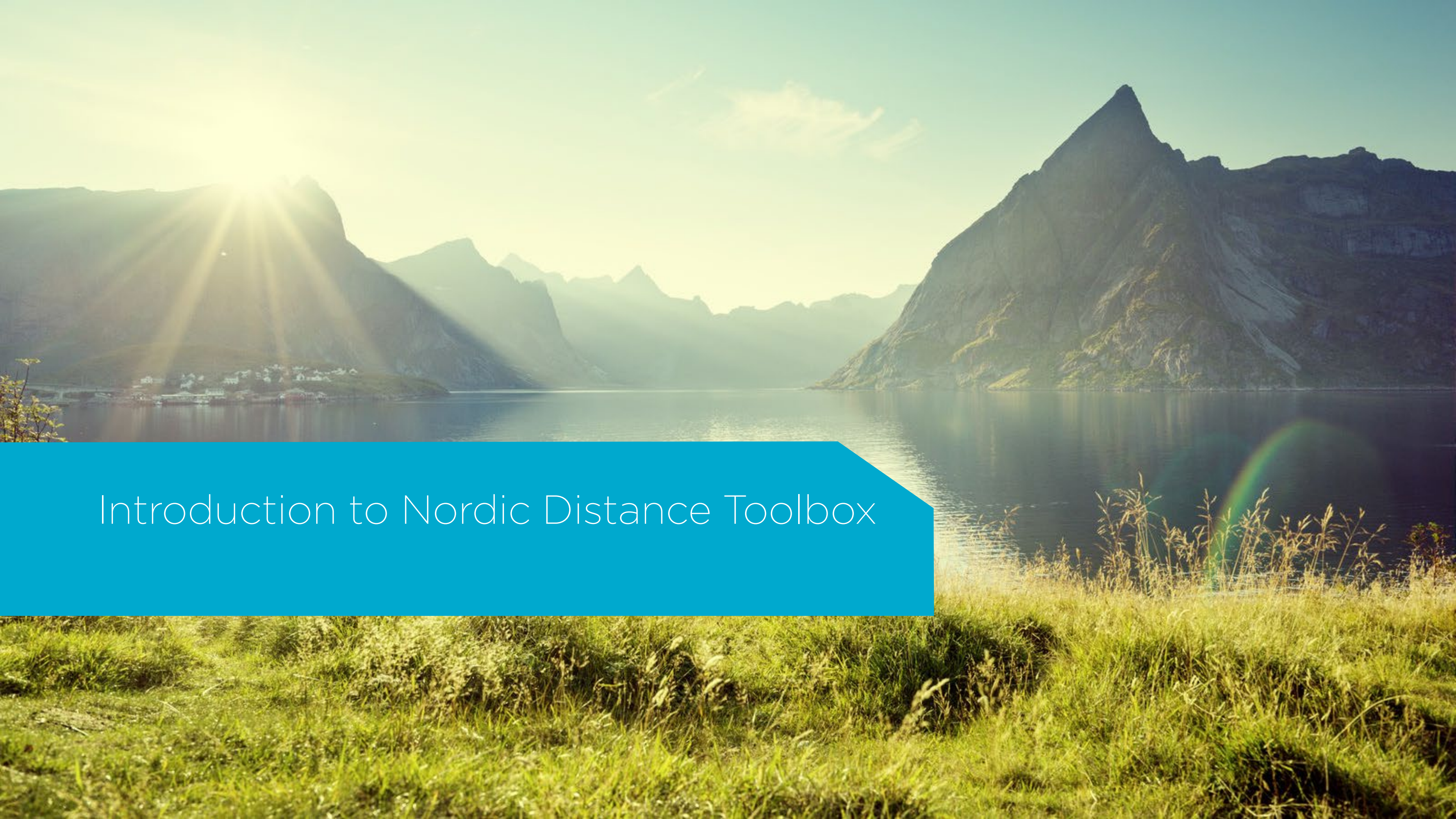


Introduction to Nordic Distance Toolbox

Nordic Distance Toolbox (NDT)

- The goal of NDT is to provide an easy to use interface for distance measurement
- The distance is computed based on all information available to the device
- All the mathematics necessary to compute distance is performed inside the toolbox

Physics

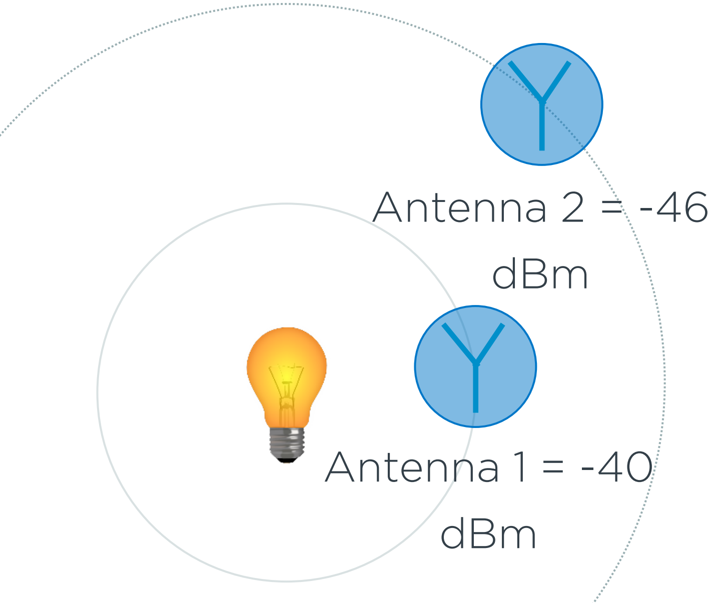
- RADIO peripheral use invisible light to communicate.
- The light has a frequency from 2.4 GHz to 2.5 GHz.
- The invisible light is not focused, it usually radiates roughly equally in all directions, like a diffuse lightbulb.

Observable parameters of 2.4 GHz light

- The RADIO peripheral with one antenna is extremely nearsighted (to use a visible light analogy), it cannot focus, and cannot see direction, it can only observe the
  - Intensity of the light (Real Signal Strength Indicator or RSSI)
  - The color of the light (Frequency) – Bluetooth Low Energy data communication uses two colors
  - When the light arrived
  - Phase of the invisible light (no direct visible light analogy)

Intensity

Distance affects intensity of the light



- Intensity is the power per unit area
- The transmit power is assumed to be constant
- The intensity is assumed to be inversly proportional to the area of a sphere ($4 \pi r^2$)
- Thus, we expect the recieved power to reduce with ~ $1/r^2$, which translates to a -6 dB per doubling of the distance

Real World Complications

- Loss is usually modelled as ~ $1/r^n$
- *n* is called the path loss factor. Most of the time the path loss factor is determined based on measurements in a certain environment.
- For example, in a home *n* might be measured to be 4.5, but that might be in a new house with walls of wood. In a home with walls of concret it might be different.
- *n* can vary between 1.6 and 6

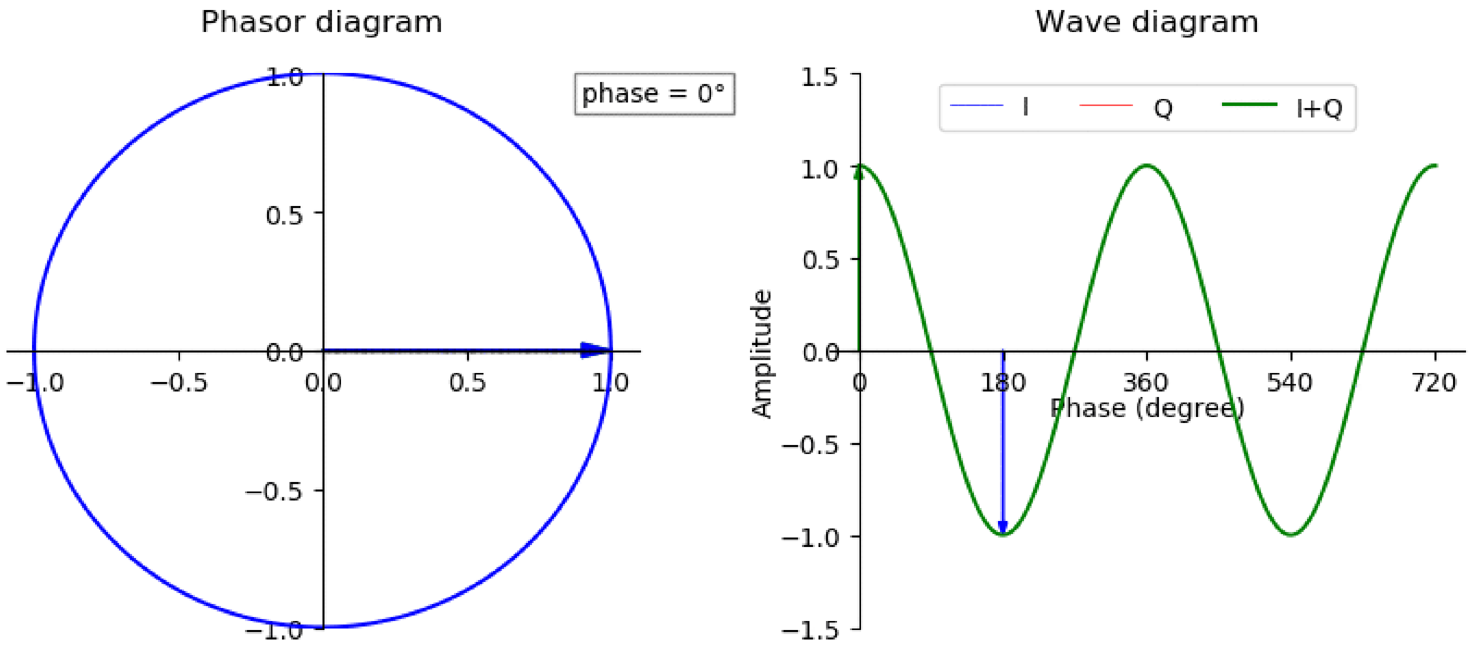
n	Link loss = - 56 dBm	Link loss = - 46 dBm
1.6	10.0 m	2.4 m
2	6.3 m	2.0 m
3	3.4 m	1.6 m
4	2.5 m	1.4 m
5	2.1 m	1.3 m
6	1.8 m	1.3 m

Distance measurement based on intensity (RSSI)

Even if you measure link loss without any error, you're still not going to know the distance accurately, since the path loss factor depends on environment.

Phase

«What is Phase?»

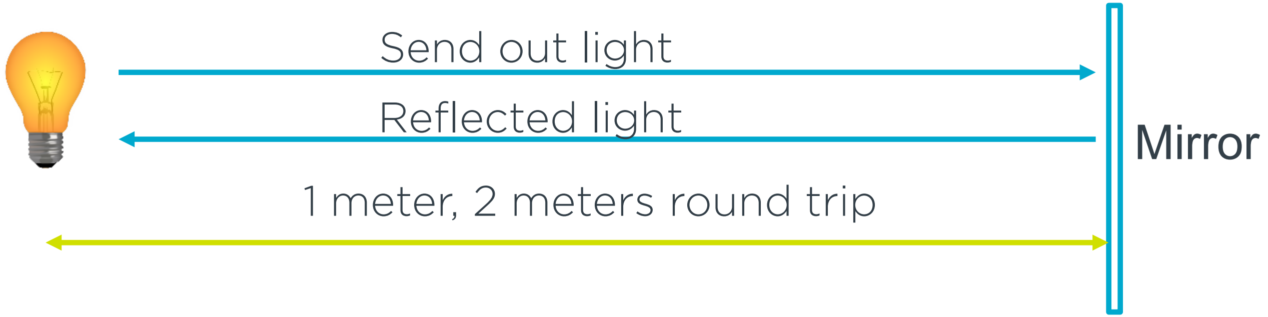


https://en.wikipedia.org/wiki/Phase_(waves)#/media/File:Phase_shifter_using_IQ_modulator.gif

Phase and wavelength of light

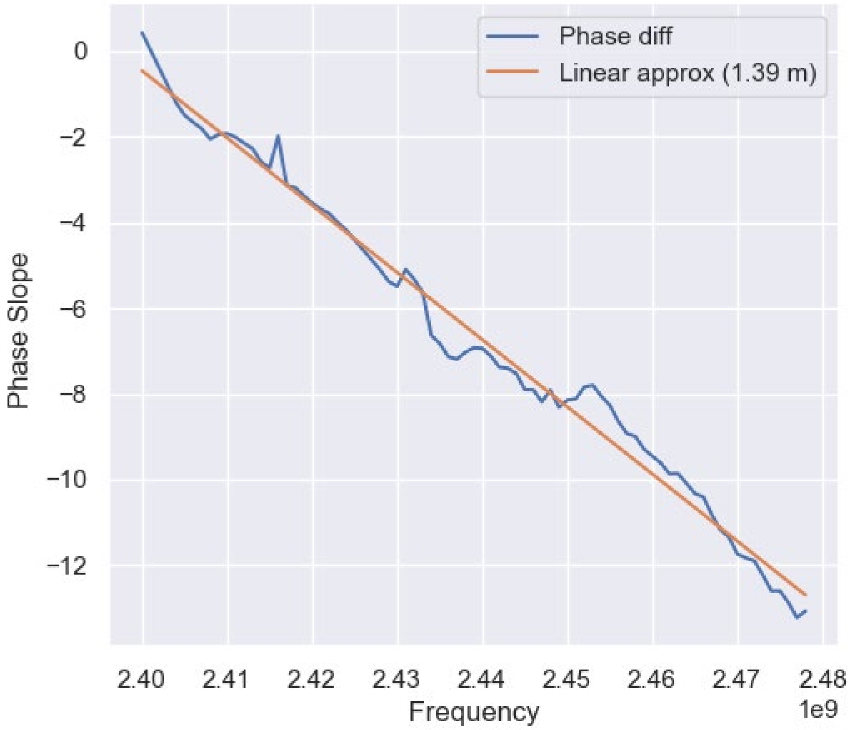
- Light is described as a photon, where the photon has a certain length (wavelength)
- The wavelength (λ) is the distance the photon travels to go through a full 2π phase rotation (360 degrees). This happens in one period, or 1/frequency.
- If we multiply the speed of the photon with the period we get the wavelength
  - $\lambda_{2.400GHz}$ = speed/frequency = 3.0e8 m/s / 2.400 GHz = 0.125 m
  - $\lambda_{2.440GHz}$ = speed/frequency = 3.0e8 m/s / 2.440 GHz = 0.123 m
  - $\lambda_{2.480GHz}$ = speed/frequency = 3.0e8 m/s / 2.480 GHz = 0.121 m

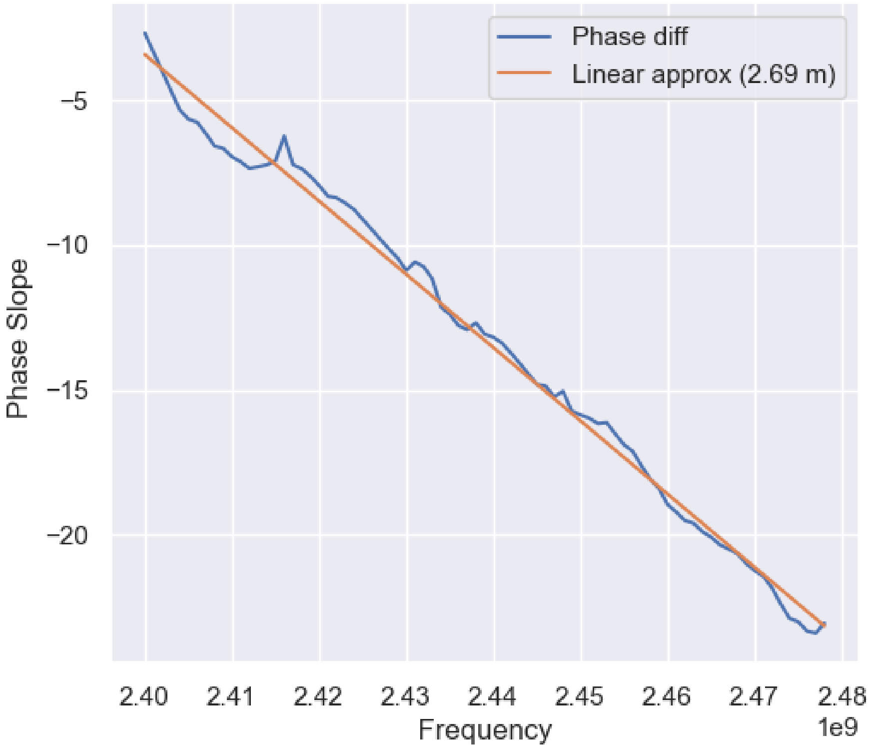
Distance affects the phase of the light



Frequency [GHz]	Wavelength [m]	Number of rotations	Remainder rotations	Phase of reflected signal
2.400	0.125	2/0.125 = 16	0	0
2.440	0.123	2/0.123= 16.26	0.26	$2\pi \times 0.26 = 0.52\ \pi$
2.480	0.121	2/0.121 = 16.53	0.53	$2\pi \times 0.53 = 1.06\ \pi$

Slope of phase vs frequency vs distance





Computing distance from phase

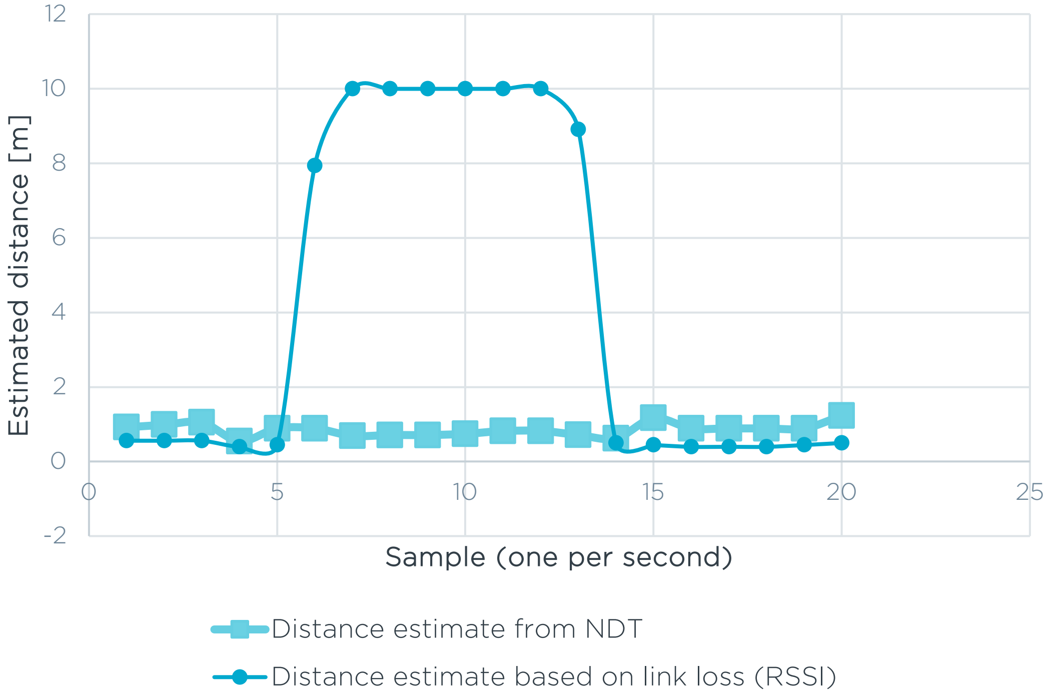
- Well known, and used for many years in radar (Multi-carrier phase ranging)
- Literally uses complex mathematics to go from I and Q measurements to distance
- For current generation of devices ranging requires communication to and from both devices

Nordic Distance Toolbox

NDT version 0.6.0

- Quality indicator
- TX power and RSSI for both remote and local device
- Distance measurement based on
  - Link Loss (RSSI)
  - Multi-carrier phase slope estimation (MCPD)
  - Inverse Fast Fourier Transform (IFFT)
  - Hi-Precision: Estimation of multipath channel impulse response from frequency spectrum measurements
  - Round Trip Timing (RTT)

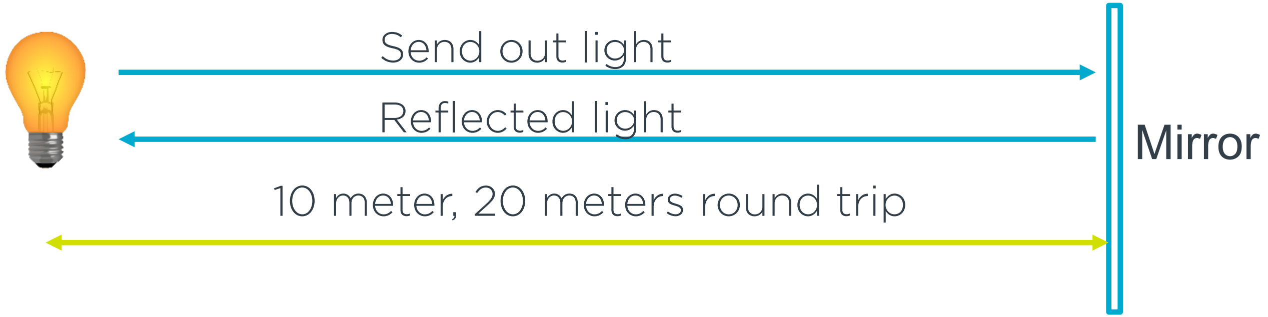
Distance estimation comparison



- Place one development kit on a chair, and sit on it.
- Actual distance between development kits is approximately 1 m

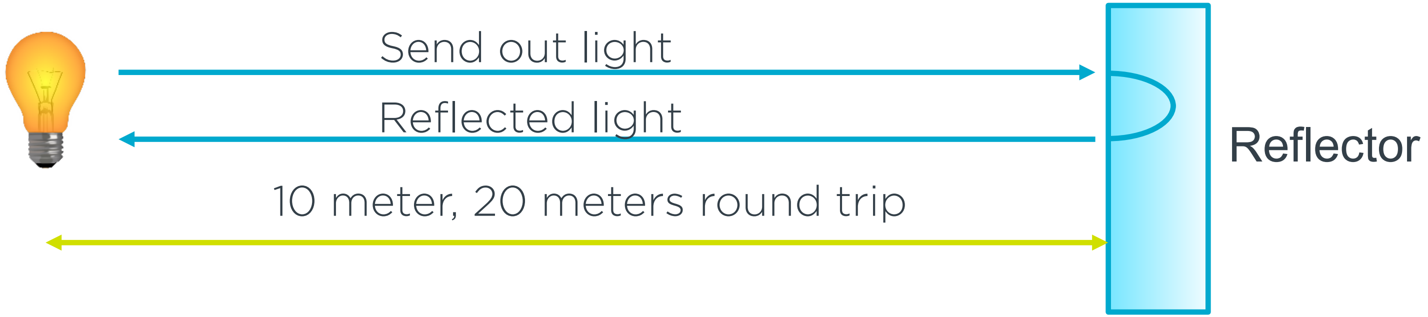
Time

Round Trip Timing



- Speed of light 299 792 458 meter per second
  - 3.33ns per meter
- In NDT the "mirror" will have a delay
  - Caused by radio changing from RX -> TX

Round Trip Timing



- Speed of light 299 792 458 meter per second
  - 3.33ns per meter
- Predictable reflector delay
- Measure Round Trip Timing over multiple frequencies and average

NDT performance

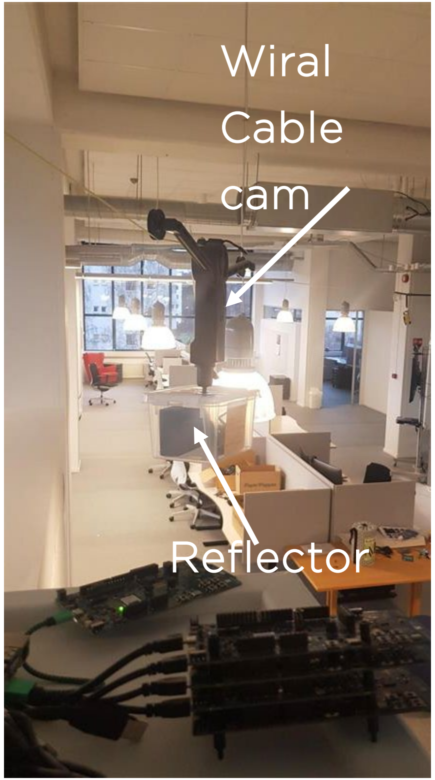
Background

The measurements have been performed in an office

The ceiling and floor is metal rich

The measurement of and calculation of the distance has been done with the Nordic Distance Library version 0.6.0

Measurement setup



- A Wiral cable cam setup is used to move the reflector
- Continuous ranging's are performed
- Reference distance determined by LIDAR

Nordic Distance Library

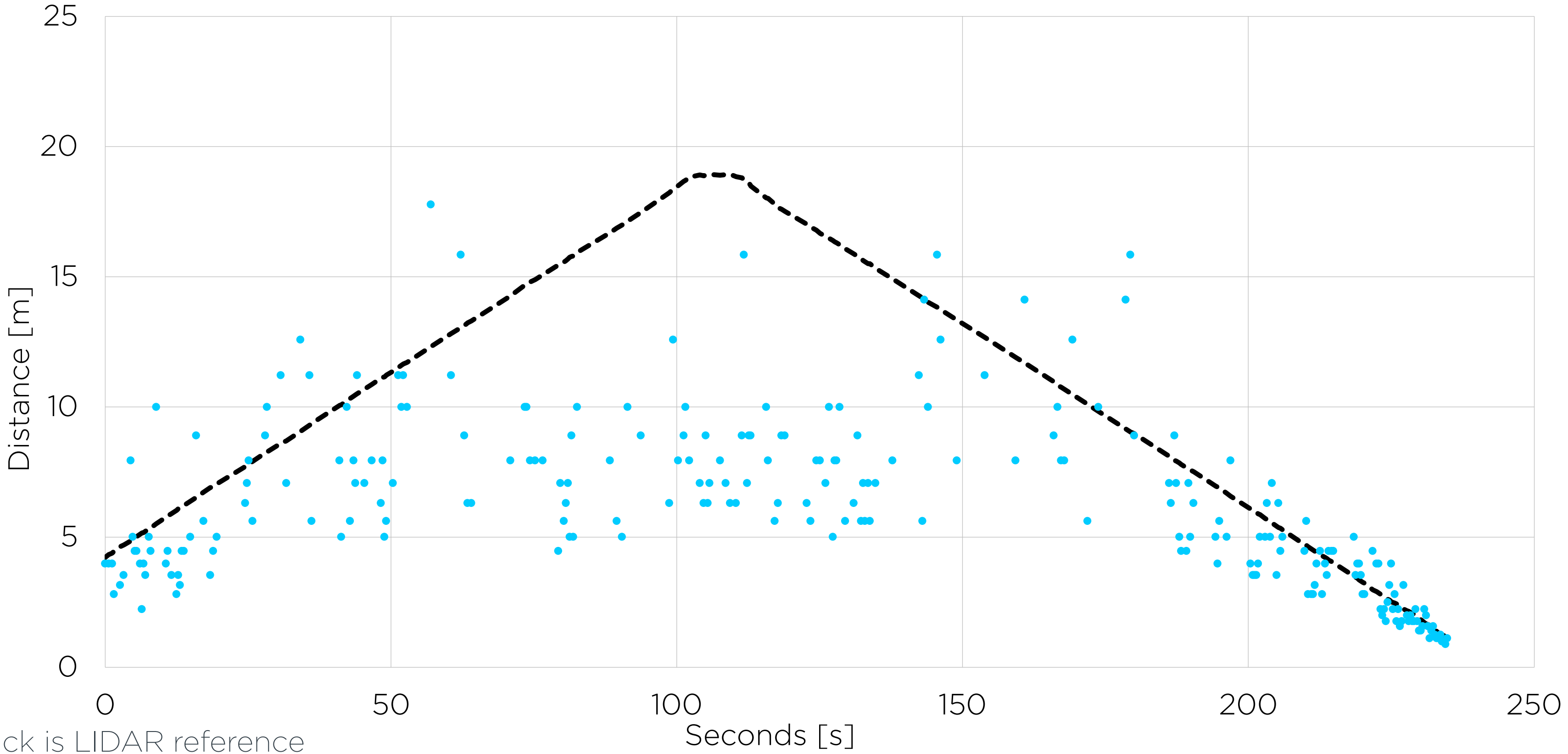
nrf_dm_calc() computes 3 distances

- Distance from Friis path loss (rssi_openspace)
- Distance based on phase slope over frequency (phase_slope)
- Distance based on inverse fast fourier transform of the channel spectrum (ifft)

nrf_dm_high_precision_calc()

- Uses advanced spectrum techniques to improve precision of the distance
- Long compute time (tens of ms), and high memory consumption
- Will contain outliers in real environment and it’s recommended to use outlier filtering.

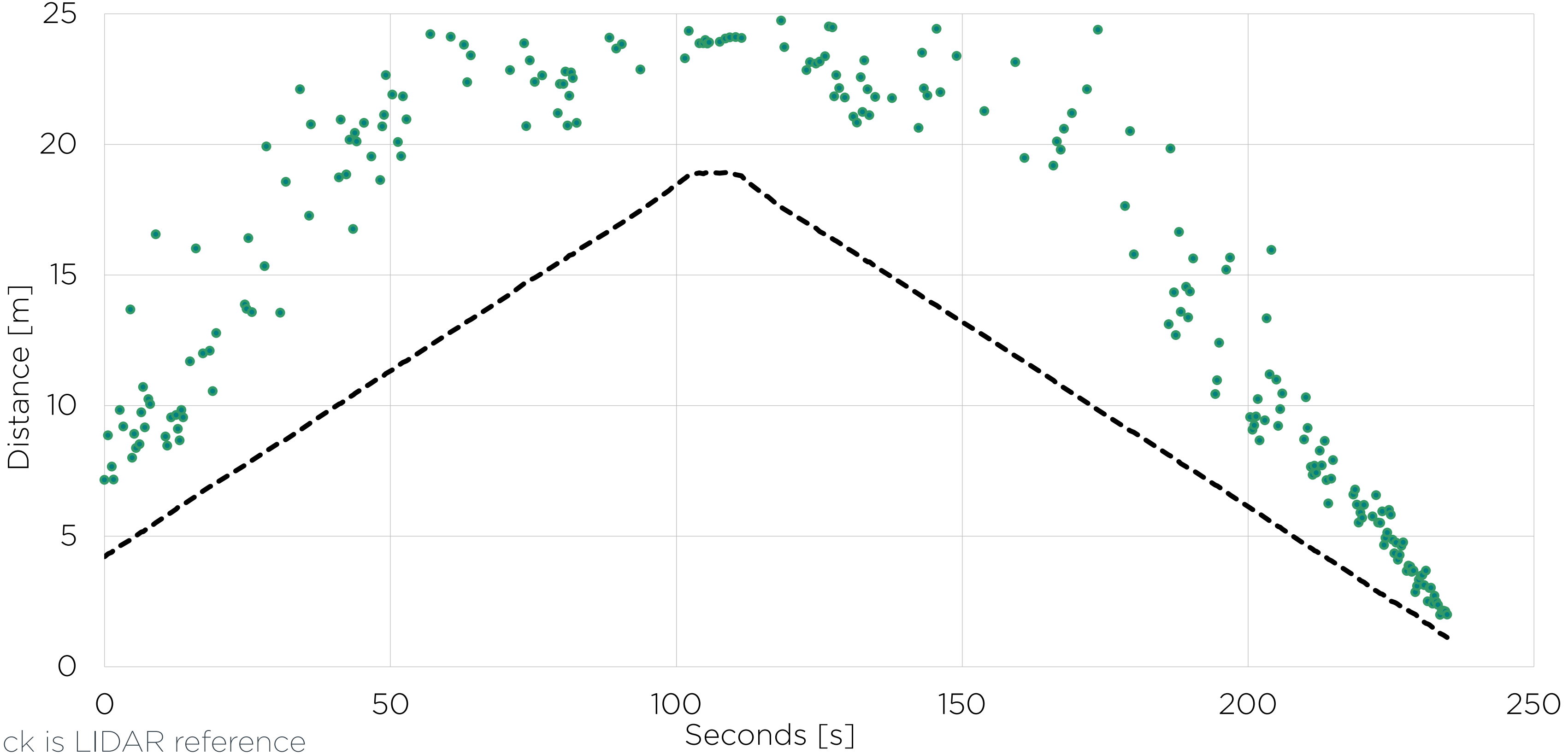
Friis path loss



Black is LIDAR reference

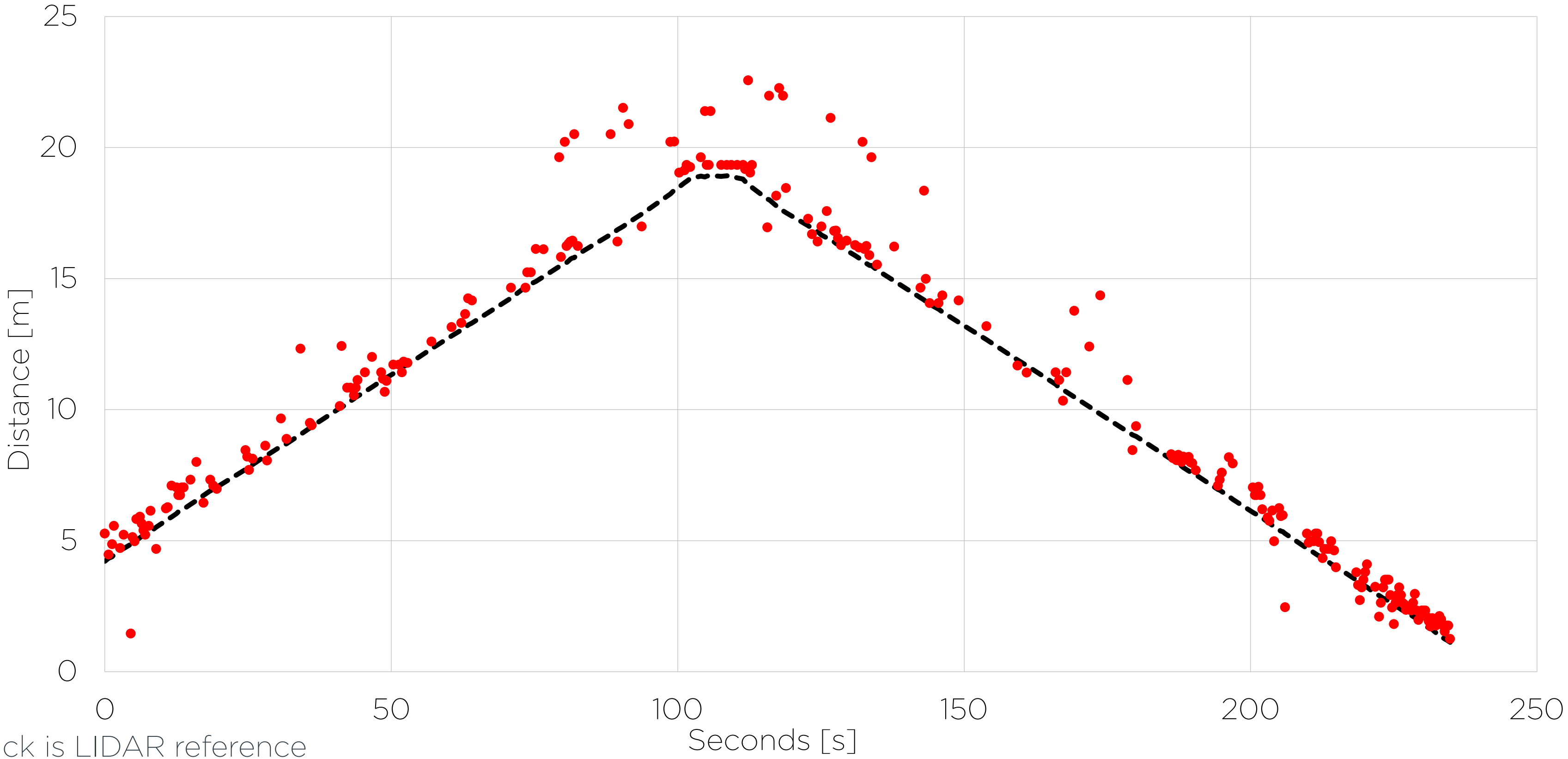
Phase slope

No attempt has been made to compensate for slope as a function of distance



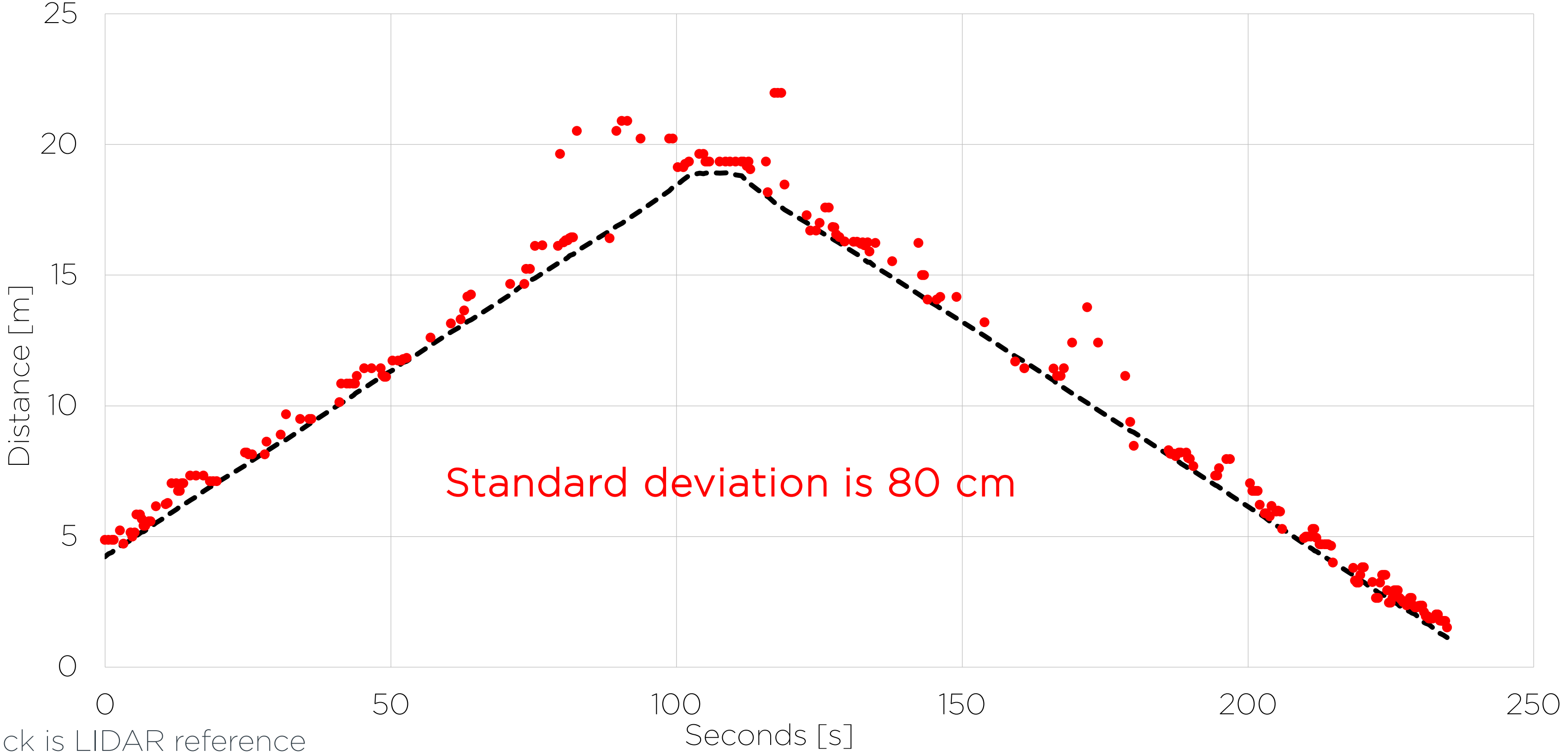
Black is LIDAR reference

Inverse fast fourier transform



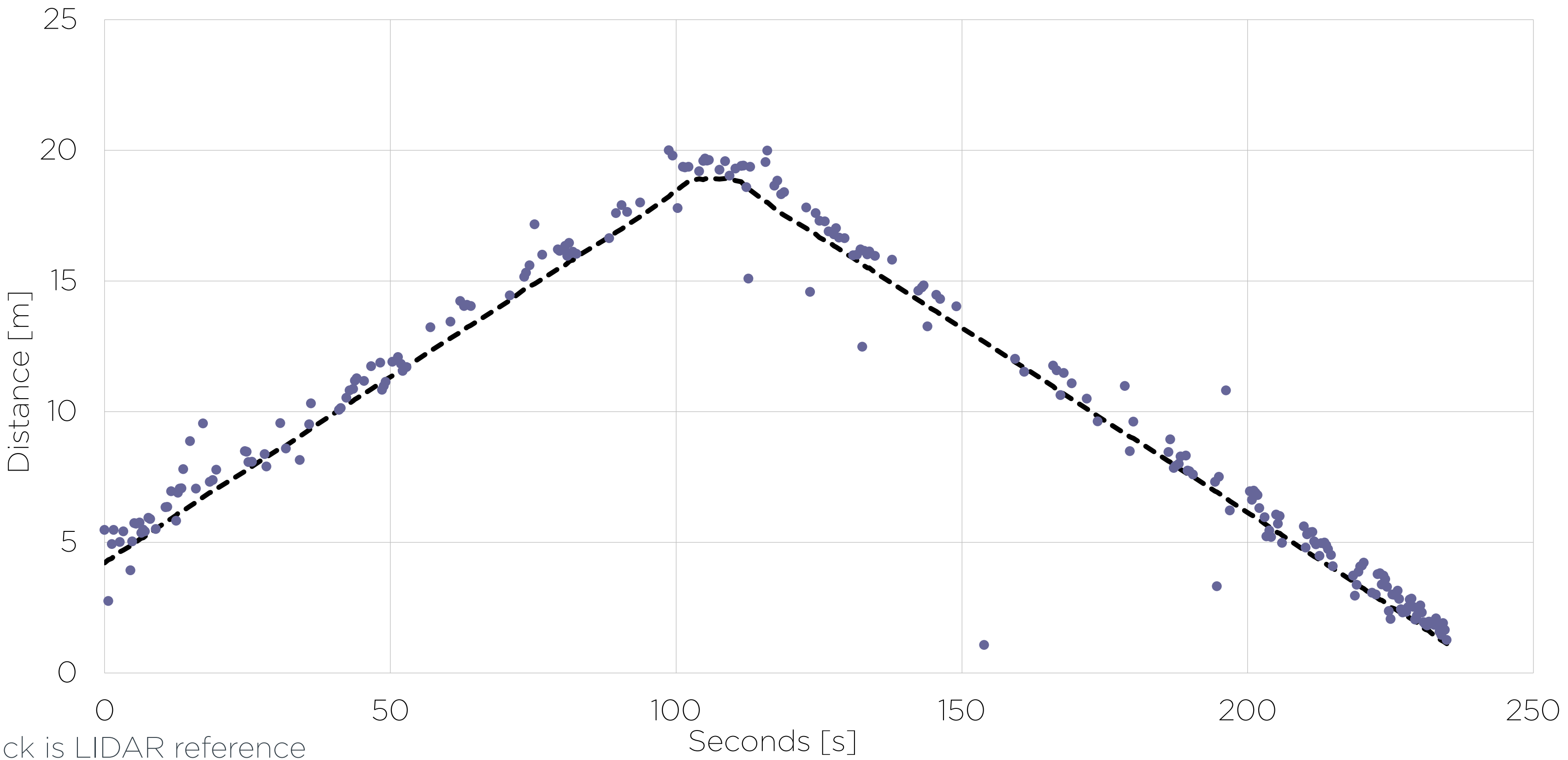
Black is LIDAR reference

Inverse fast fourier transform with median 3 filter



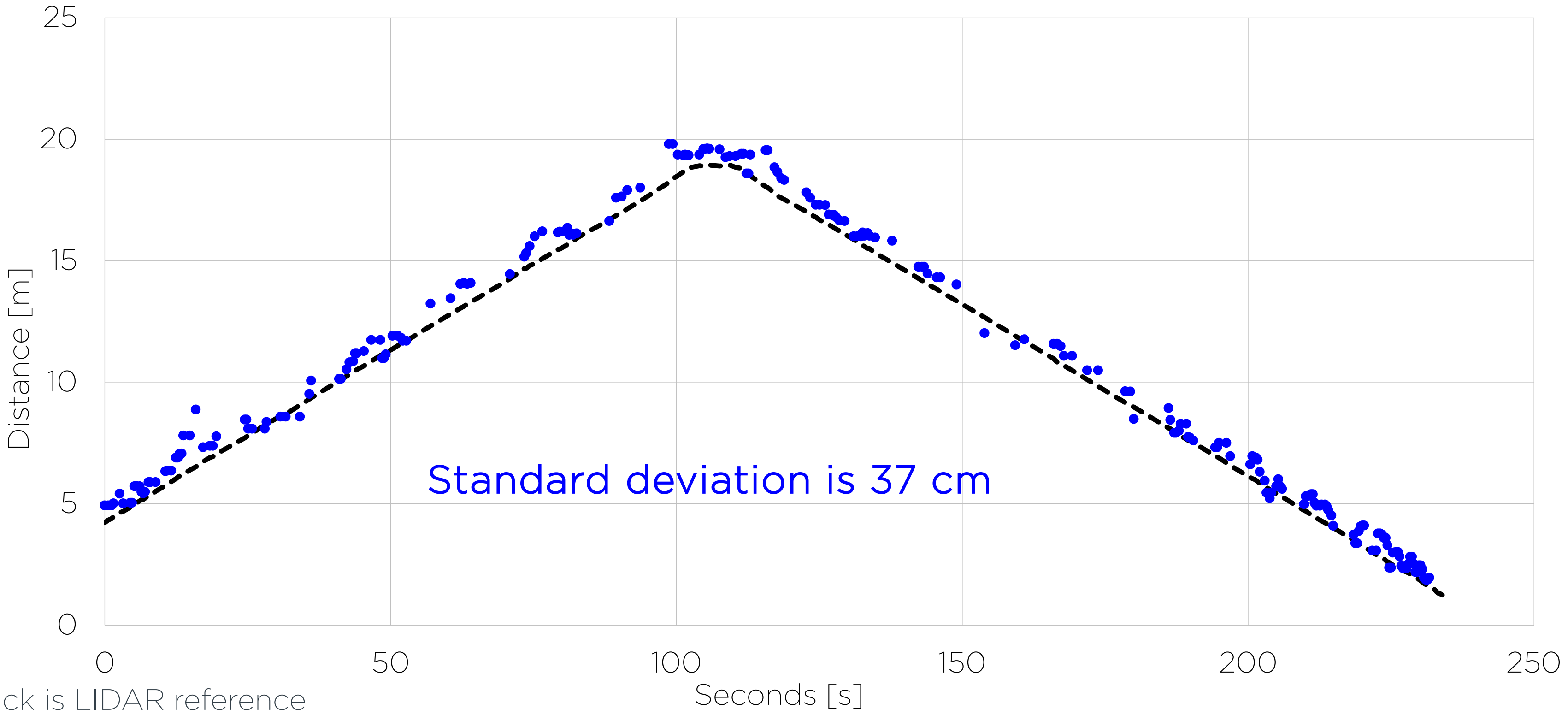
Black is LIDAR reference

High Precision



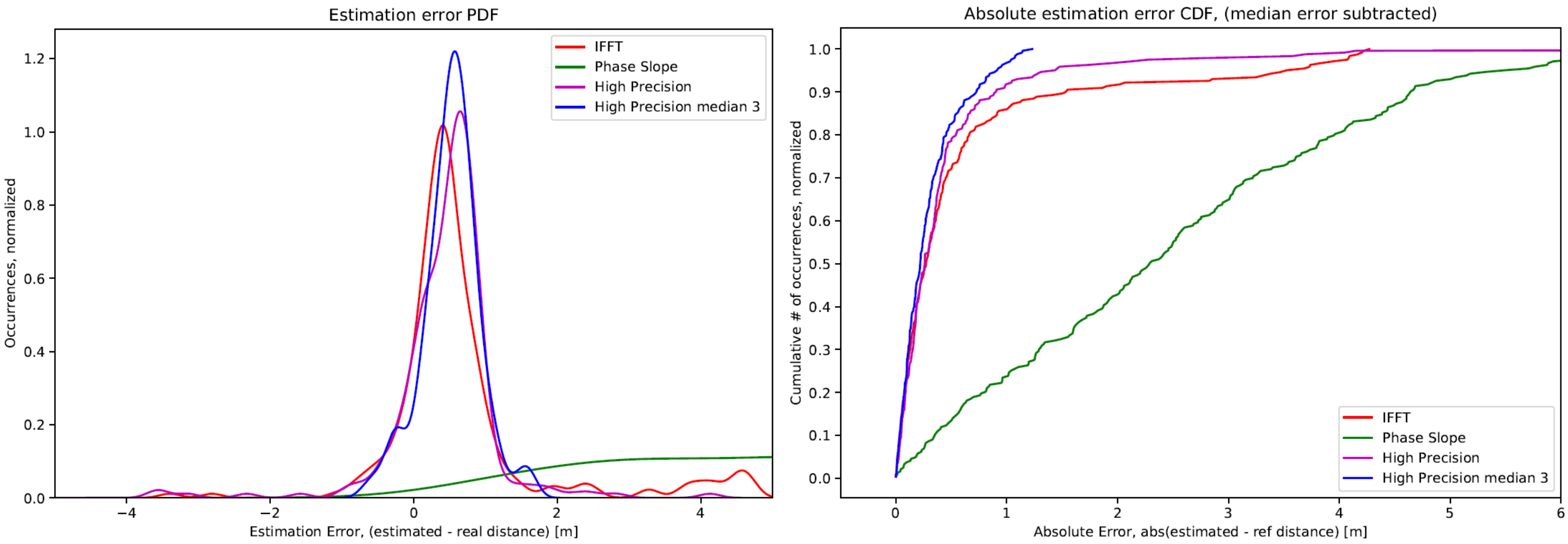
Black is LIDAR reference

High Precision with median 3 filter

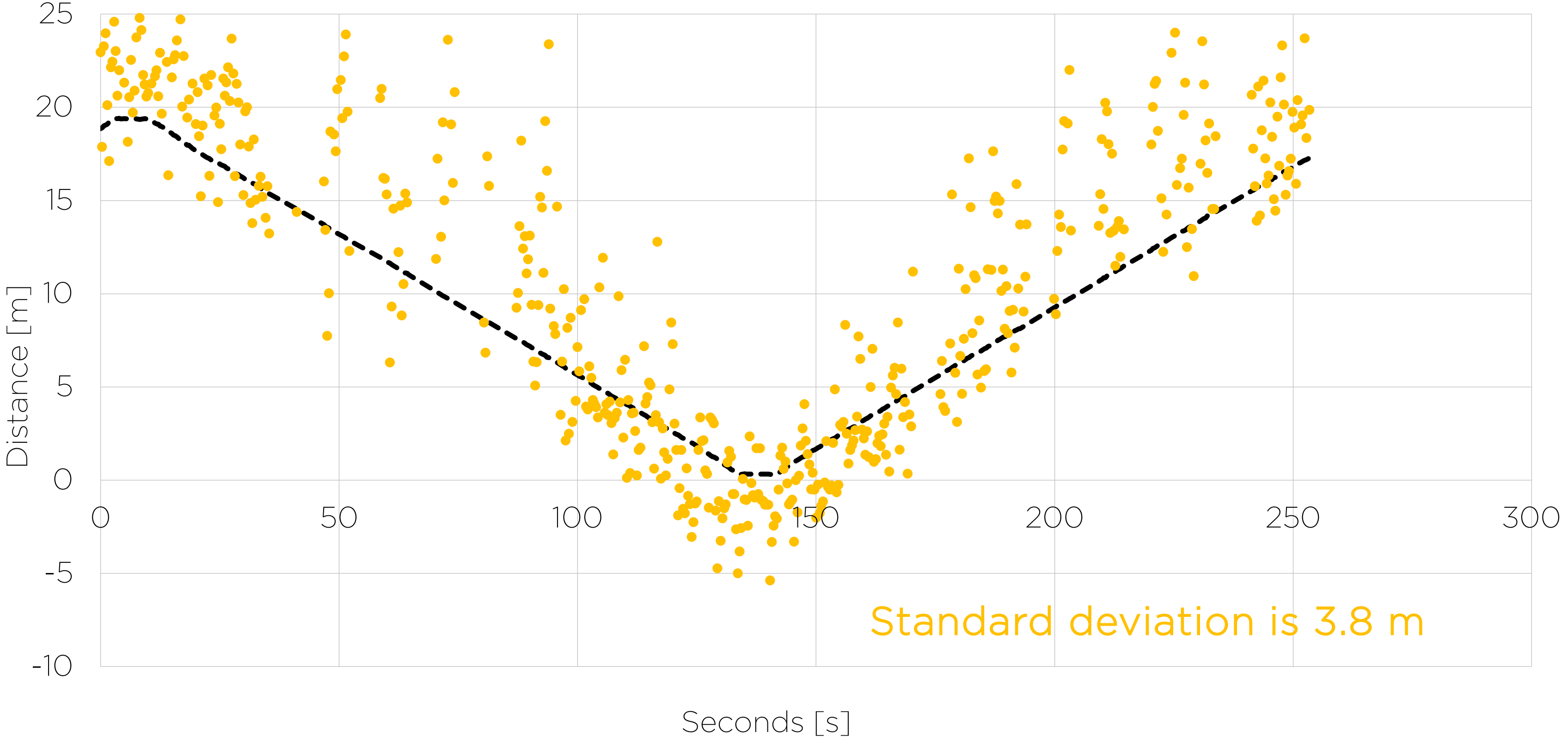


Black is LIDAR reference

Probability distribution, and Cumulative Distribution Function



RTT



Black is LIDAR reference

Measurement summary

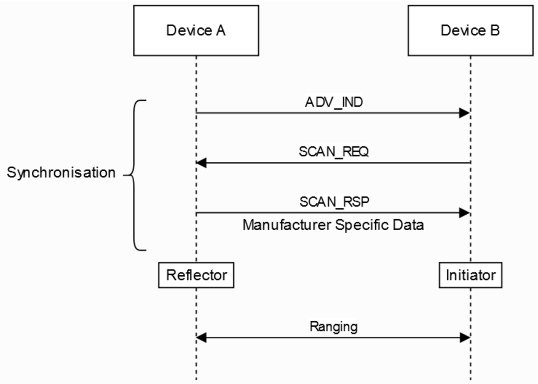
- Phase based ranging gives best accuracy, but is range limited
  - Maximum range depends on environment
  - In office space, reliable results up to 8-10 meters with filter
- RTT gives lower accuracy but is only range limited to max Bluetooth connectivity range
  - Can be several 100 meters
  - Standard deviation of ranging result is 3.8 meters

Measurement summary distance <10 meters

Technique	Comment
Friis open space	Bad estimate of distance in real environment
Phase slope	Imprecise, few outliers, always larger than real distance
IFFT	More precise, but outliers
High precision	Even more precise, but outliers
High precision with median 3	Best result

nRF Connect SDK NDT sample

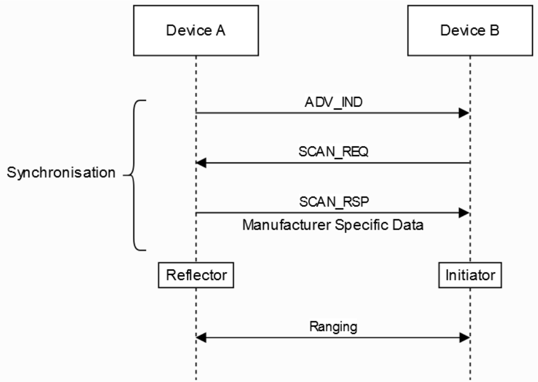
nRF Connect SDK sample



Synchronisation process

- One simple demo sample to showcase NDT
- Each device is scanning and advertising
  - Advertising over Bluetooth
  - Scanning when not advertising
- No filtering of devices
  - Will try to range to all devices in the vicinity
  - Will range to multiple devices if present
- Output data over UART and to PC through USB CDC ACM interface
  - Use standard terminal to watch results

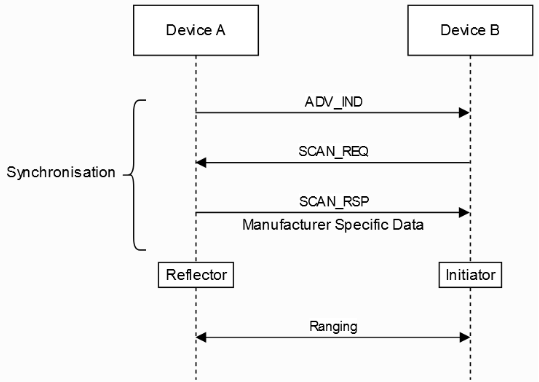
nRF Connect SDK sample



Synchronisation process

- Adding a lot of devices in a small area will impact performance of sample
  - Will require more advanced application to avoid flooding the system
- Bluetooth is only used for synchronization of the ranging
  - Can be replaced by proprietary radio if wanted, just need to provide synchronization mechanism

nRF Connect SDK sample



Synchronisation process

- Currently supported
  - nRF52833 DK
  - nRF52840 DK
- Next device
  - nRF5340-DK
- Code is tuned for the device and the board so changes will require to trim offset and gain

Thanks!