



# Bluetooth Direction Finding

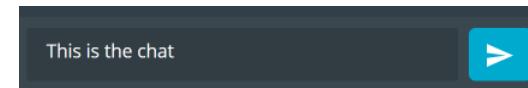
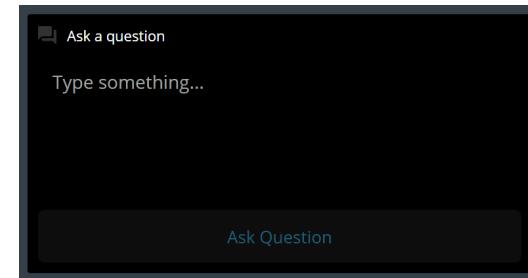
Nordic offering

*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](http://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*

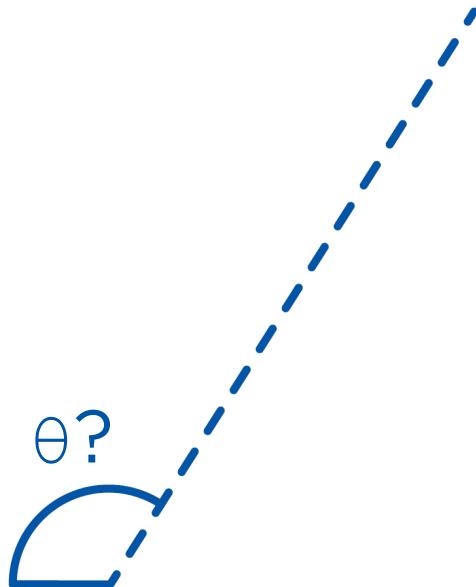
# Agenda

- 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

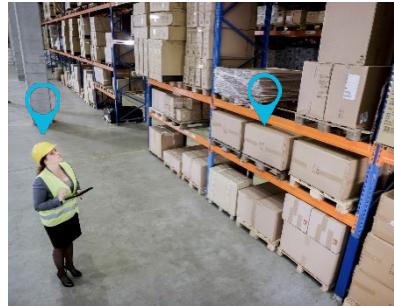
# Direction Finding



- 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



Wayfinding



Point of interest



Item finding



Real-Time  
Locationing Systems  
(RTLS)

Indoor positioning

Proximity marketing

More advanced item  
finding solutions

Positioning systems

Proximity solutions

# Bluetooth qualification

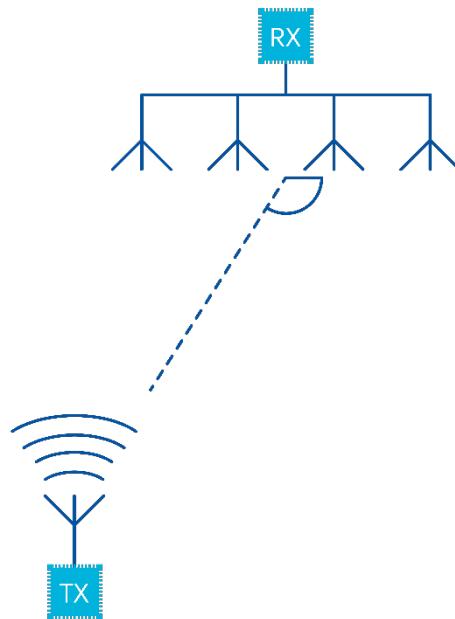
- nRF Connect Bluetooth Host qualified with Direction Finding support for tag 2.1.0
  - [Bluetooth Host QDID](#)
- SoftDevice Controller subsystem qualified for AoA transmitter since tag 2.0.0
  - [SoftDevice QDID](#)
- Zephyr Controller Subsystem qualified for Direction Finding for tag 2.1.0
  - [Zephyr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

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

Table 1. nRF52833 nRF Connect SDK QDIDs

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

# Angle of Arrival (AoA)



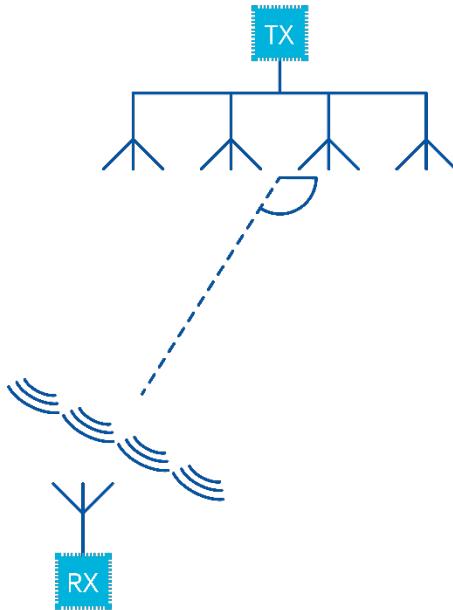
## Transmitter

- 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

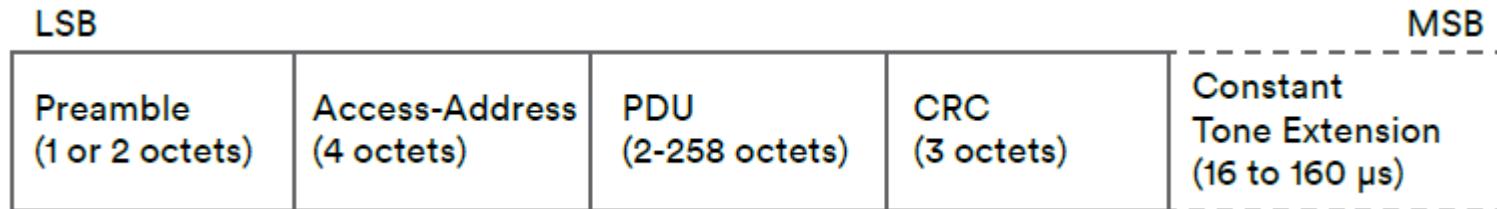
## Receiver

- 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 background features a minimalist, abstract design. It consists of several large, white, undulating waves that resemble ripples on water or the surface of a soft material. Interspersed among these waves are several semi-transparent, light gray circles of varying sizes, some overlapping the waves and others existing on their own. The overall aesthetic is clean, modern, and organic.

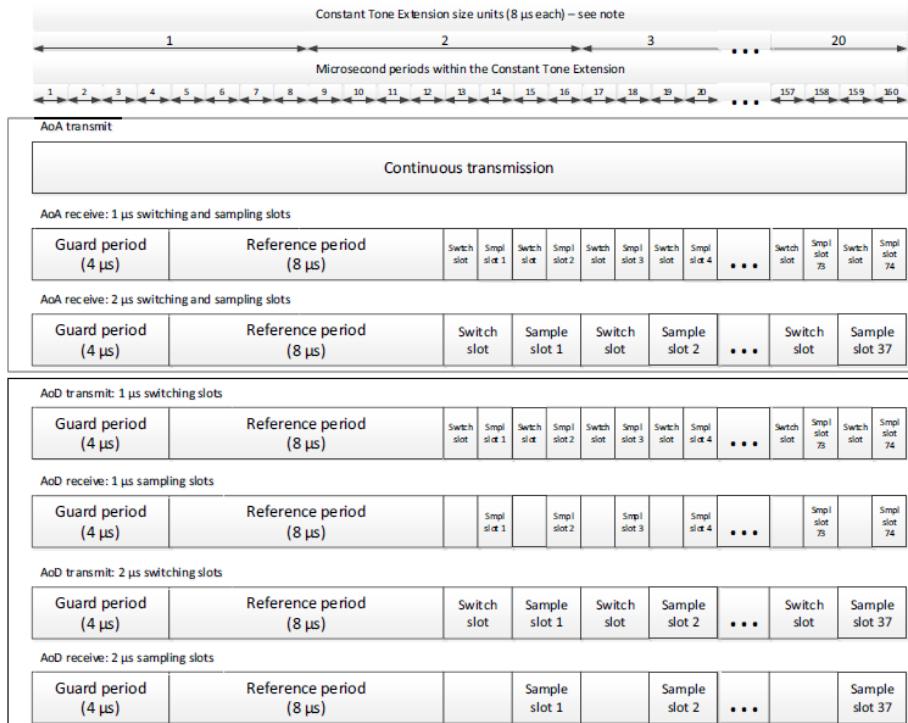
The physics behind direction  
finding

# Constant Tone Extension (CTE)



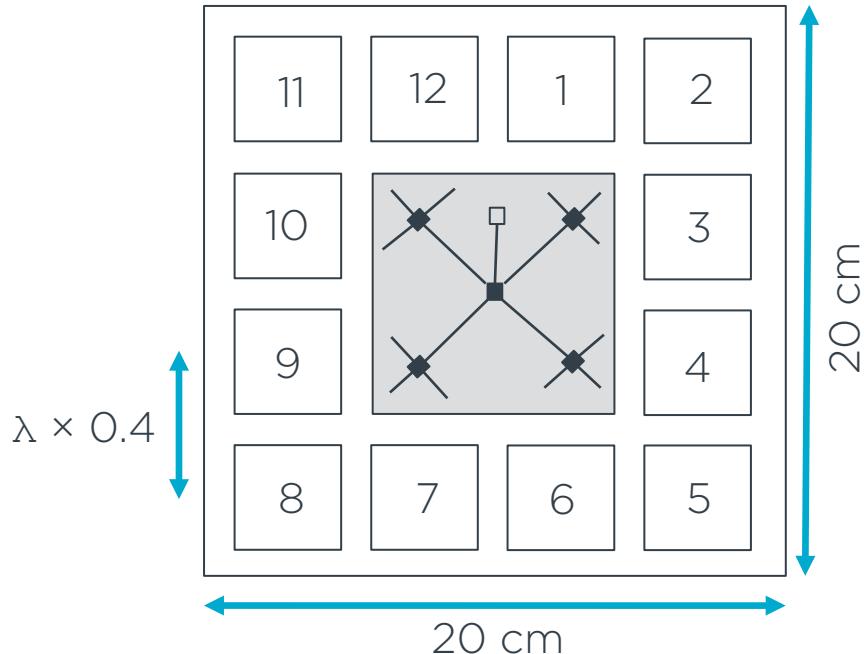
- CTE provides constant frequency signal for IQ sampling
- Unwhitened sequence of 1s (Tone) and is appended after CRC
- Connectionless and connection-oriented modes
- In connectionless, periodic advertising is required (deterministic timing)
- Supported for 1 Mbit and 2 Mbit PHYs

# Constant Tone Extension and I/Q sampling



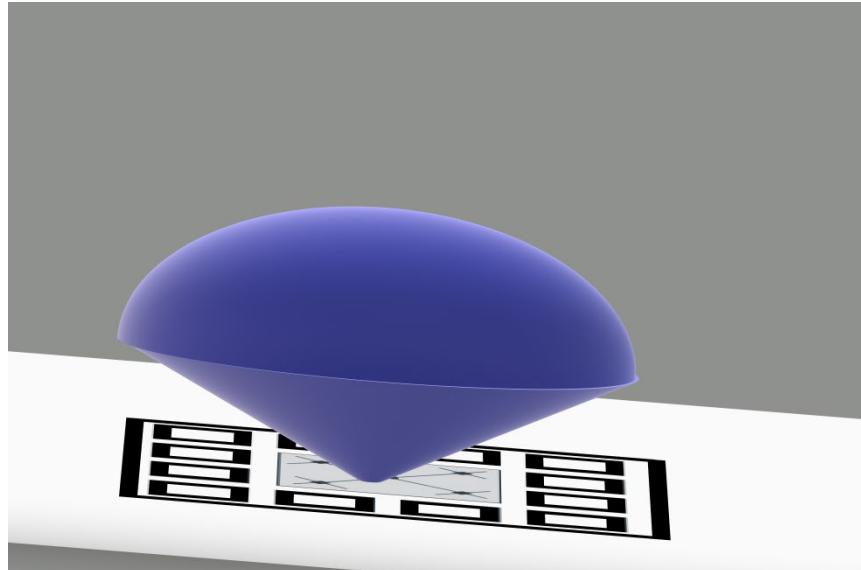
- CTE range: 16 us to 160 us
- Minimum 2 antennas, maximum 38/75 antennas (switch and slot length dependent)
- Guard Period – antenna may switch
- Reference Period – 8 reference I/Q samples
- Switch/Sample slots are 2us or 1us:
  - Switch Slot: Antenna switching period
  - Sample Slot: I/Q sampling period

# Antenna array example - patch antennas



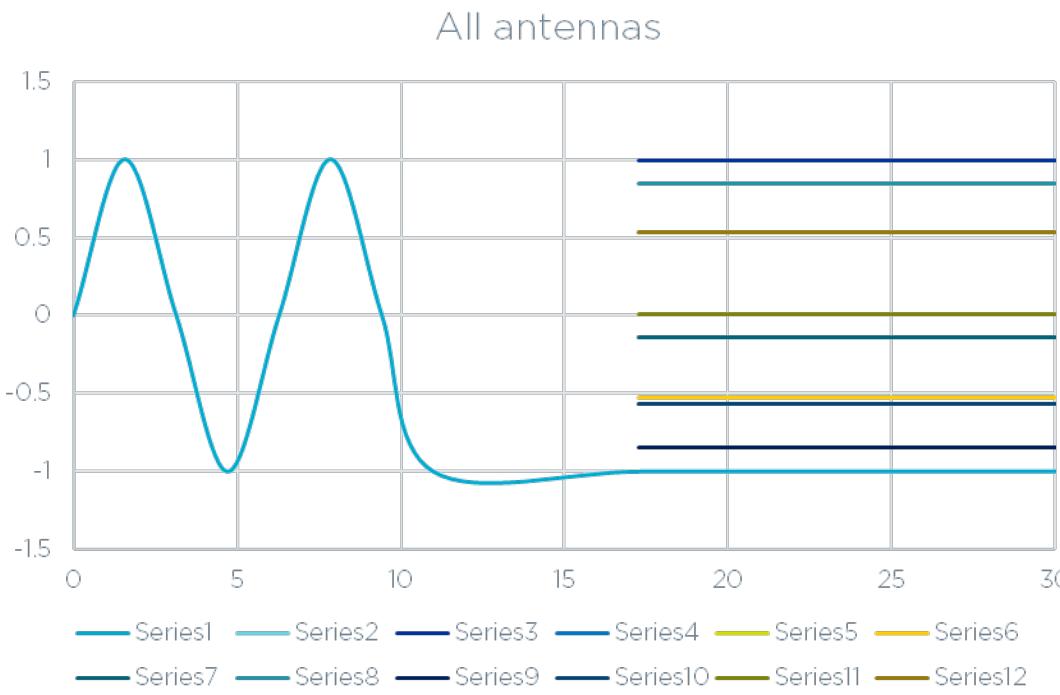
- 12 patch antennas
  - High-performance RF switches
- HW will scan through antennas in pre-defined patterns
  - one antenna set as a reference
- Array design will give 2 angles
  - “Line” antenna design will give 1 angle
- Design files available
  - HW can be purchased from InsightSiP as ISP1907-AOA-DK

# Antenna array -Area of coverage



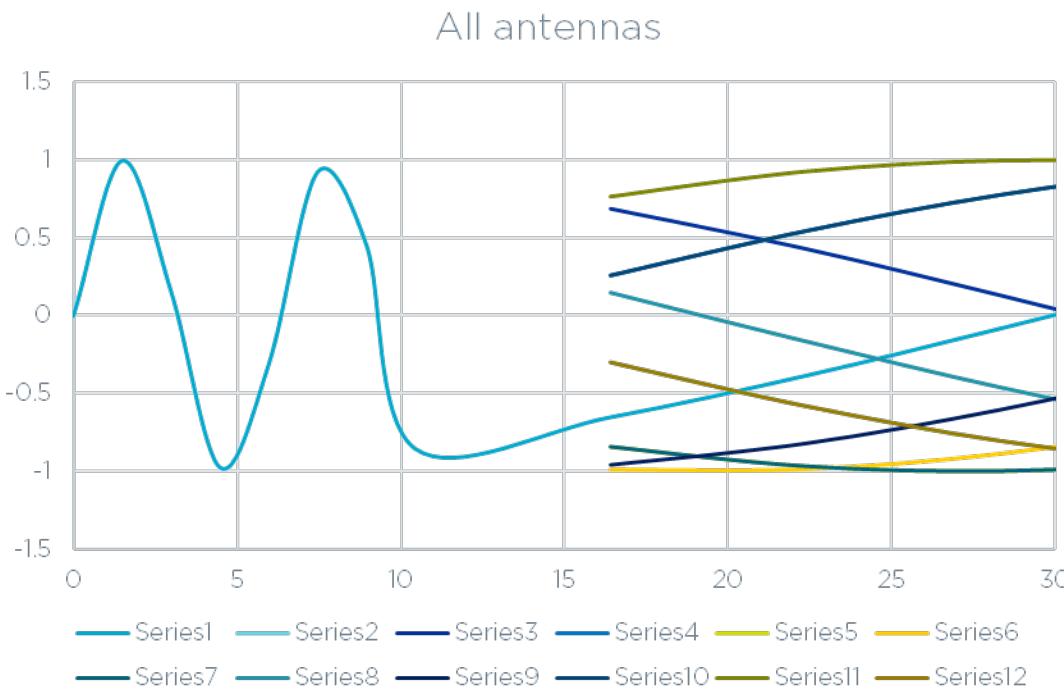
- Hemisphere above the plane is covered
- Performance degradation close to plane
  - Noticeable from about 15°
  - Caused by patch antenna radiation pattern

# Input signal with theoretical values



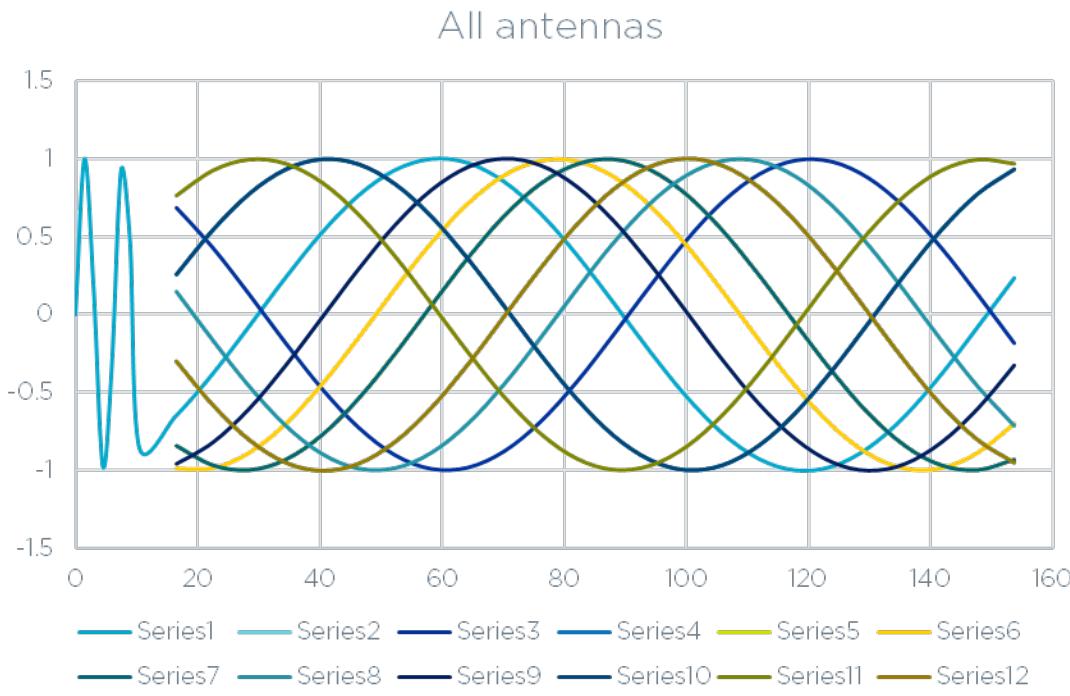
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @ $11 \mu\text{s}$
- **Perfect 500 kHz constant tone**
  - All antennas will have constant phase due to under-sampling

# Input signal with frequency offset



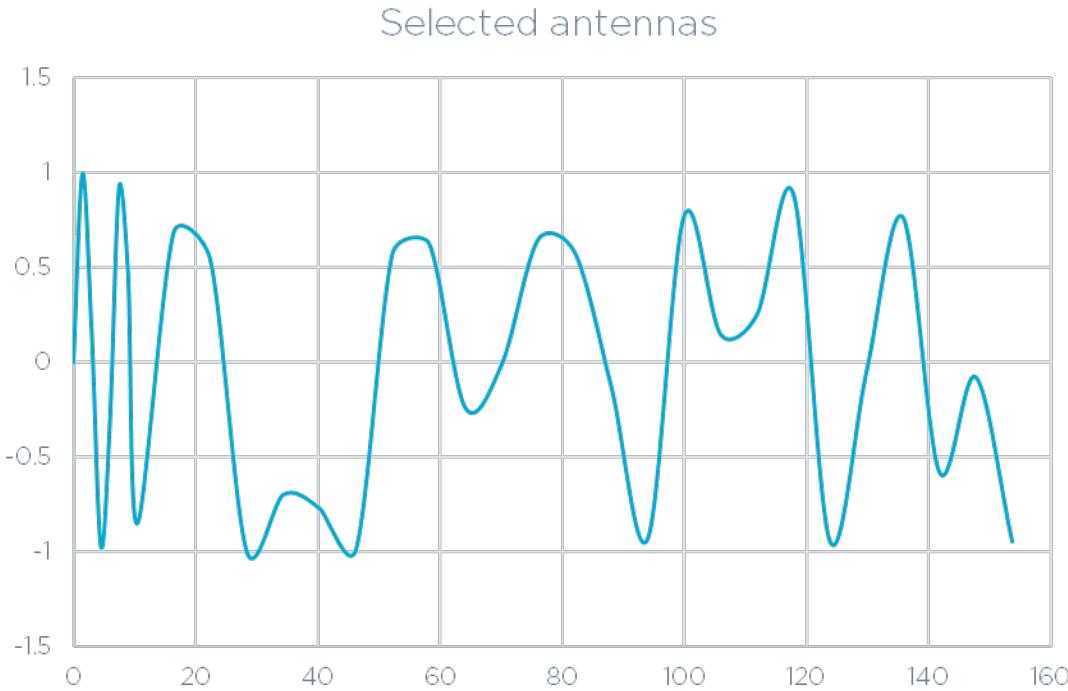
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @ $11 \mu\text{s}$
- Constant tone will not be 500 kHz
  - Phase shifting slowly due to under-sampling

# Input signal from all antennas



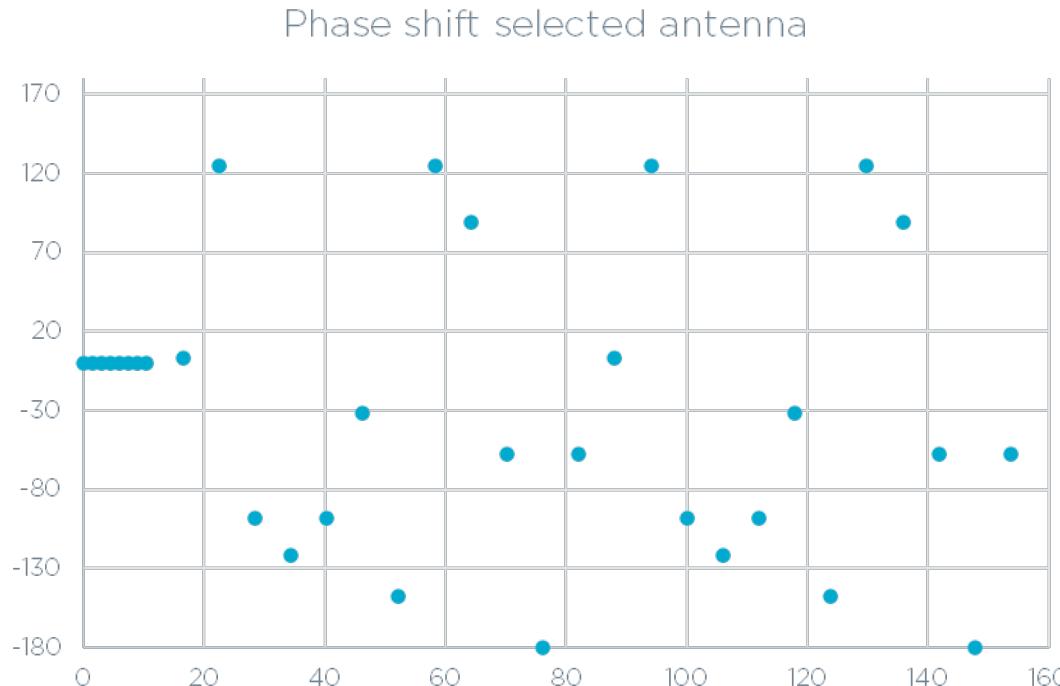
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @ $11 \mu\text{s}$
- Constant tone will not be 500 kHz
  - Phase shifting slowly due to under-sampling

# Input signal from selected antennas



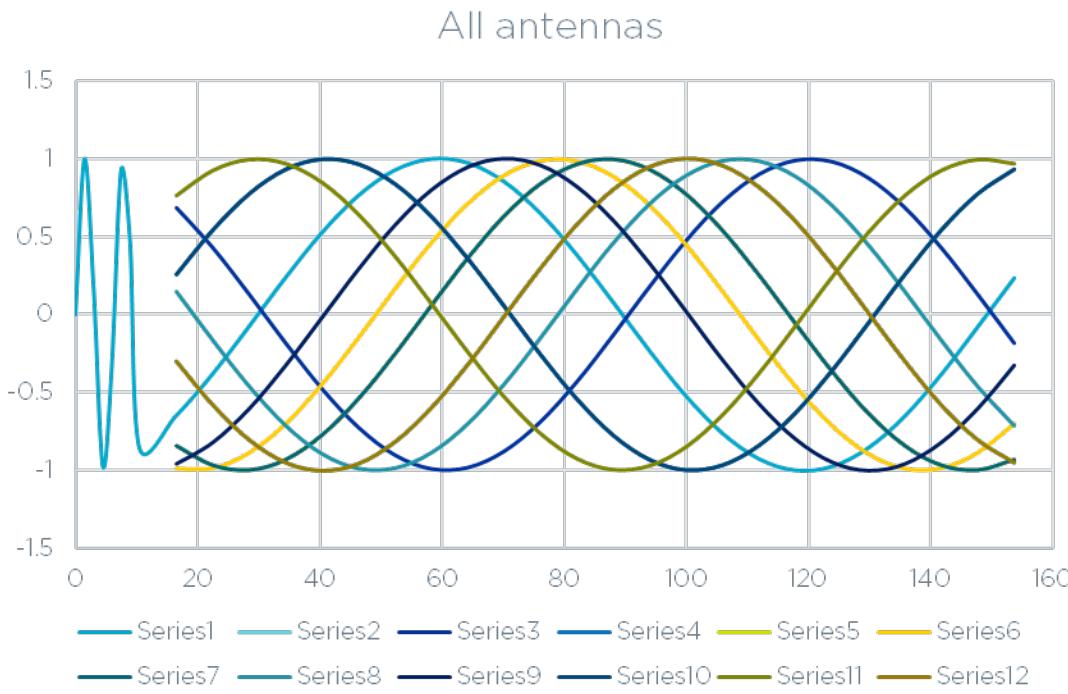
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @ $11 \mu\text{s}$
- Signal will not look like a sine as each sample is for a separate antenna

# Phase of input signal from selected antennas



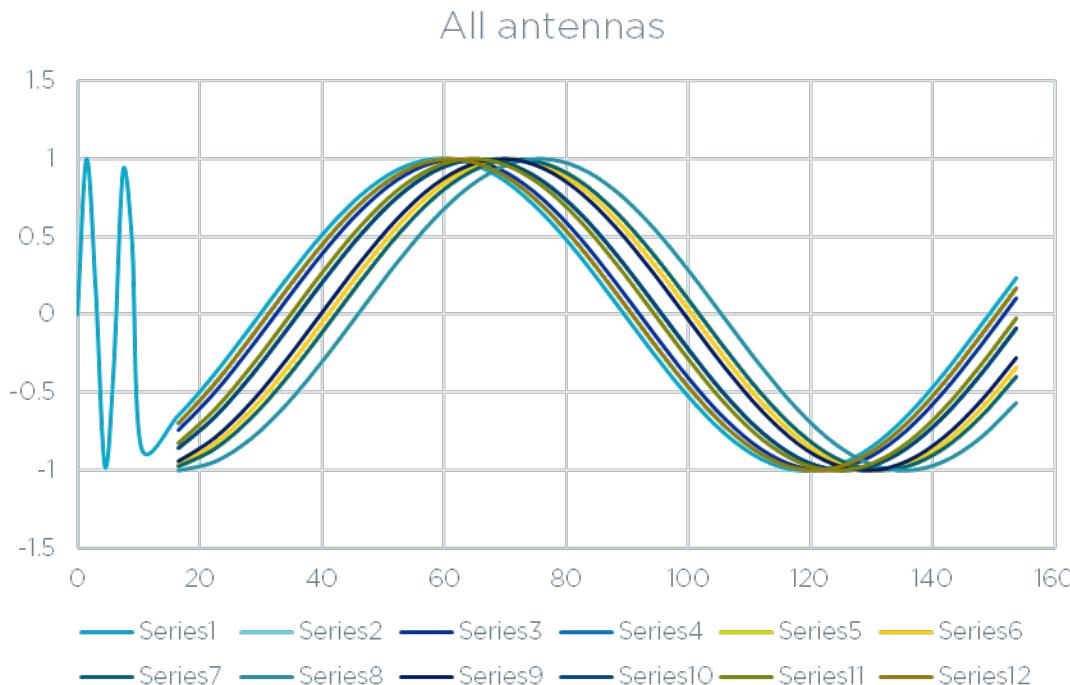
- Displaying phase shift of input signal compared to reference
- Reference period used to find frequency and phase of input signal

# Input signal from all antennas



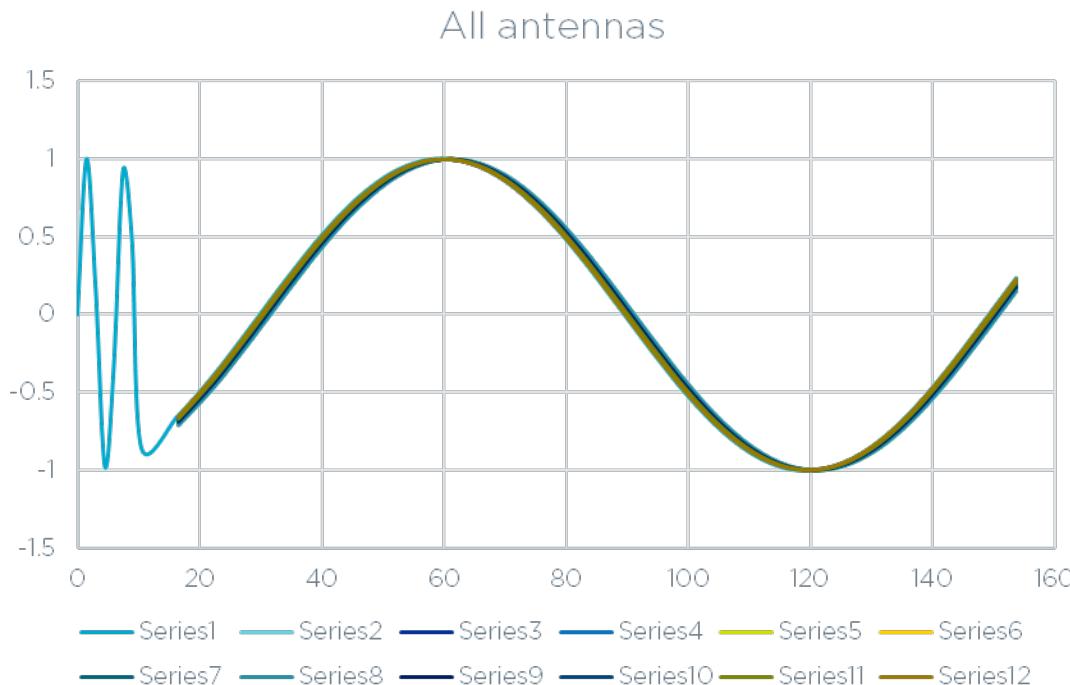
- Using antenna 1 as a reference
  - Transmitter 1 cm above antenna 1
  - 2Mbps
- 8 samples reference
  - Last sample @ $11\ \mu\text{s}$
- Constant tone will not be 500 kHz
  - Phase shifting slowly due to under-sampling

# Input signal from all antennas



- Using antenna 1 as a reference
  - Transmitter 100 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @ $11 \mu\text{s}$
- Phase shift smaller due to increased distance

# Input signal from all antennas



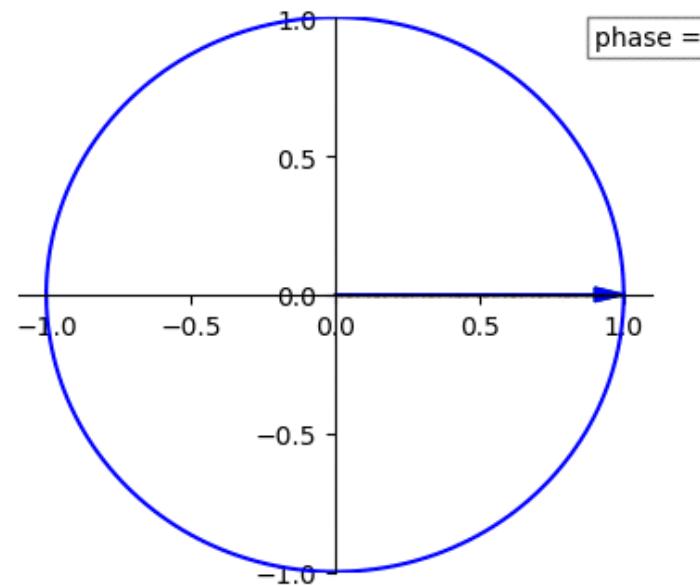
- Using antenna 1 as reference
  - Transmitter 1000 cm above antenna 1
  - 2 Mbps
- 8 samples reference
  - Last sample @ $11 \mu\text{s}$
- Phase shift **imperceptible** due to increased distance

A photograph of two men in a modern office setting, viewed from behind and slightly to the side. They are looking at a computer monitor on a desk. The scene is overlaid with a dense network of white lines and dots, suggesting connectivity or data flow. The man on the left wears glasses and a dark jacket, while the man on the right wears a light-colored hoodie. In the background, there are large windows and other office elements.

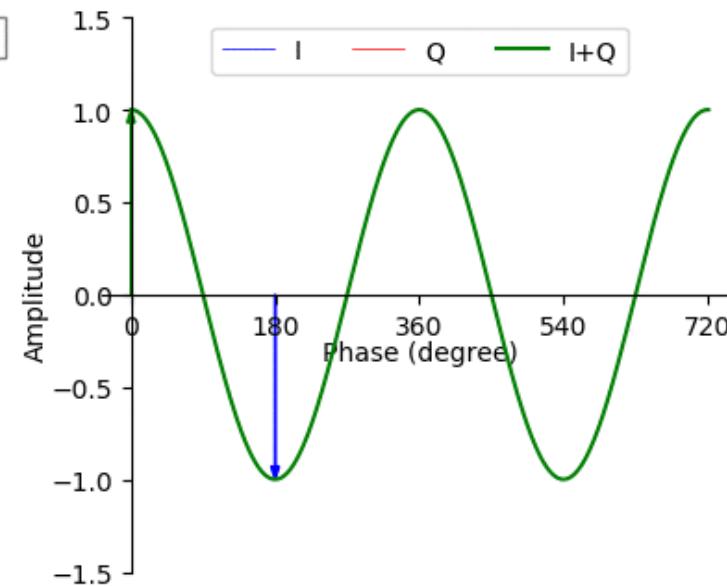
IQ samples, what are they  
and how to use them

# «What is Phase?»

Phasor diagram



Wave diagram



[https://en.wikipedia.org/wiki/Phase\\_\(waves\)#/media/File:Phase\\_shifter\\_using\\_IQ\\_modulator.gif](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

# Specifications

Bluetooth 5.1 Direction  
finding spec

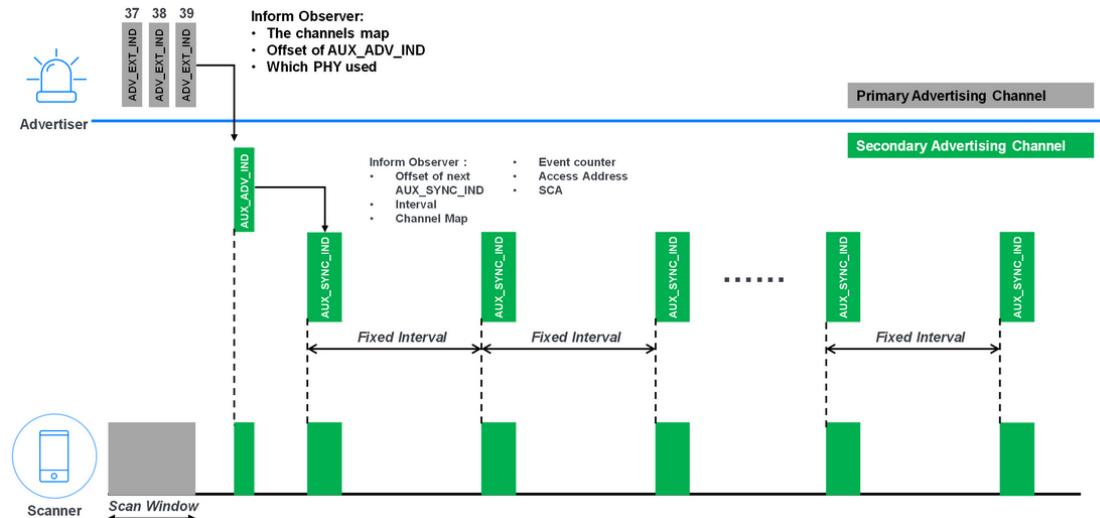
# Bluetooth specification

- 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

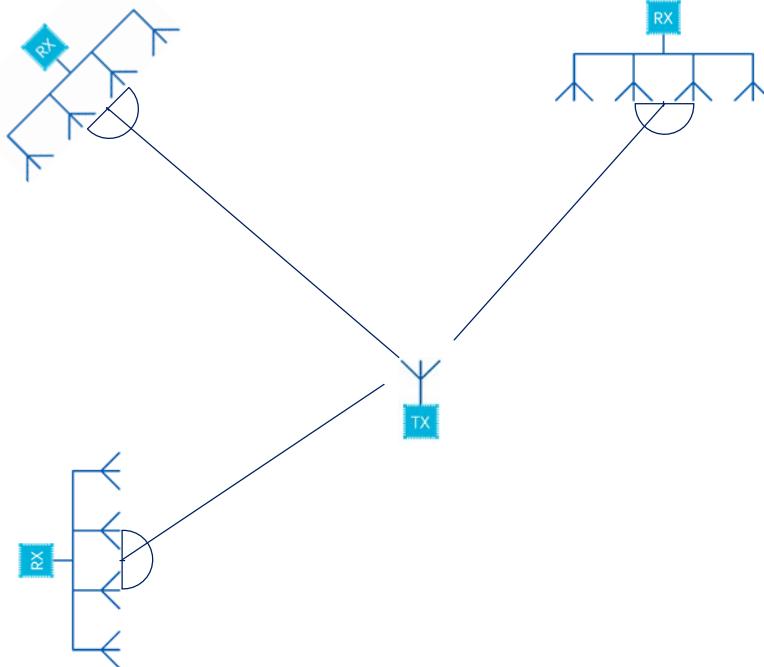
Bluetooth Specification ends with I/Q data being delivered from the Controller subsystem to the application

# 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



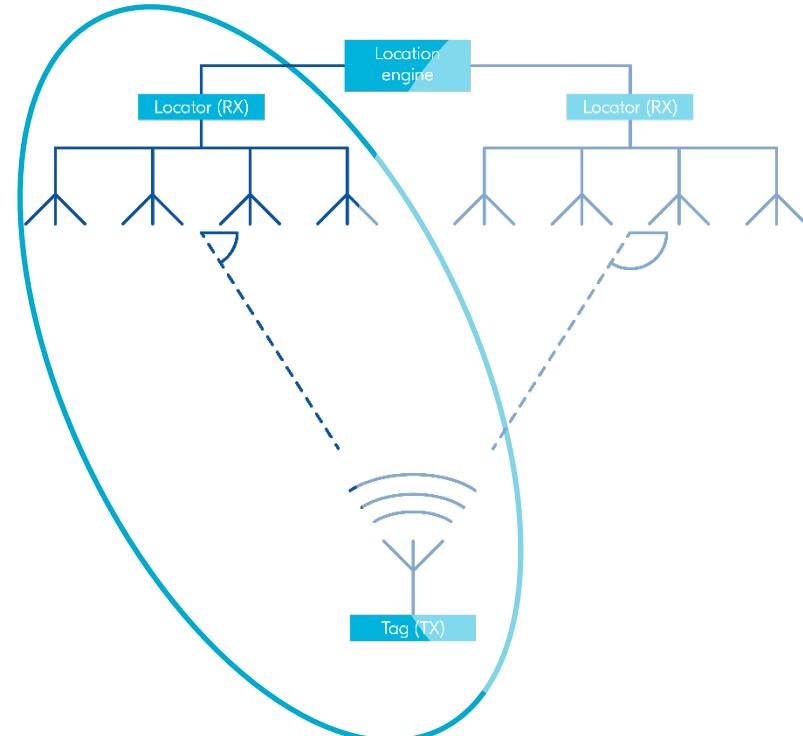
# Triangulation

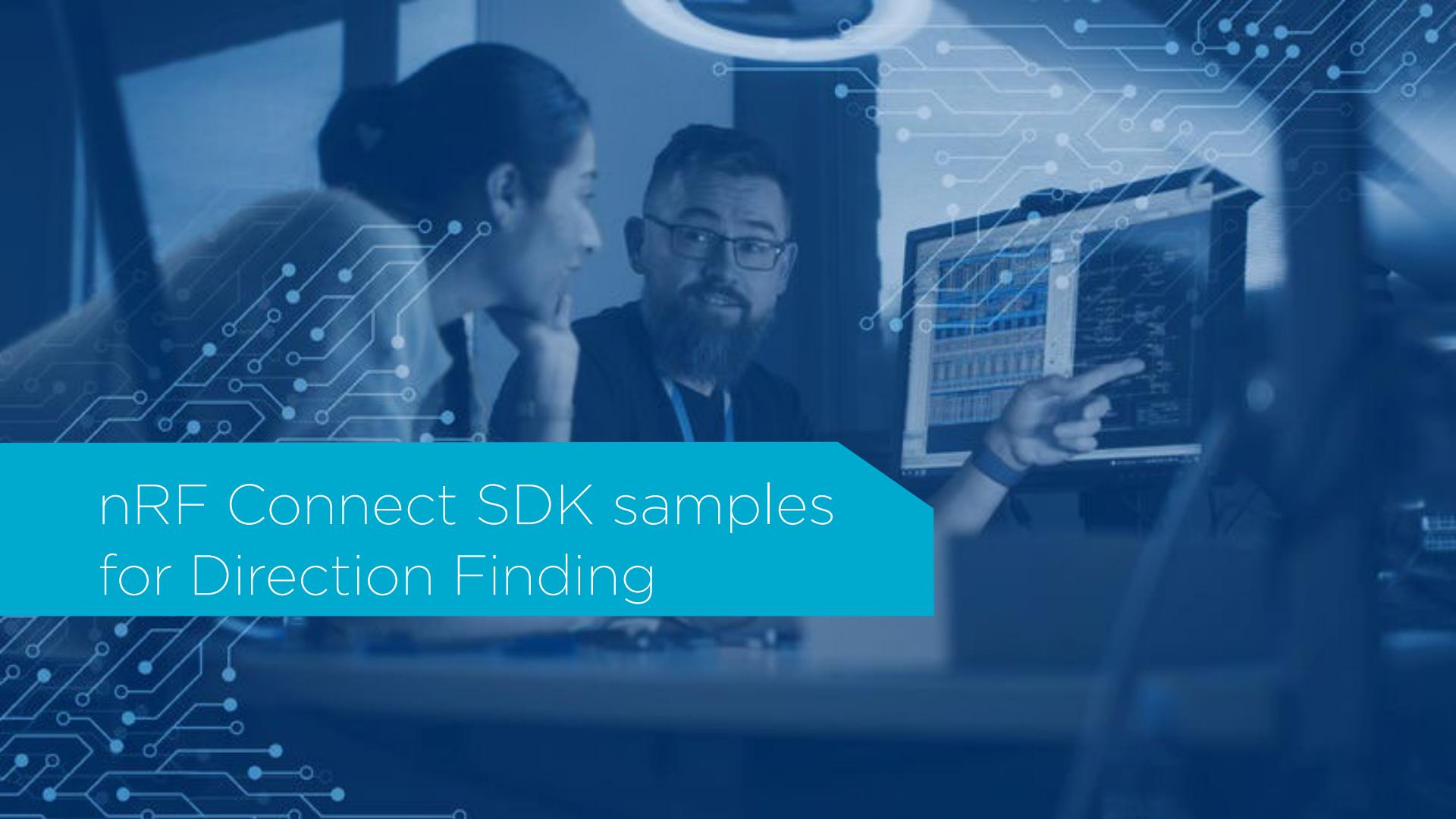


- Utilize multiple anchor points at known position
- Measure angle from all anchor points to Device
- Calculate position based on data
- Requires accurate and stable angle measurement
- Supported by AoA and AoD Direction Finding since Bluetooth 5.1

# 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



A blue-tinted photograph of two people, a man and a woman, looking at a computer monitor. The monitor displays a complex circuit board design. A hand points at the screen. The background is blurred, suggesting a professional or technical environment.

# 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

<b>Bluetooth samples</b>
Bluetooth: Central and Peripheral HRS
Bluetooth: Central BAS
Bluetooth: Central HID\$
Bluetooth: Central Heart Rate Monitor with Coded PHY
Bluetooth: Central NFC pairing
Bluetooth: Central SMP Client
Bluetooth: Central UART
Bluetooth: Direct Test Mode
Bluetooth: Direction finding central
<b>Bluetooth: Direction finding connectionless locator</b>
Requirements
Overview
Configuration
Building and running
Dependencies
Bluetooth: Direction finding connectionless beacon
Bluetooth: Direction finding peripheral

[Samples](#) / [Bluetooth samples](#) / [Bluetooth: Direction finding connectionless locator](#)

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## Bluetooth: Direction finding connectionless locator

The direction finding connectionless locator sample application demonstrates Bluetooth® LE direction finding reception.

### Requirements

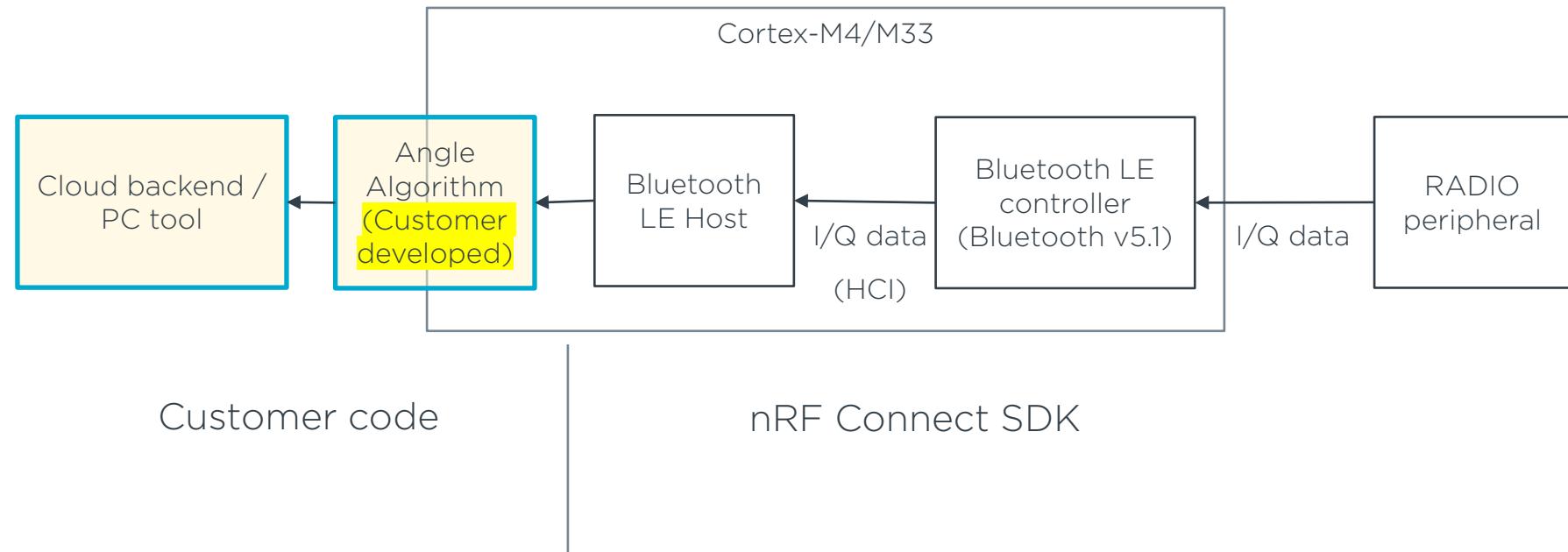
The sample supports the following development kits:

Hardware platforms	PCA	Board name	Build target
nRF5340 DK	PCA10095	nrf5340dk_nrf5340	<a href="#">nrf5340dk_nrf5340_cpuapp</a>
nRF52833 DK	PCA10100	nrf52833dk_nrf52833	<a href="#">nrf52833dk_nrf52833</a>
nRF52833 DK (emulating nRF52820)	PCA10100	nrf52833dk_nrf52820	<a href="#">nrf52833dk_nrf52820</a>

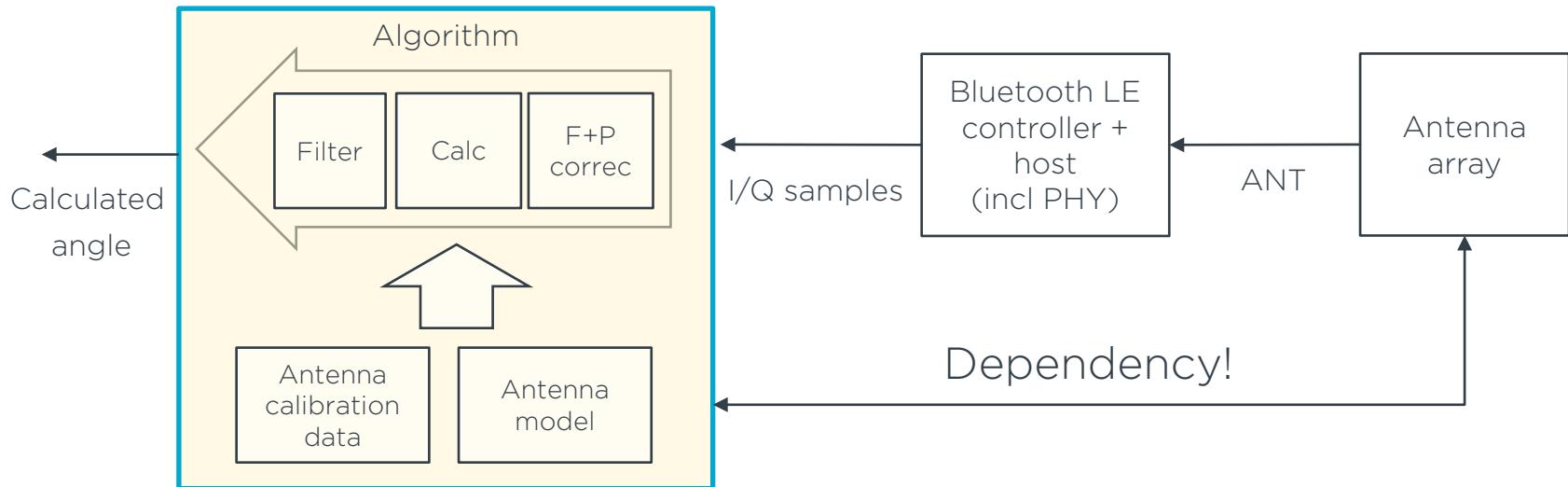
- Requirements
- Overview
- Configuration
  - nRF5340 configuration files
  - Angle of departure mode
  - Antenna matrix configuration for angle of arrival mode
  - Antenna patterns
  - Constant Tone Extension transmit and receive parameters
- Building and running
- Testing
- Dependencies

The sample also requires an antenna matrix when operating in angle of arrival mode. It can be a Nordic Semiconductor design 12 patch antenna matrix, or any other antenna matrix.

# Software architecture: Locator full solution



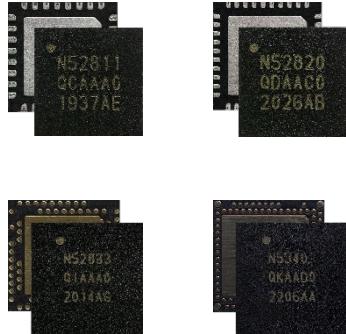
# Angle computation – essential components



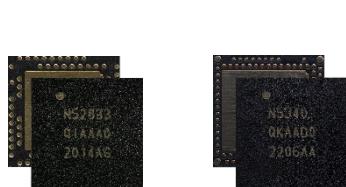


Supported HW for Direction  
Finding

# 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

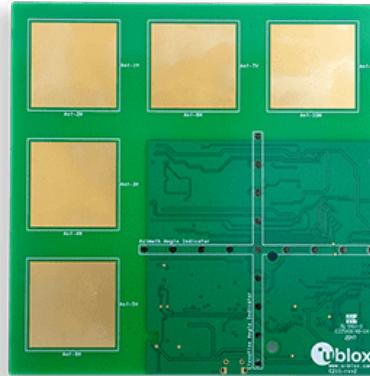


# InsightSiP antenna array - patch antennas



- 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 12<sup>th</sup> 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