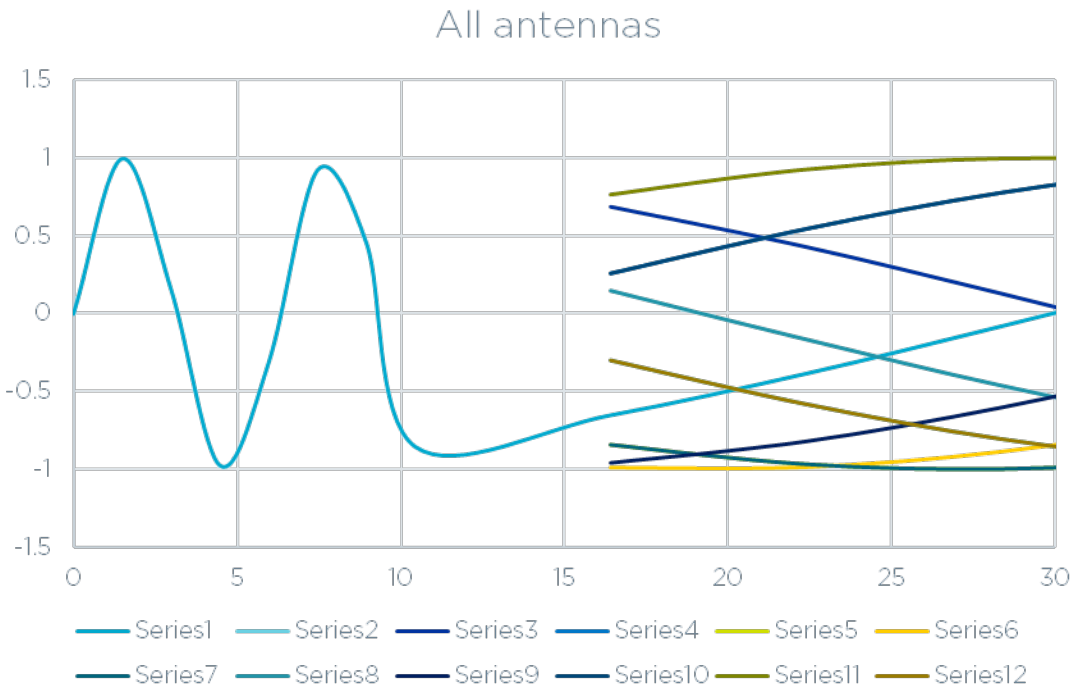
- Hemisphere above the plane is covered
- Performance degradation close to plane
  - Noticeable from about 15°
  - Caused by patch antenna radiation pattern

Input signal with theoretical values



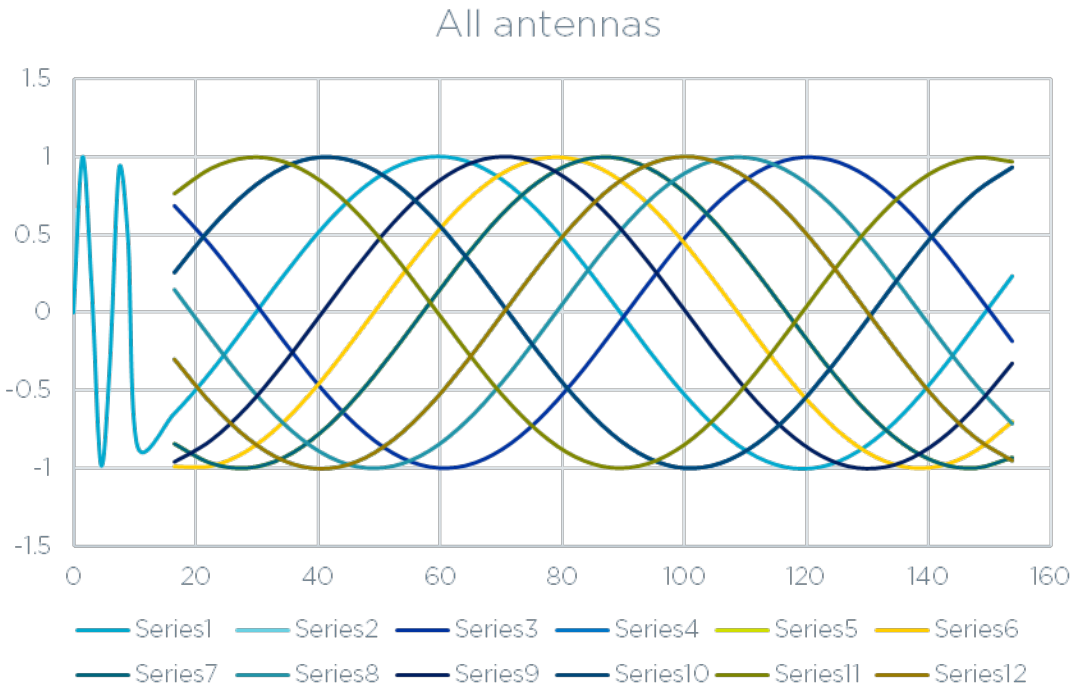
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @11 µs
- Perfect 500 kHz constant tone
  - All antennas will have constant phase due to under-sampling

Input signal with frequency offset



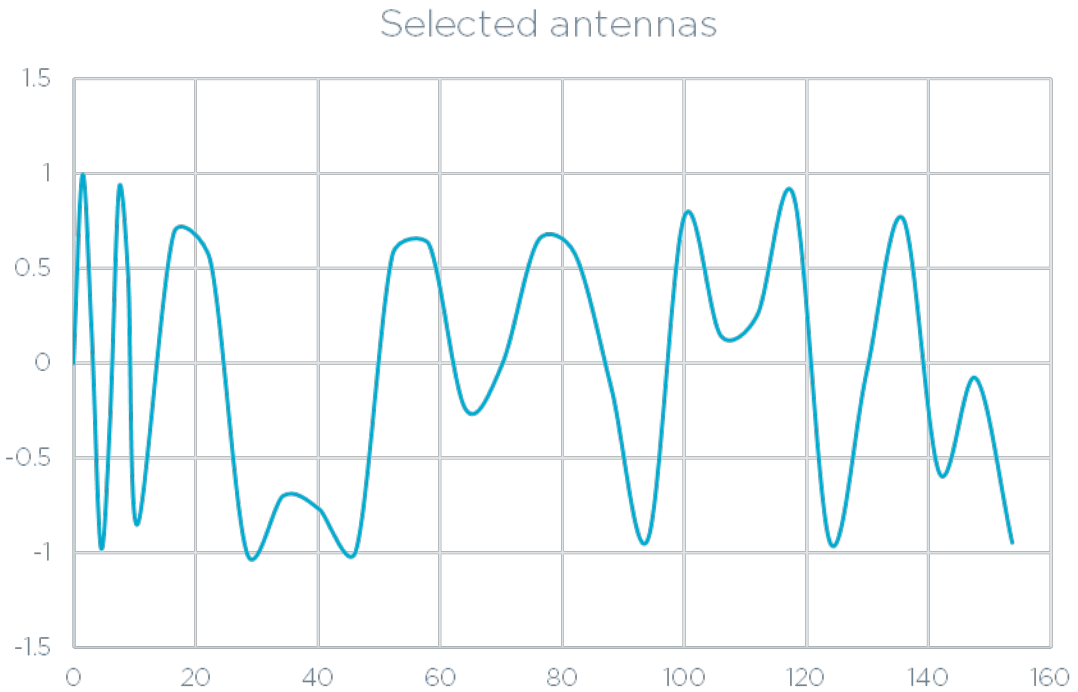
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @11 µs
- Constant tone will not be 500 kHz
  - Phase shifting slowly due to under-sampling

Input signal from all antennas



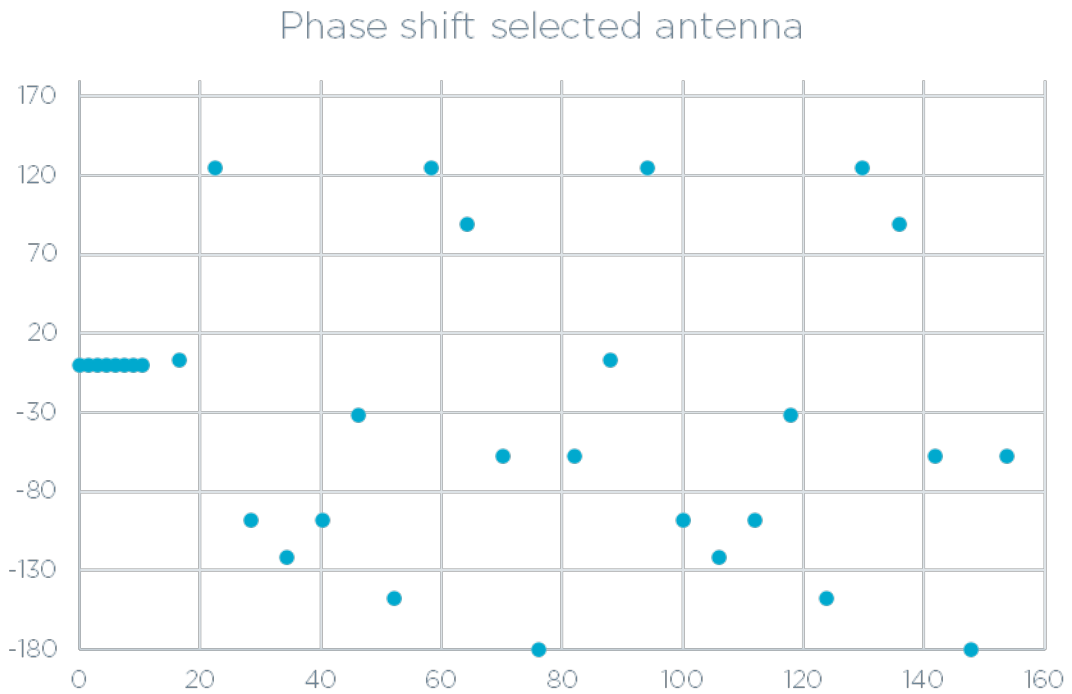
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @11 µs
- Constant tone will not be 500 kHz
  - Phase shifting slowly due to under-sampling

Input signal from selected antennas



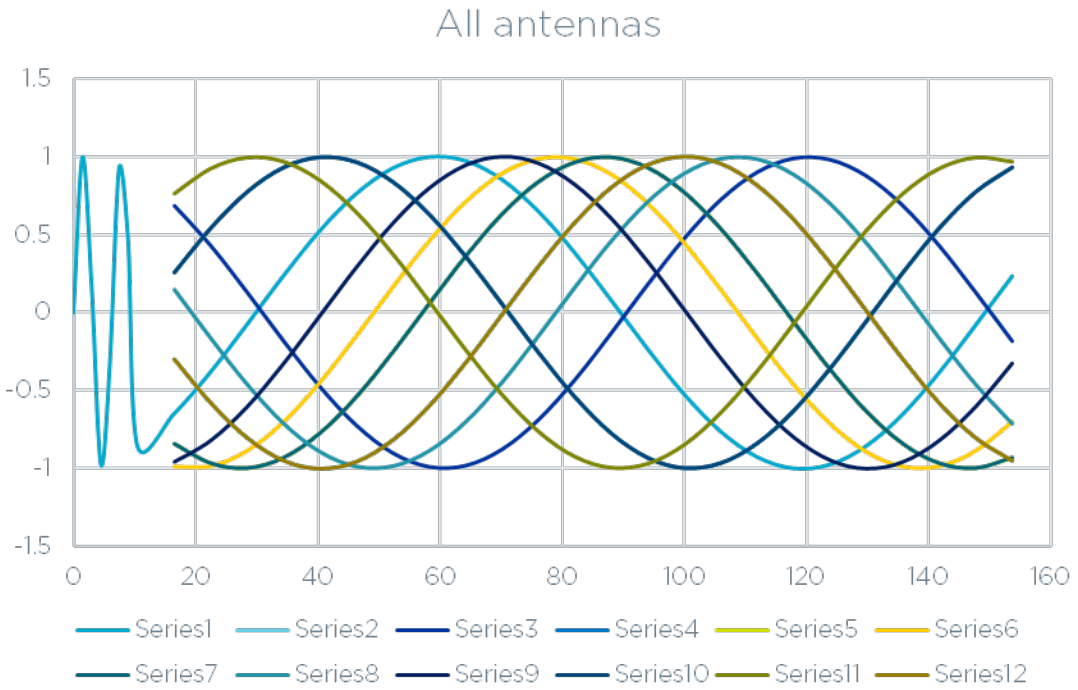
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @11 µs
- Signal will not look like a sine as each sample is for a separate antenna

Phase of input signal from selected antennas



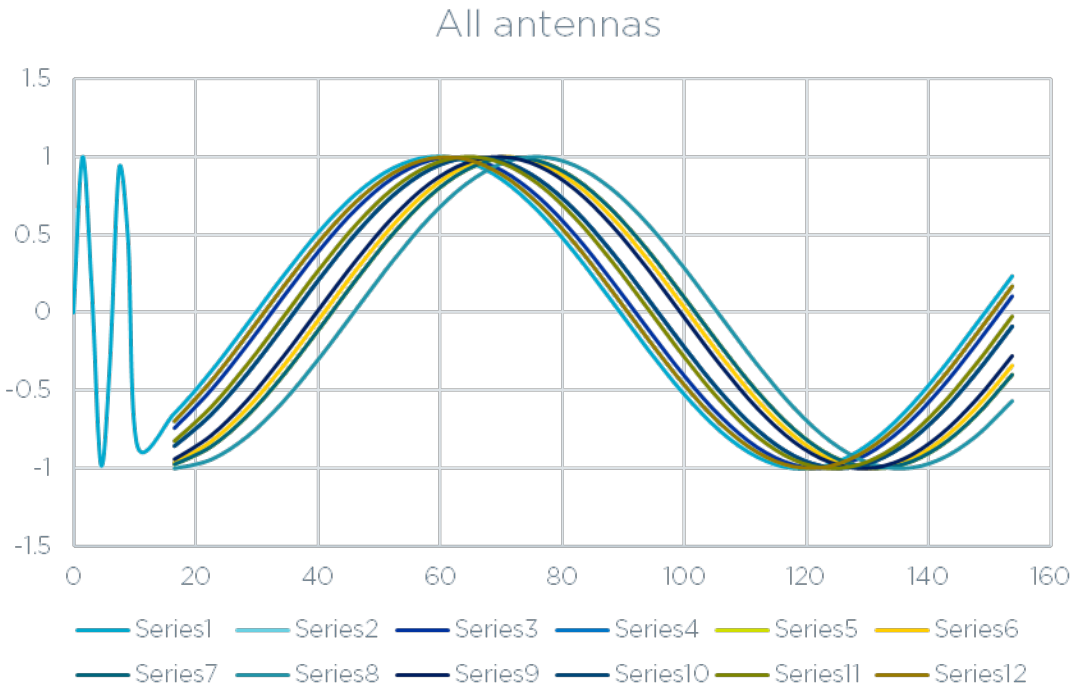
- Displaying phase shift of input signal compared to reference
- Reference period used to find frequency and phase of input signal

Input signal from all antennas



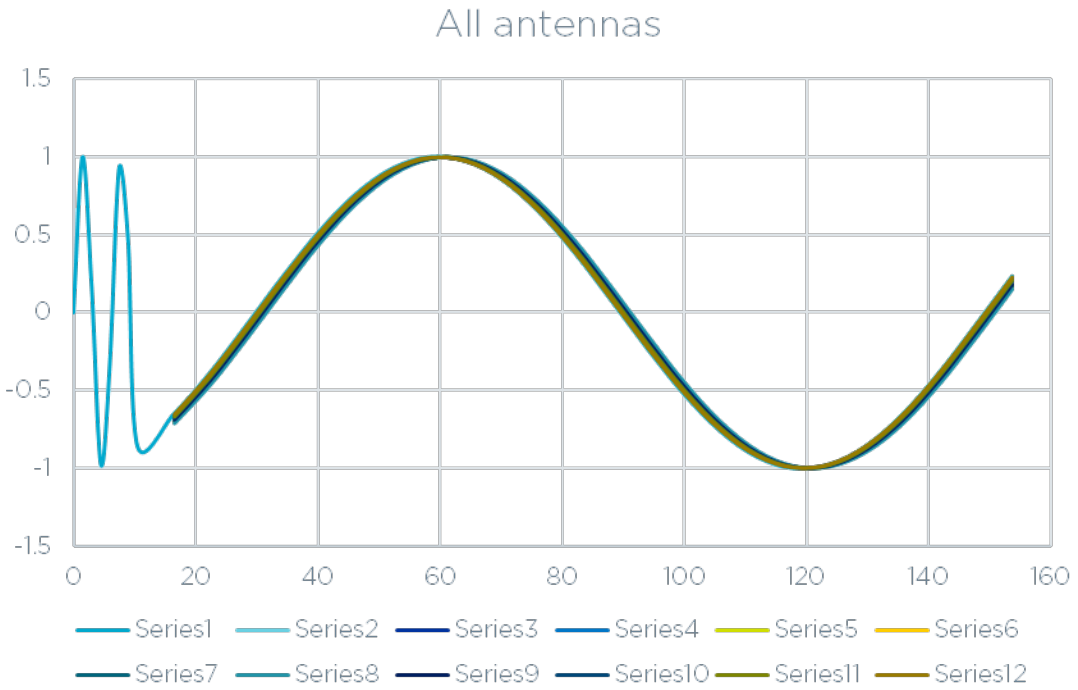
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2Mbps
- 8 samples reference
  - Last sample @11 µs
- Constant tone will not be 500 kHz
  - Phase shifting slowly due to under-sampling

Input signal from all antennas



- Using antenna 1 as a reference
  - Transmitter 100 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @11 µs
- Phase shift smaller due to increased distance

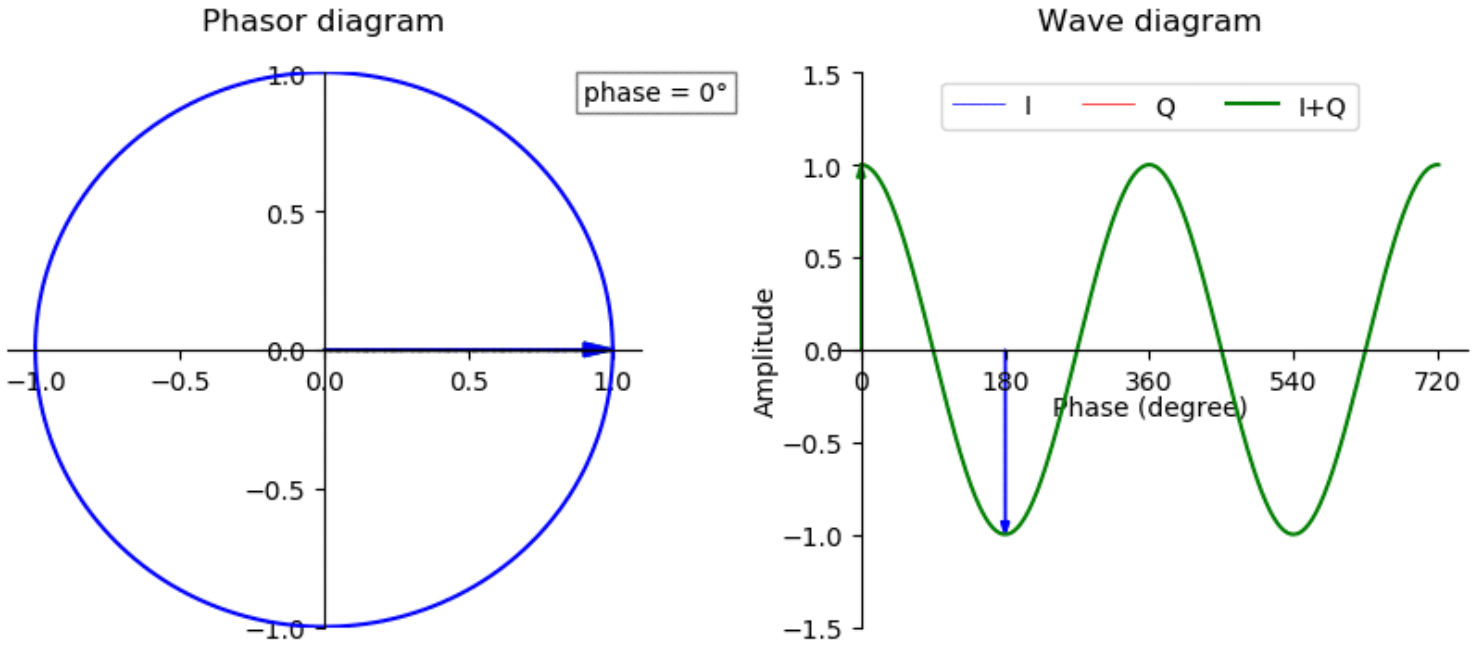
Input signal from all antennas



- Using antenna 1 as reference
  - Transmitter 1000 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @11 µs
- Phase shift **imperceptible** due to increased distance

IQ samples, what are they and how to use them

«What is Phase?»



https://en.wikipedia.org/wiki/Phase_(waves)#/media/File:Phase_shifter_using_IQ_modulator.gif

Conversion and Bluetooth format

- To convert from I/Q data to phase and amplitude
  - Phase: $\theta = arctan\frac{Q}{I}$
  - Amplitude: $A = \sqrt{I^2 + Q^2}$

- Bluetooth spec states I/Q data should be 8 bit
  - Signal has to be truncated in nRF devices, normally max I/Q values seen are in the 30-50 range
    - Kept low to avoid saturation
  - Saturated signals shall return a -128 according to Bluetooth spec

Bluetooth 5.1 Direction finding spec

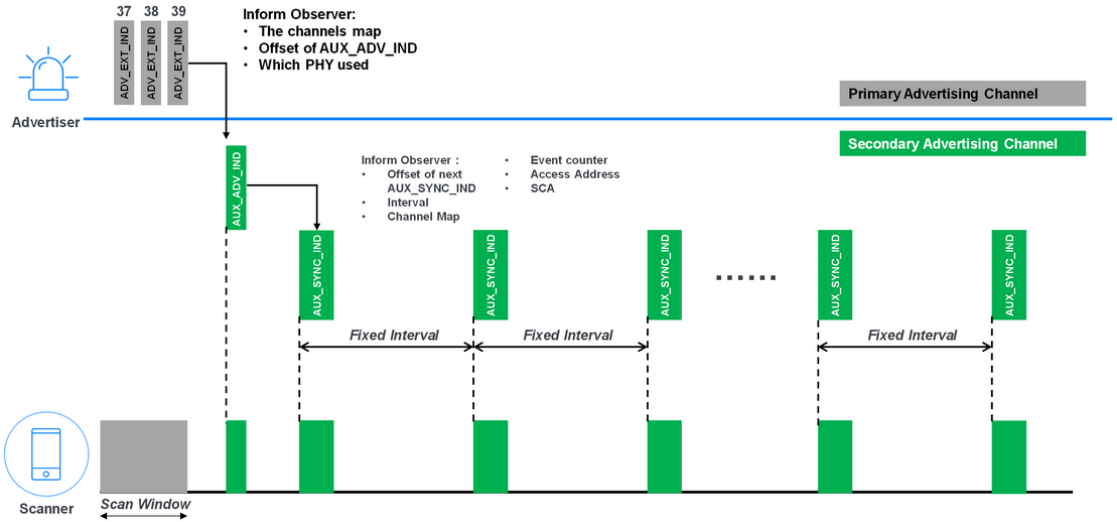
Bluetooth specification

- Covers
  - Host functionality
  - HCI commands
  - On-air packet format
  - Sample timing
  - I/Q data format
  - What packets can have CTE appended
- Does not cover
  - Antenna array design
  - Algorithms for calculating angles
  - Exchange of antenna array design
  - Locationing

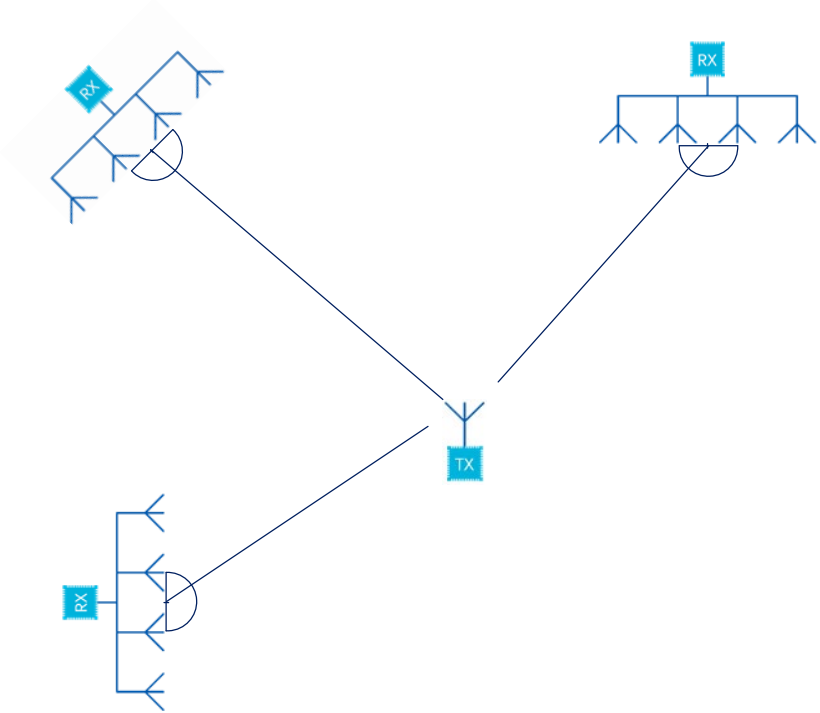
Bluetooth Specification ends with I/Q data being delivered from the Controller subsystem to the application

Periodic advertising

- CTE can only be appended to packets in the data channels
- For non-connected Bluetooth Direction Finding it is thus mandated to use periodic advertising for the packets with CTE



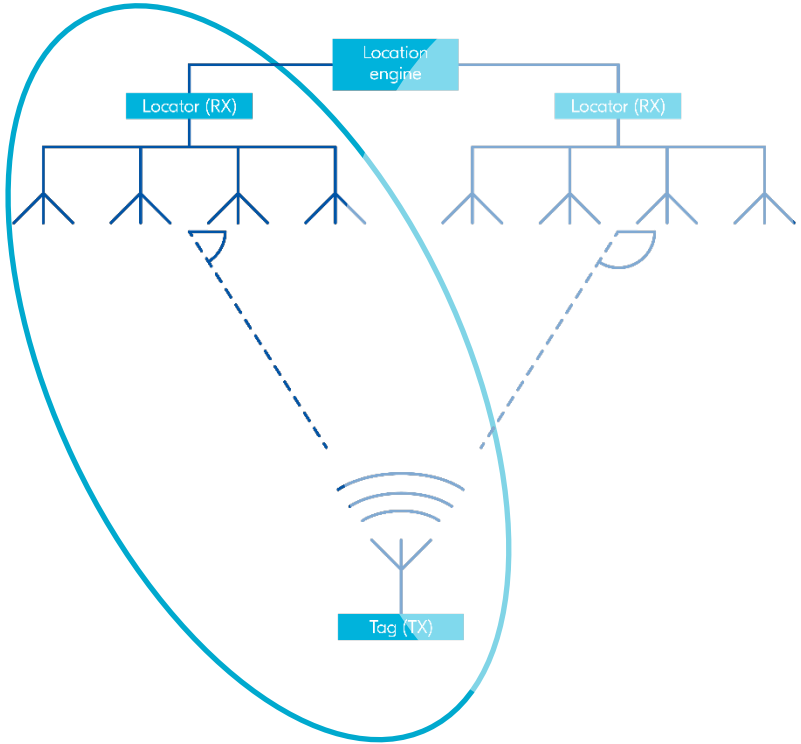
Triangulation

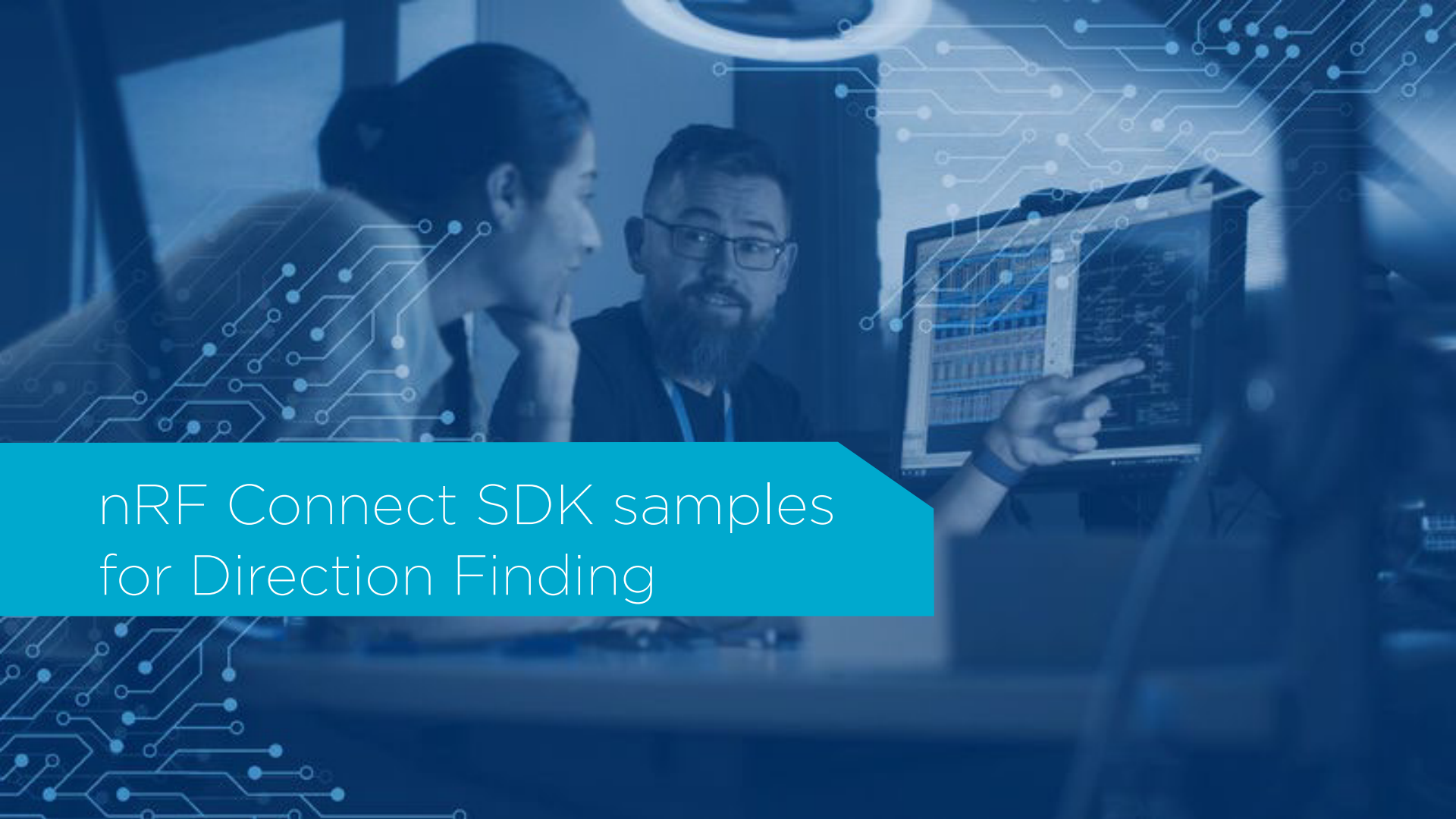


- Utilize multiple anchor points at known position
- Measure angle from all anchor points to Device
- Calculate position based on data
- Requires accurate and stable angle measurement
  - Supported by AoA and AoD Direction Finding since Bluetooth 5.1

Asset tracking - RTLS

- Tag is a simple transmitter
  - Majority of devices is the lowest-cost unit
  - Low power operation
- Multiple AoA locators at fixed locations reporting angles
- The location engine determines the position of the tag based on angle data from multiple locators

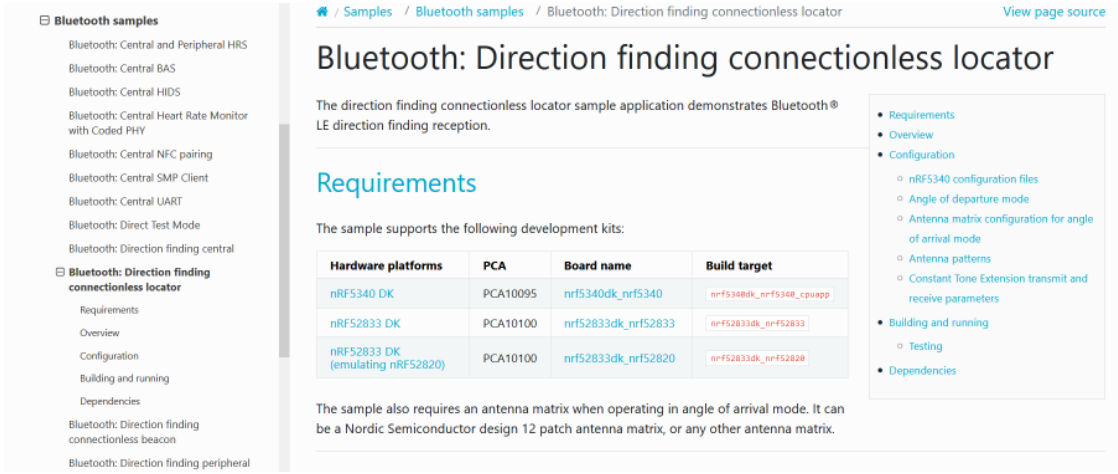




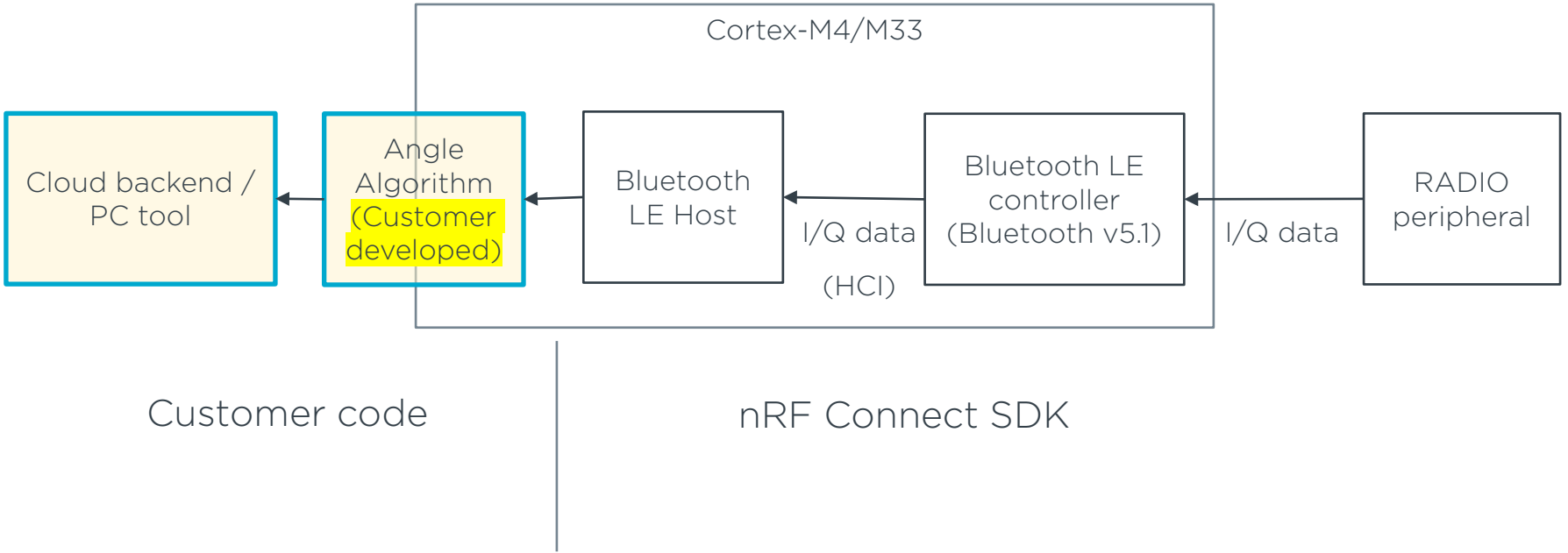
nRF Connect SDK samples for Direction Finding

nRF Connect SDK samples

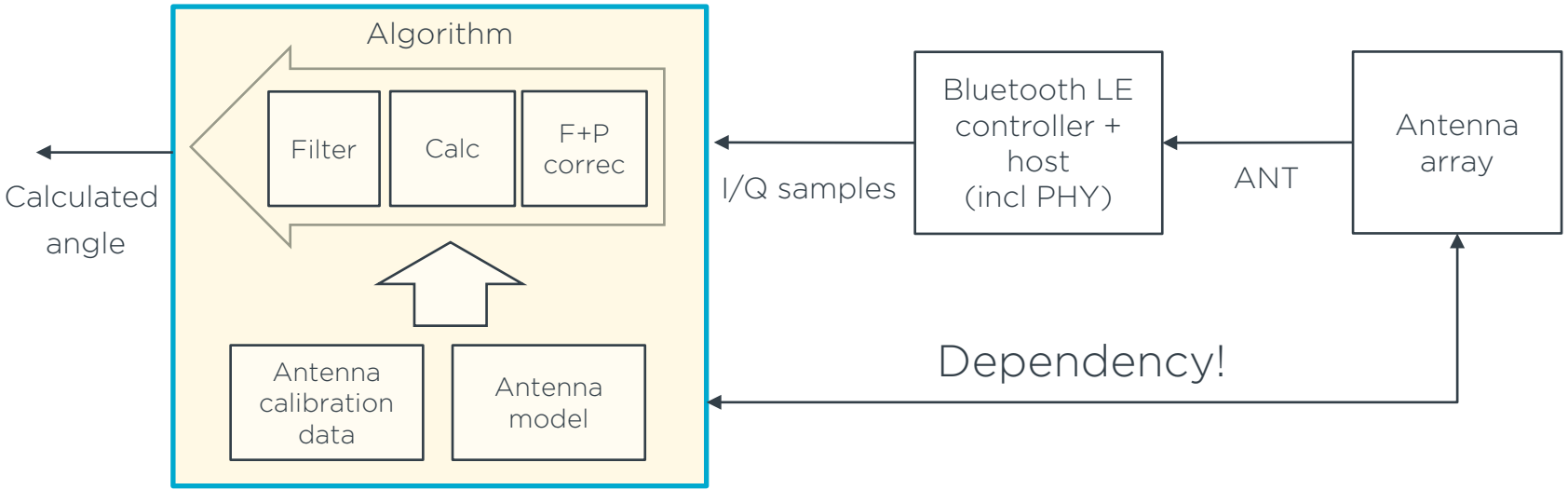
- Samples for
  - Connectionless locator
  - Connected locator
  - Connectionless beacon
  - Connected peripheral
- All samples can be configured for AoA or for AoD
  - Basically, RF switches or no RF Switches



Software architecture: Locator full solution

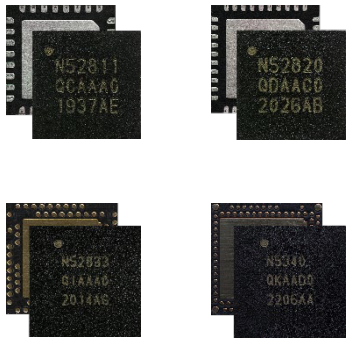


Angle computation – essential components

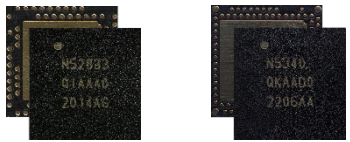


Supported HW for Direction Finding

Supported HW for Direction Finding



- Devices supported for AoA &AoD transmitter functionality
  - nRF52811
  - nRF52820
  - nRF52833 – Fully qualified HW and SW solution
  - nRF5340



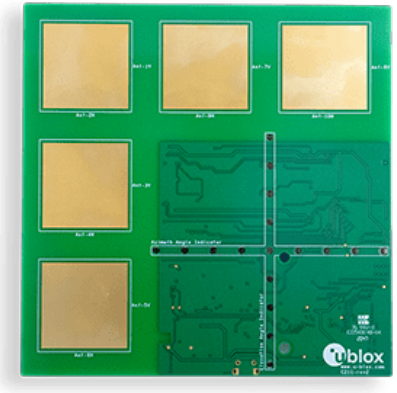
- Devices supported for AoA &AoD receiver
  - nRF52833 – Fully qualified HW and SW solution
  - nRF5340
  - Receiver support requires significant amount of RAM

Nordic Partner support for Direction Finding

InsightSiP antenna array – patch antennas

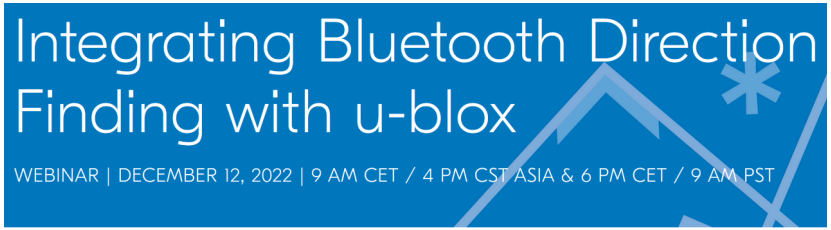
- 12 patch antennas
  - Design available from Nordic Devzone
  - Antenna array designed by Nordic, manufactured by InsightSiP
- nRF52833 module mounted directly on antenna board

u-blox antenna array – patch antennas



- 4 patch antennas
- u-blox antenna design
- nRF52833 based
- u-blox angle algorithm
- u-blox multi locator SW solution available

u-blox partner webinar



12 Dec 2022 Webinar

Integrating Bluetooth Direction Finding with u-blox

Indoor positioning is definitely on the rise, and many want to jump onto the train toward successful Bluetooth Direction Finding systems. But how to build an efficient solution that is easy to deploy and manage?

In this webinar, we have with us u-blox who will walk you through their Angle of Arrival (AoA) solution, which is built on top of our nRF52833 SoC and the nRF Connect SDK. They will cover all important aspects of the solution — including the antenna board, the application board, the tags, the positioning engine, the u-blox algorithm evaluation leading to implementation, and the Traxmate IoT tracking platform. u-blox will also look into the wide range of possible use cases, illustrating a few of them with dedicated demonstrations (e.g. "Follow-me", "Indoor positioning"), and give you all the tools to get started.

Come and join us — and secure your seat today!

To get the most out of this webinar, we recommend attending the Introduction to Bluetooth Direction Finding webinar.

- U-blox will hold a webinar on this platform 12th of December
- Covering how they extend the HW & SW offering from Nordic to include
  - u-blox designed antenna arrays
  - u-blox developed angle resolution algorithms
  - u-blox indoor positioning engine supporting multiple locators
  - Nordic Webinar

Thanks! Time for Q&A