University of BRISTOL

Measurements, Modelling and Testing Millimetre Wave Communication Systems

EPSRC Pioneering research and skills

KEYSIGHT TECHNOLOGIES

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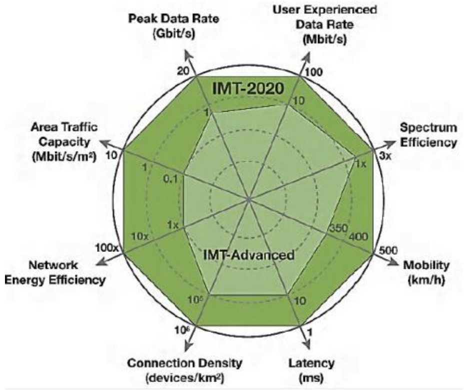
Instituto de Fomento al Talento Humano

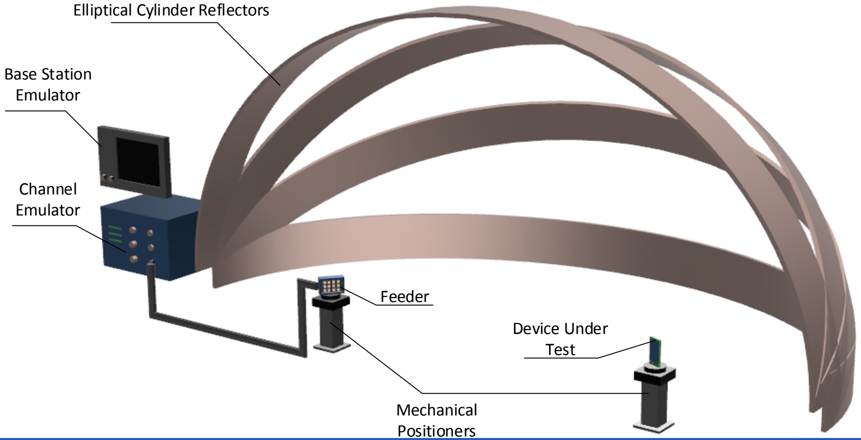
mmMAGIC

CW Radio Technology SIG,
Commercialising Millimetre-Wave Technology, 15th May 2019

Summary of Presentation

- 5G Operational Goals
  - Why Millimetre Wave?
- Propagation Environment
  - Pathloss
  - Diffraction
  - Reflection / Scatter
- The Sparse Spatial Channel
- Emulation & Testing of Devices
  - Conductive
  - Over The Air (OTA)
- Conclusions



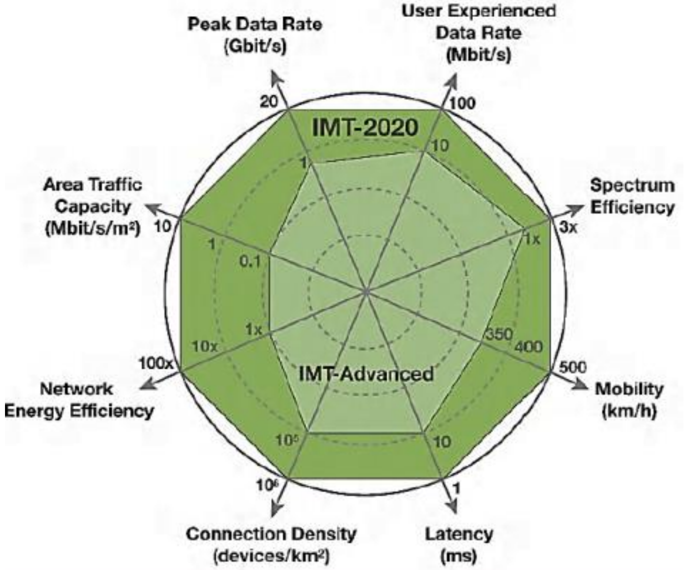


5G: The Networked Society

- Broadband experience: everywhere; anytime
- Industry 4.0, Smart Vehicles, Transport & Infrastructure

Target Specs:

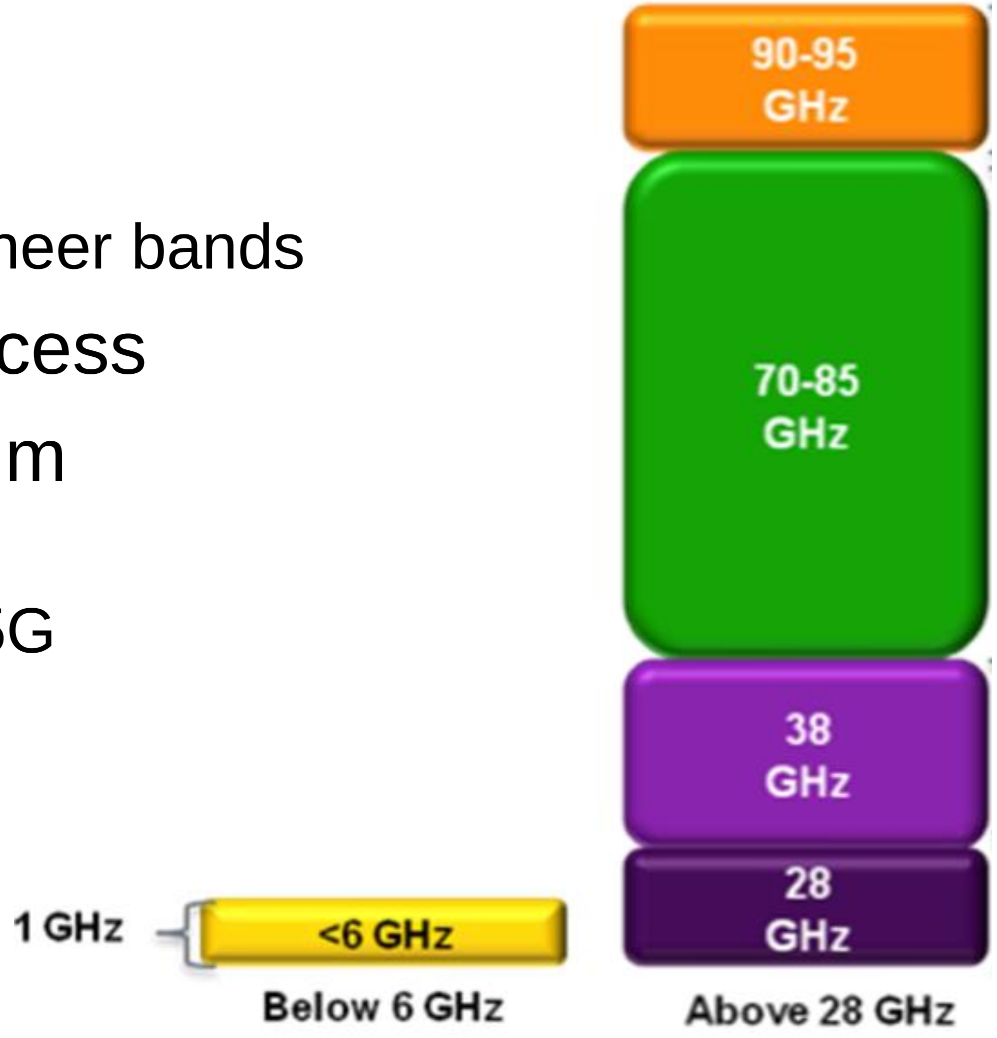
  - 10Gbit/s Peak, 100Mbit/s where ever needed
  - X100 – x1000 Capacity
  - X10 battery life
  - Reduced Latency (0.5ms)



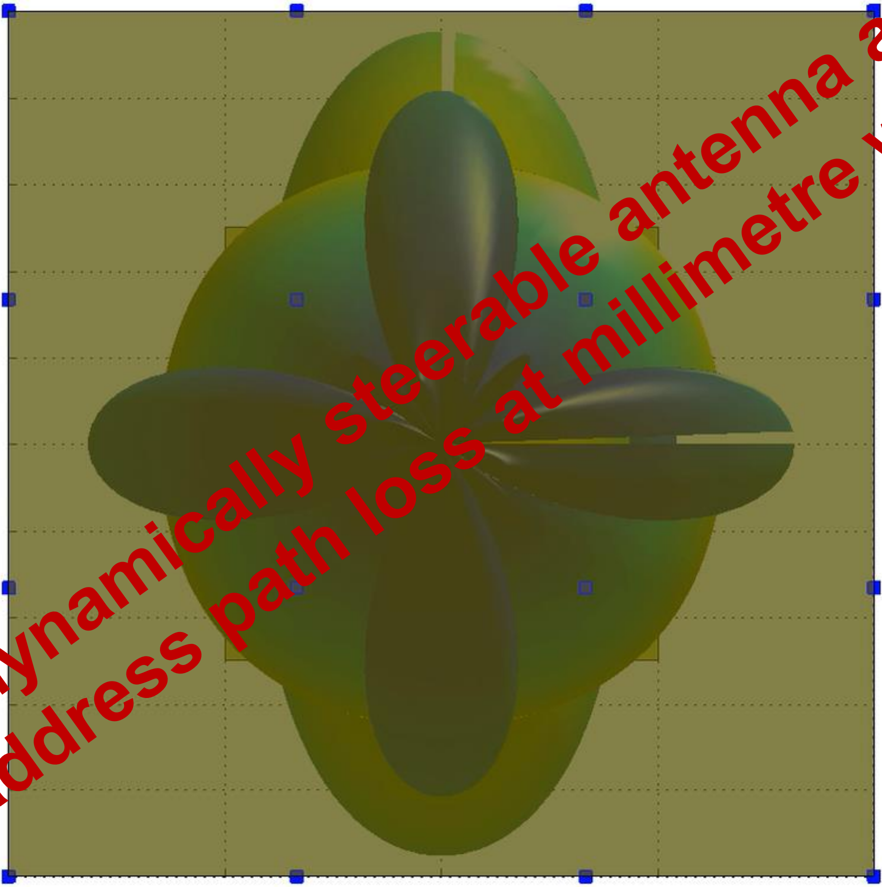
- 5G Requires
  - Enhanced Spectrum Efficiency .. Massive MIMO for sub-6GHz
  - New Spectrum …… Millimetre wave bands

Millimetre Wave

- 30GHz – 300GHz
  - Includes 26 (& 28) GHz pioneer bands
- Unused for cellular-like access
- Lots of continuous spectrum
  - Addresses both capacity & data rate requirements for 5G
- Shorter wavelength
- Greater path-loss
  - O_2 absorption bands



Antenna Array & Beamformer



Use of dynamically steerable antenna arrays to address path loss at millimetre wave

Millimetre Wave

- 30GHz – 300GHz
  - Includes 26(28) GHz pioneer bands
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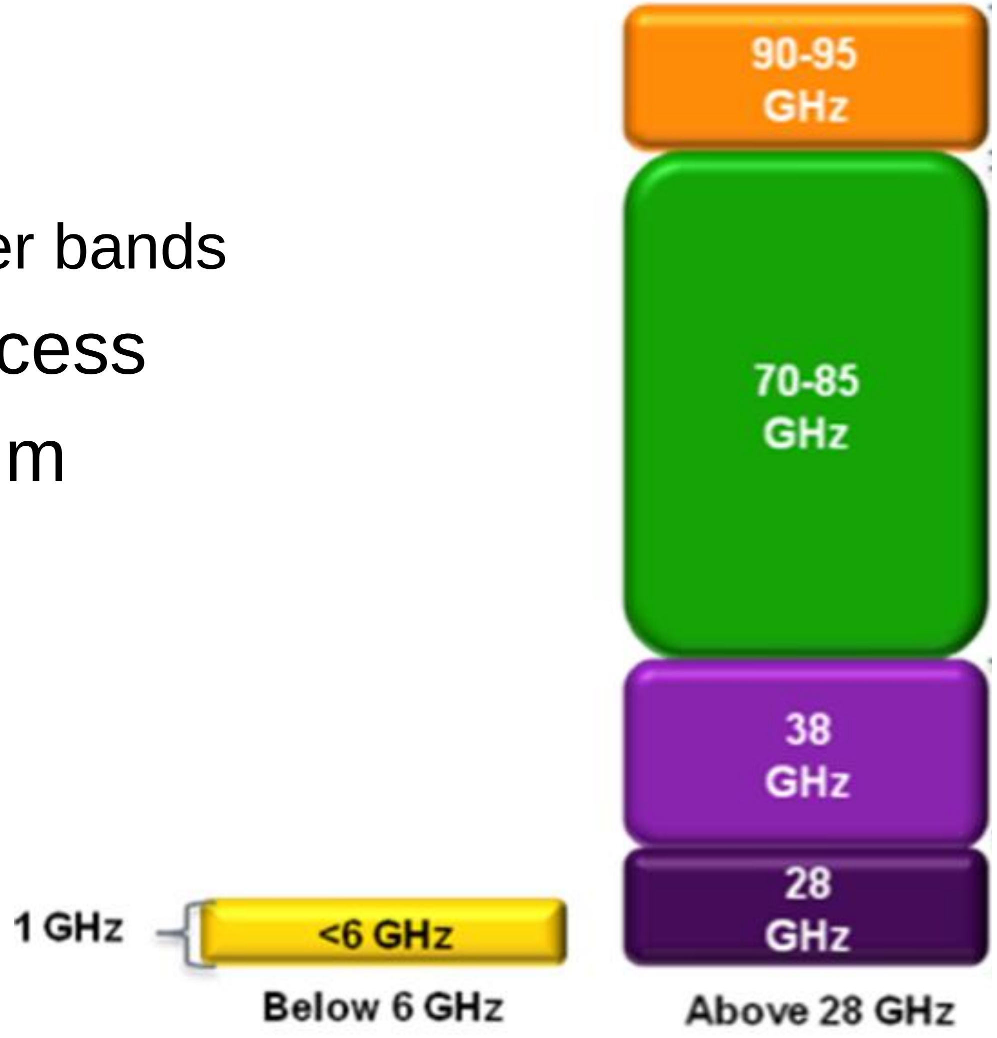
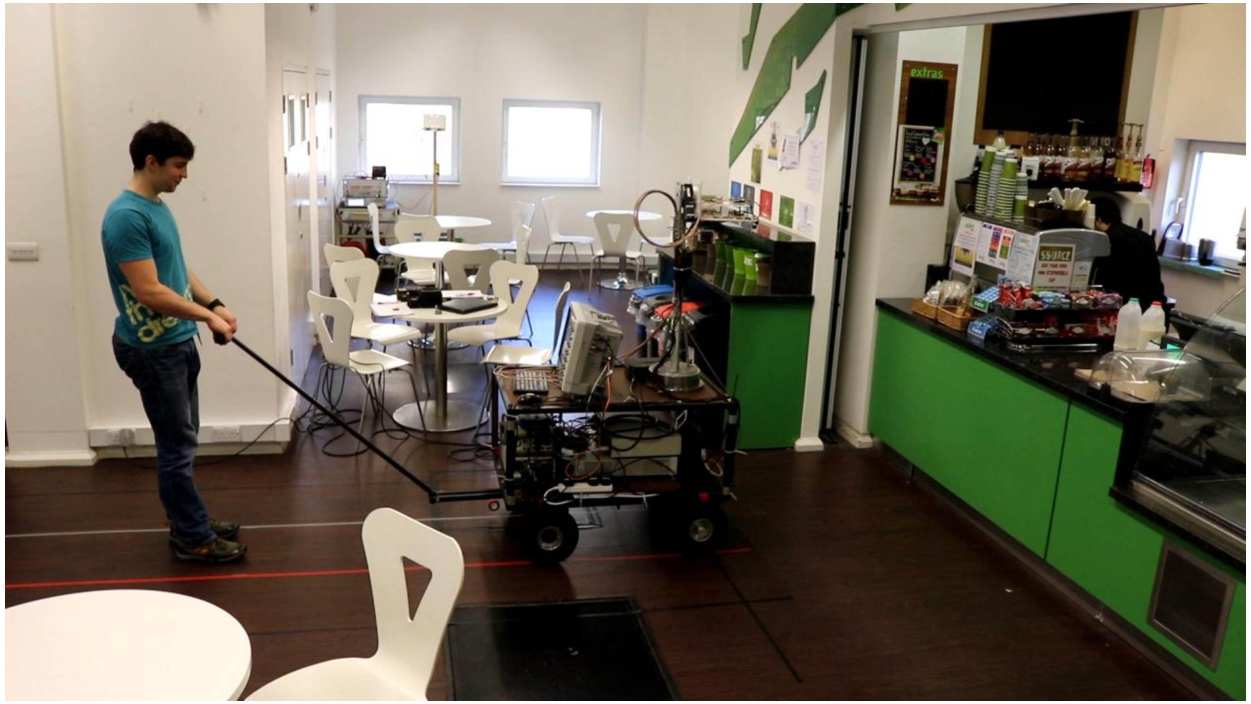
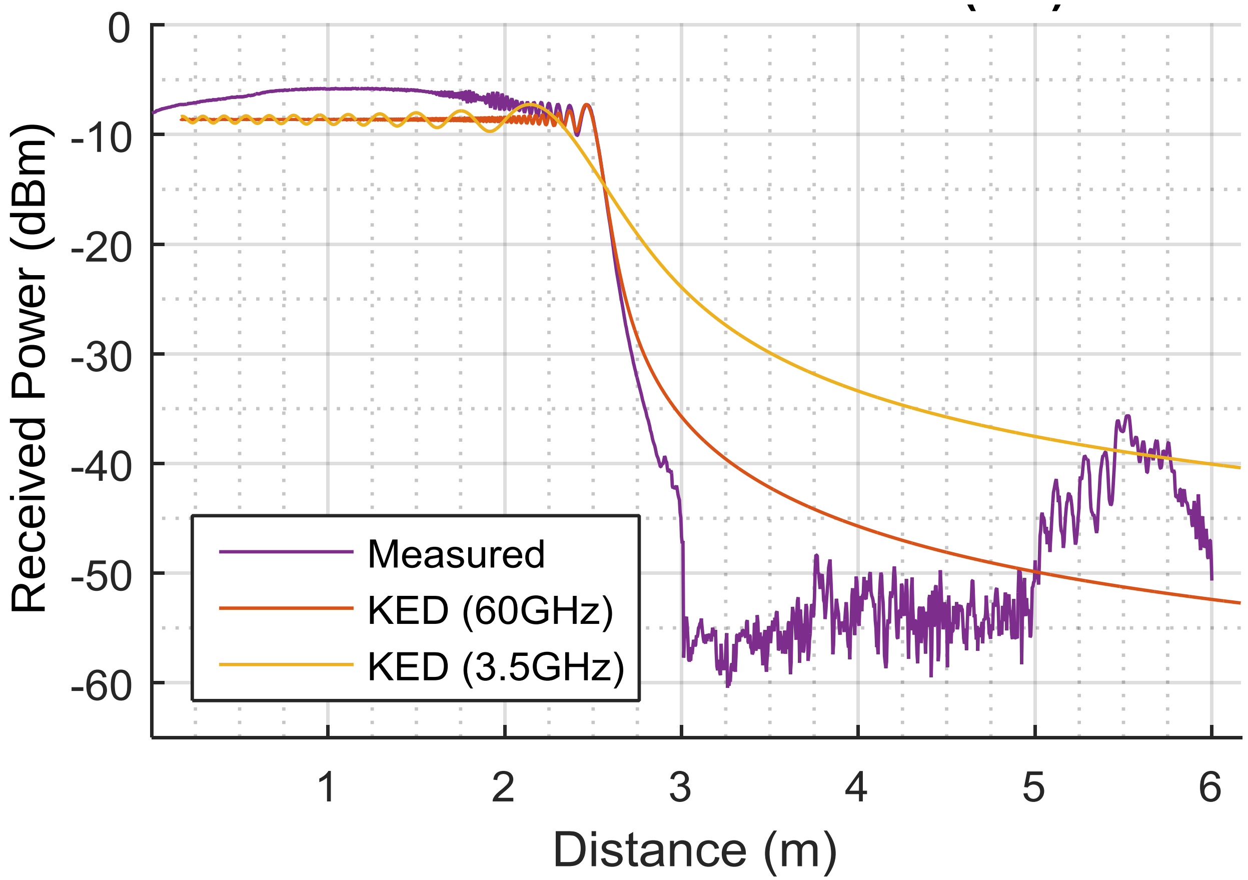
- Lots of continuous spectrum
  - Addresses both capacity & data rate for 5G
- Shorter wavelength
- Greater path-loss
  - O_2 absorption bands
- What else is different?



Corner Diffraction (60GHz, 2GHz Bandwidth

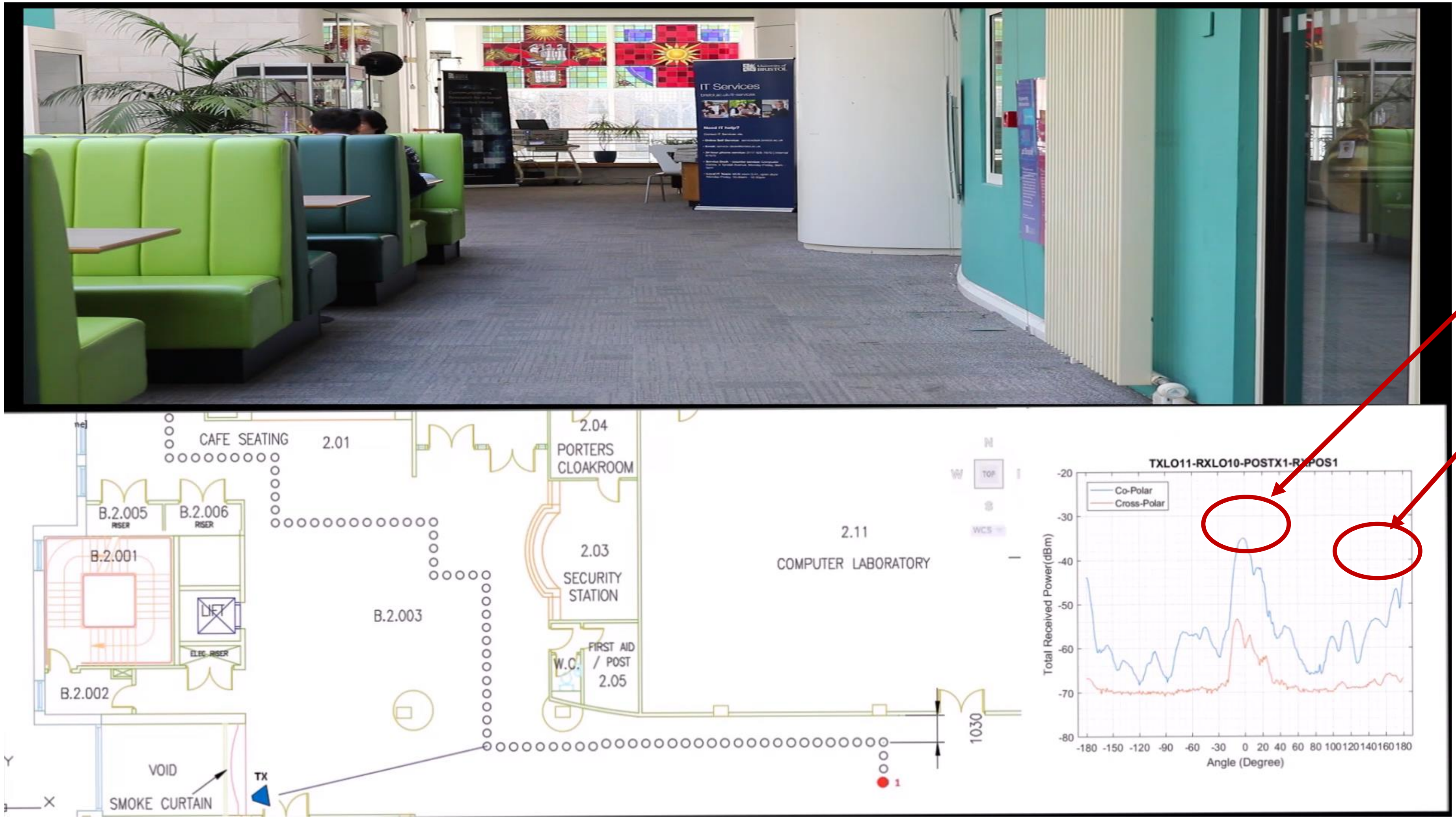


Transition from LoS to NLoS – corner diffraction



- Transition from LoS to NLoS can be modelled using diffraction theory.
- Agreement of 60GHz measurements with Knife Edge Diffraction theory.
- Using KED theory for a frequency of 3.5GHz, an attenuation of 30dB required movement of 2.5m into the shadow region for the same scenario as opposed to 50cm at 60GHz.
- Diffraction loss is very high at millimetre wave frequencies, so it is questionable as to whether it needs to be modelled.

LoS and Multipath Reflections (indoor)



LoS

Strong Reflection from Beyond Trolley

LoS and Multipath Reflections (indoor)

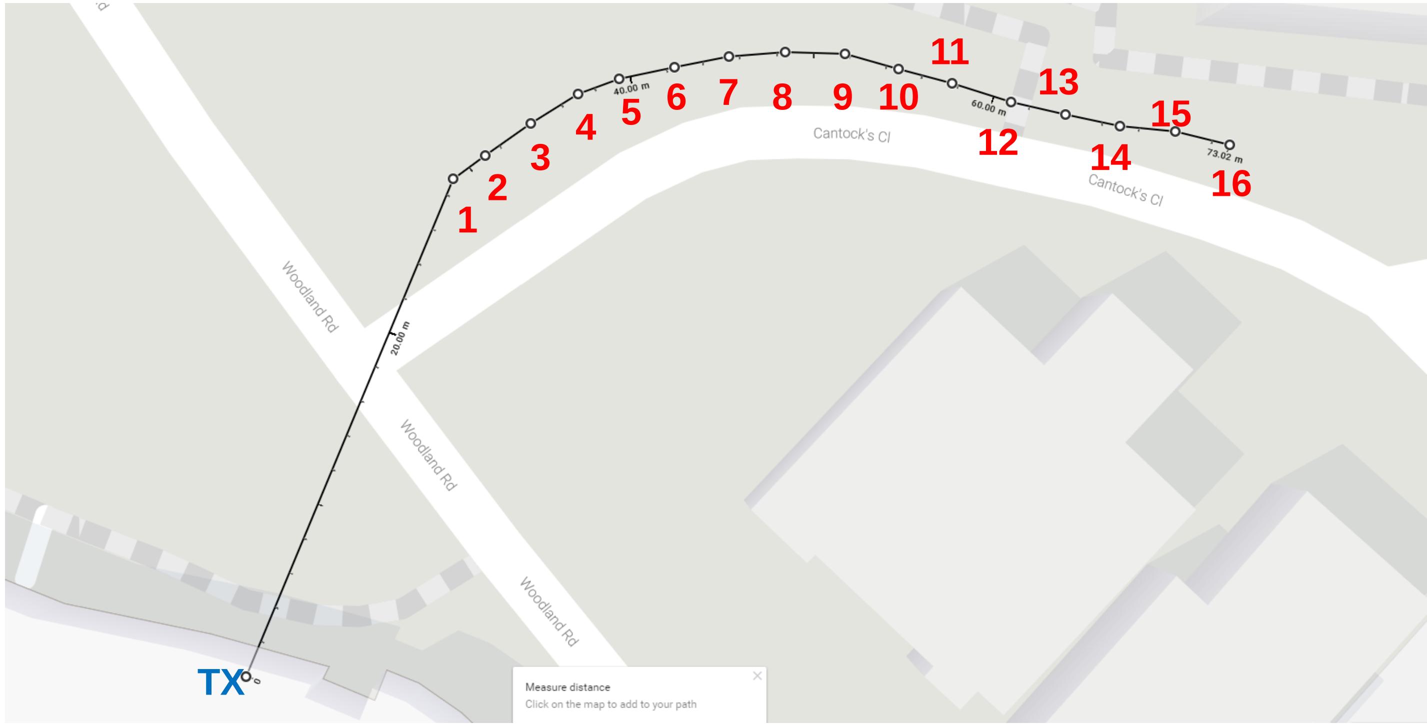
Metal Pillar

LoS

Multiple Reflections

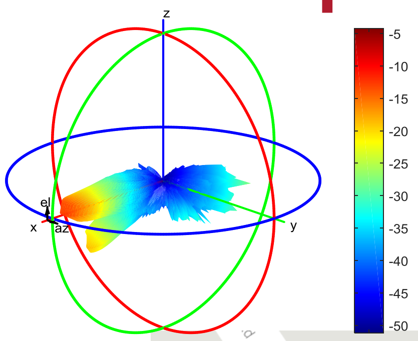
LoS and Multipath Reflections (outdoor)

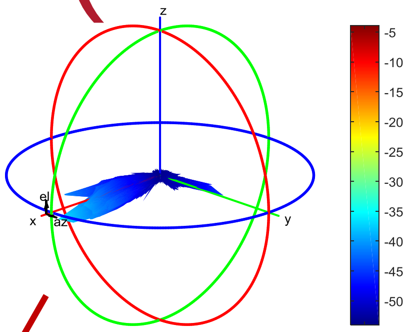
LoS and Multipath Reflections (outdoor)



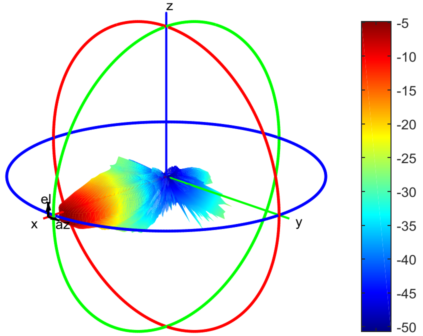
LoS and Multipath Reflections (outdoor)

Additional loss on LoS component due increased range and ground reflection

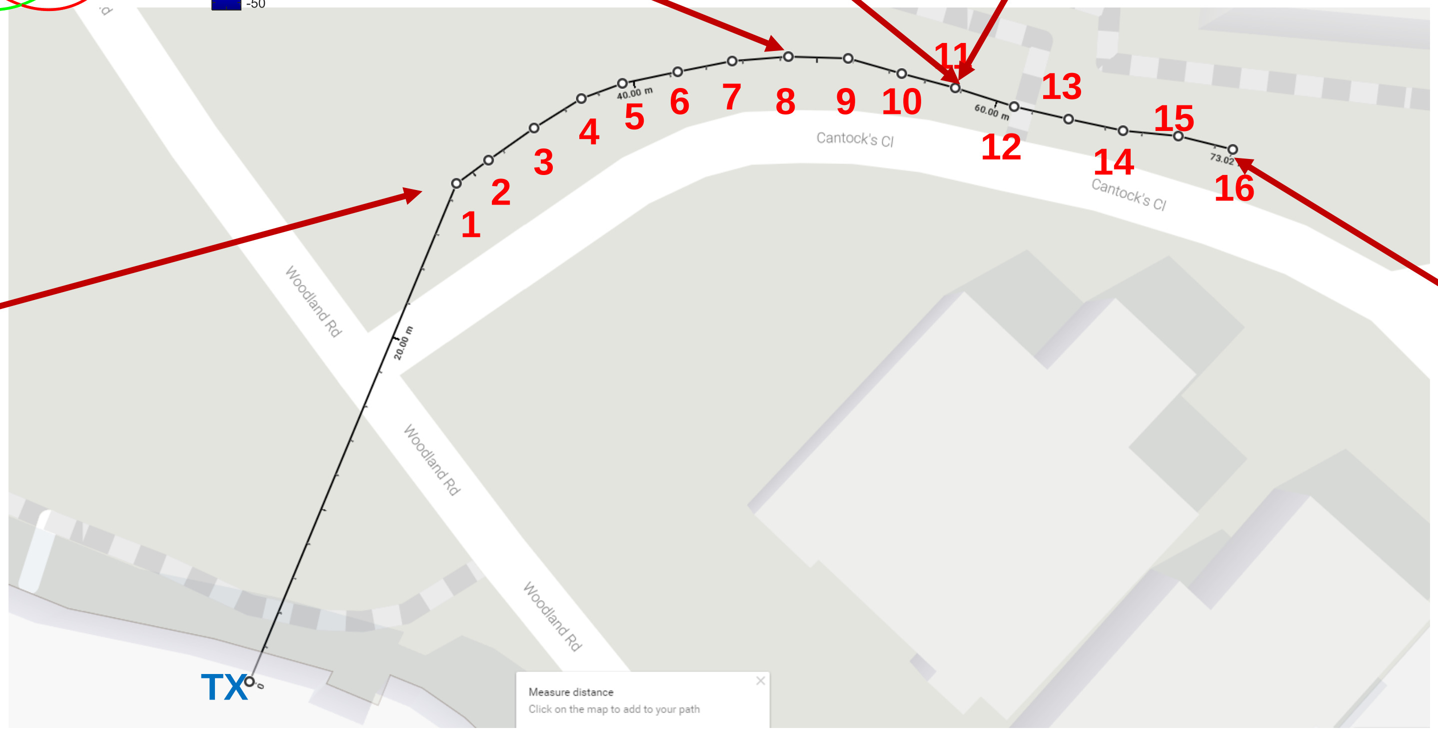


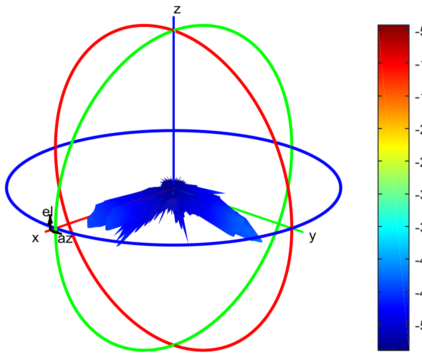


Further 20dB of Foliage attenuation



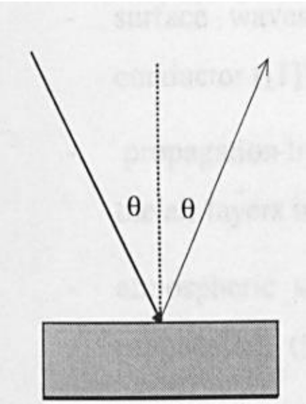
LoS, with weak rear reflection



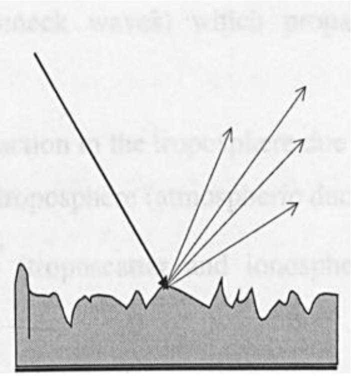


Building & foliage obstruction. Weak spatial response

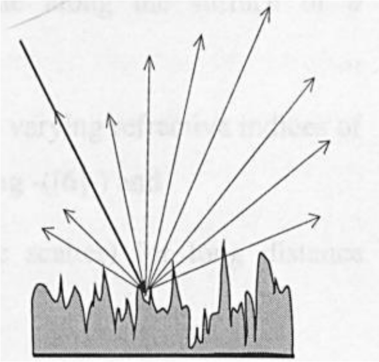
Specular and Diffusion Reflections



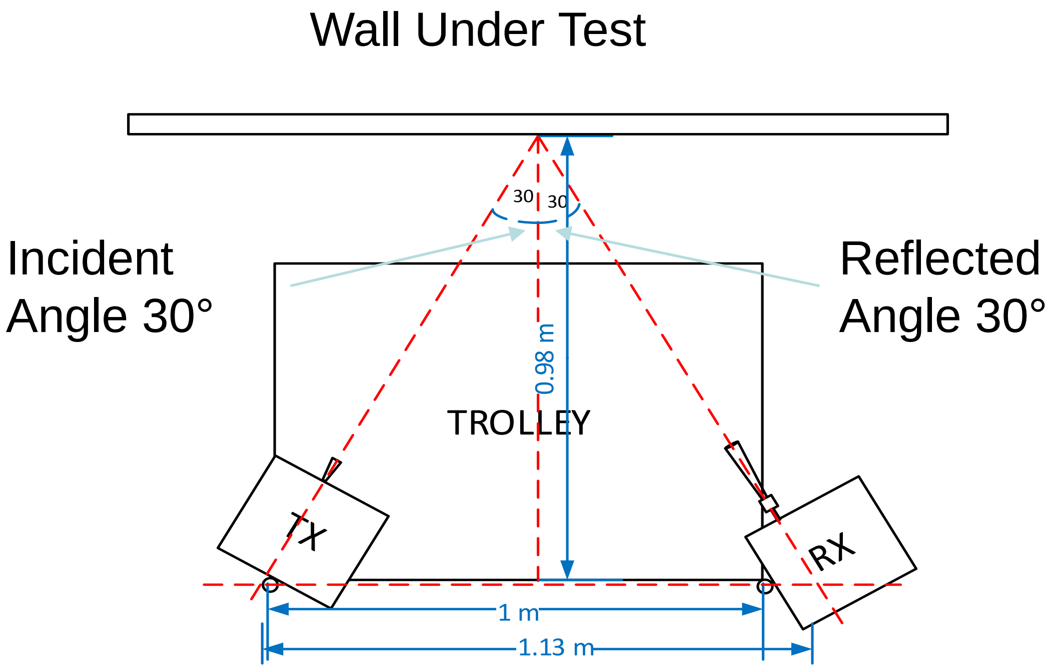
Smooth Surface
Specular Reflection



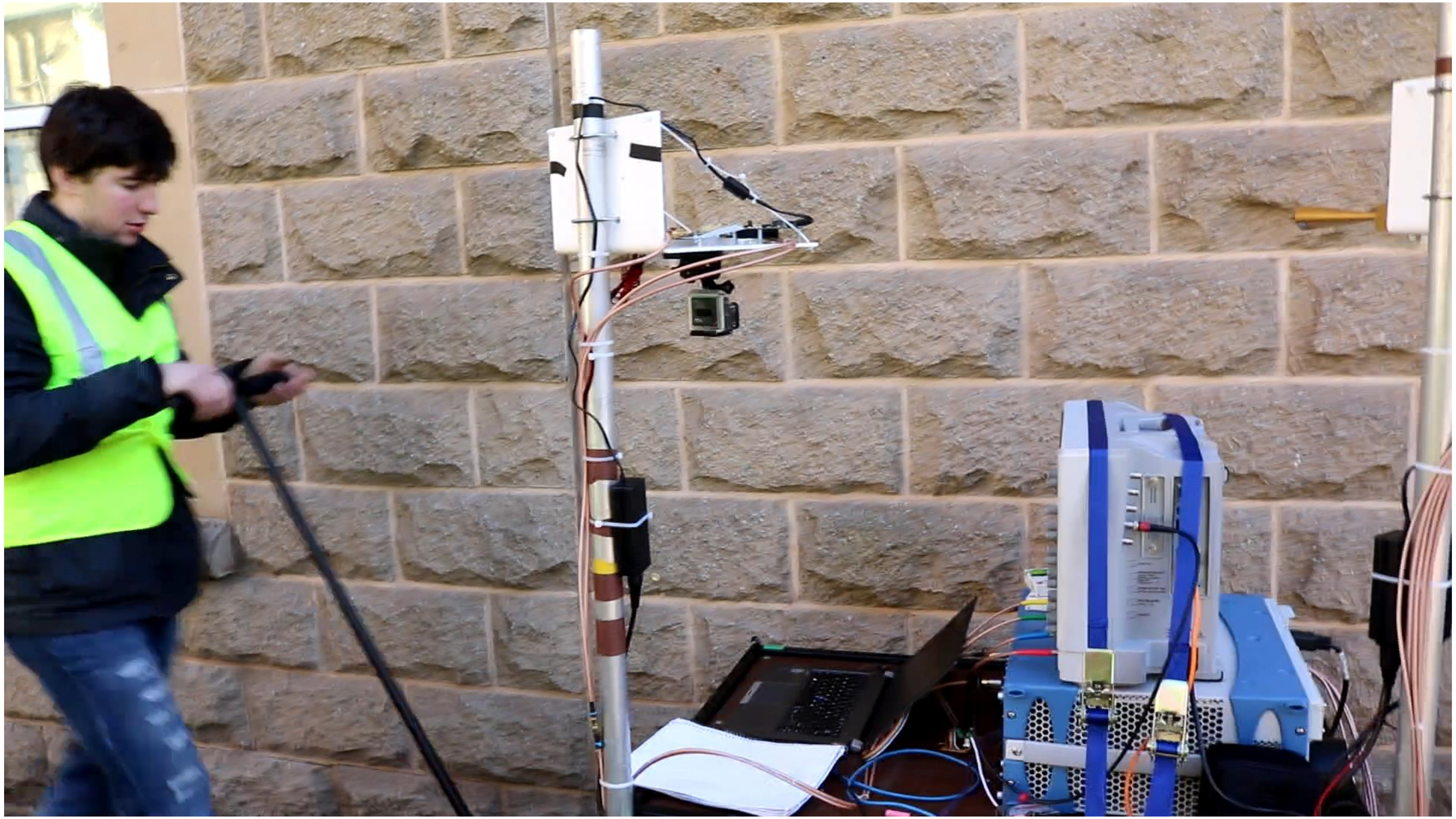
Slightly Rough Surface
Diffuse Reflection



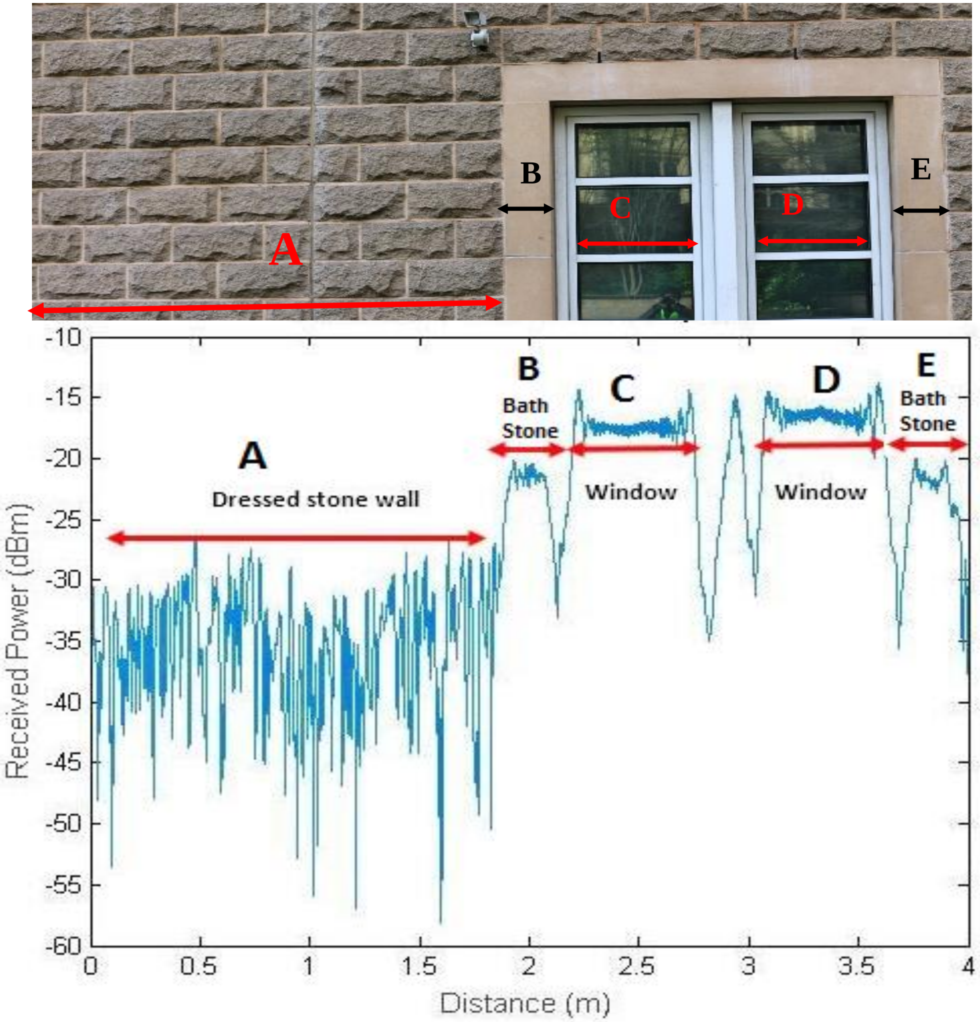
Very Rough Surface
Diffuse Scatter



Reflections: Specular and Diffusion



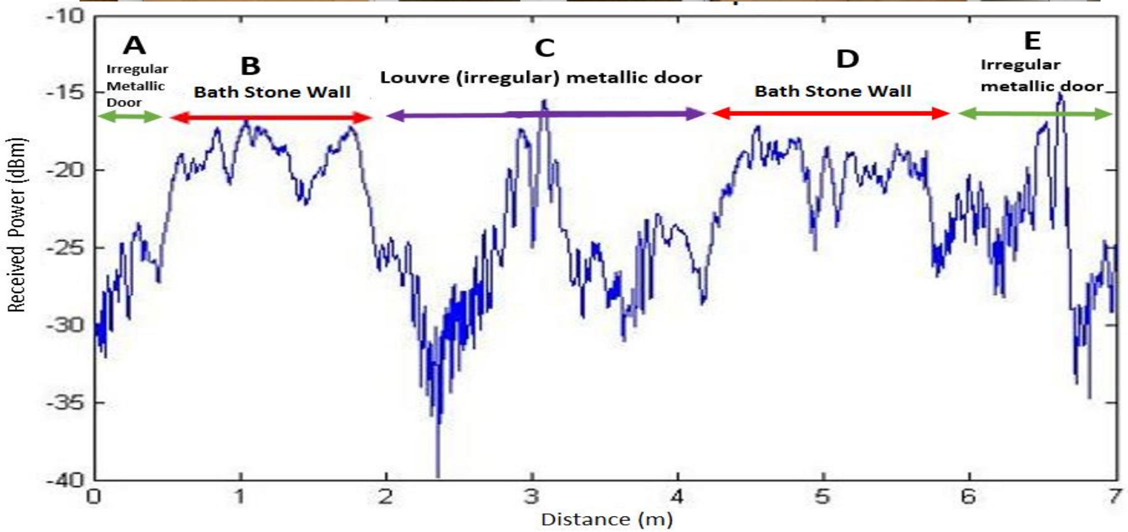
Reflections from Multiple Surface types



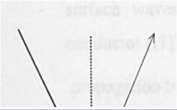
- Power of specular scattered path along a travel distance of 4m parallel to the dressed stone wall (rough surface - section A) and the glass window (smooth surface – sections C and D). Sections B and E were not analysed.
- For rough dressed-stone wall measurement fading depths of up to 20dB compared to smooth window reflections, where the maximum fading depth is only about 2dB.
- Transition areas between the wall and the window can be clearly identified.

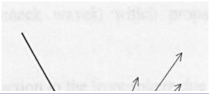
Reflections from Multiple Surface types

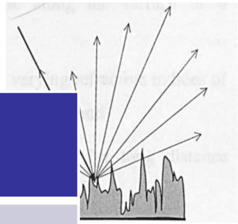
- Power of specular scattered path along a travel distance of 7m parallel to the Bath stone wall (medium roughness – sections B and D)
- Power received from metallic louvre door (sections A, C and E) has been excluded from the analysis here due to its large irregularities.
- A maximum observed fading depth of approximately 5dB.



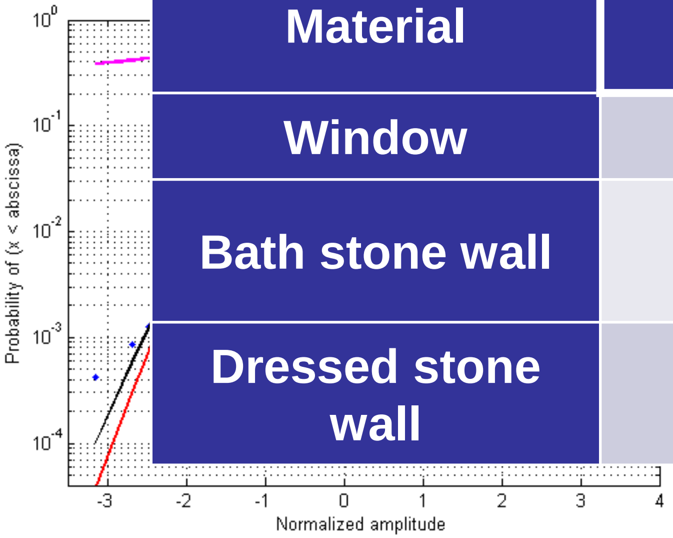
Multiple Surface Analysis



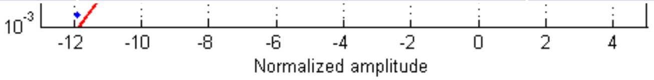




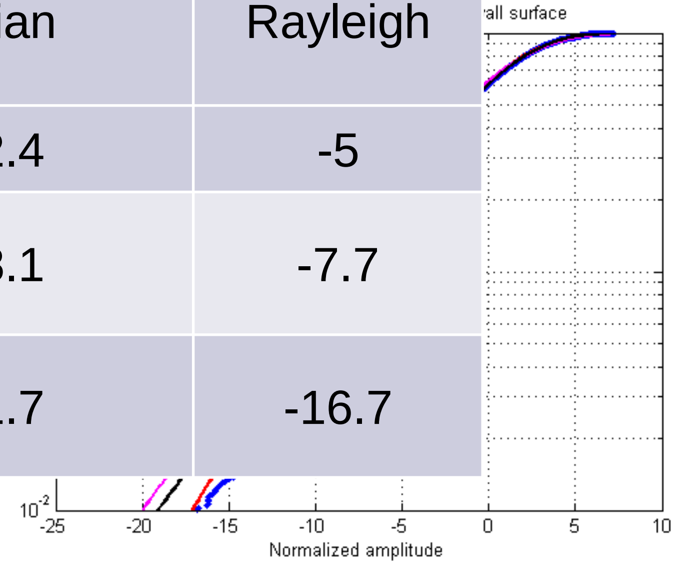
	K –factor (dB)	RMSE (dB)		
Material		Nakagami	Rician	Rayleigh
Window	18.7	-12.5	-12.4	-5
Bath stone wall	7.1	-18.5	-18.1	-7.7
Dressed stone wall	-0.9	-21.2	-21.7	-16.7



Rayleigh distribution does not model the glass reflection, where as Nakagami-m is a better fit

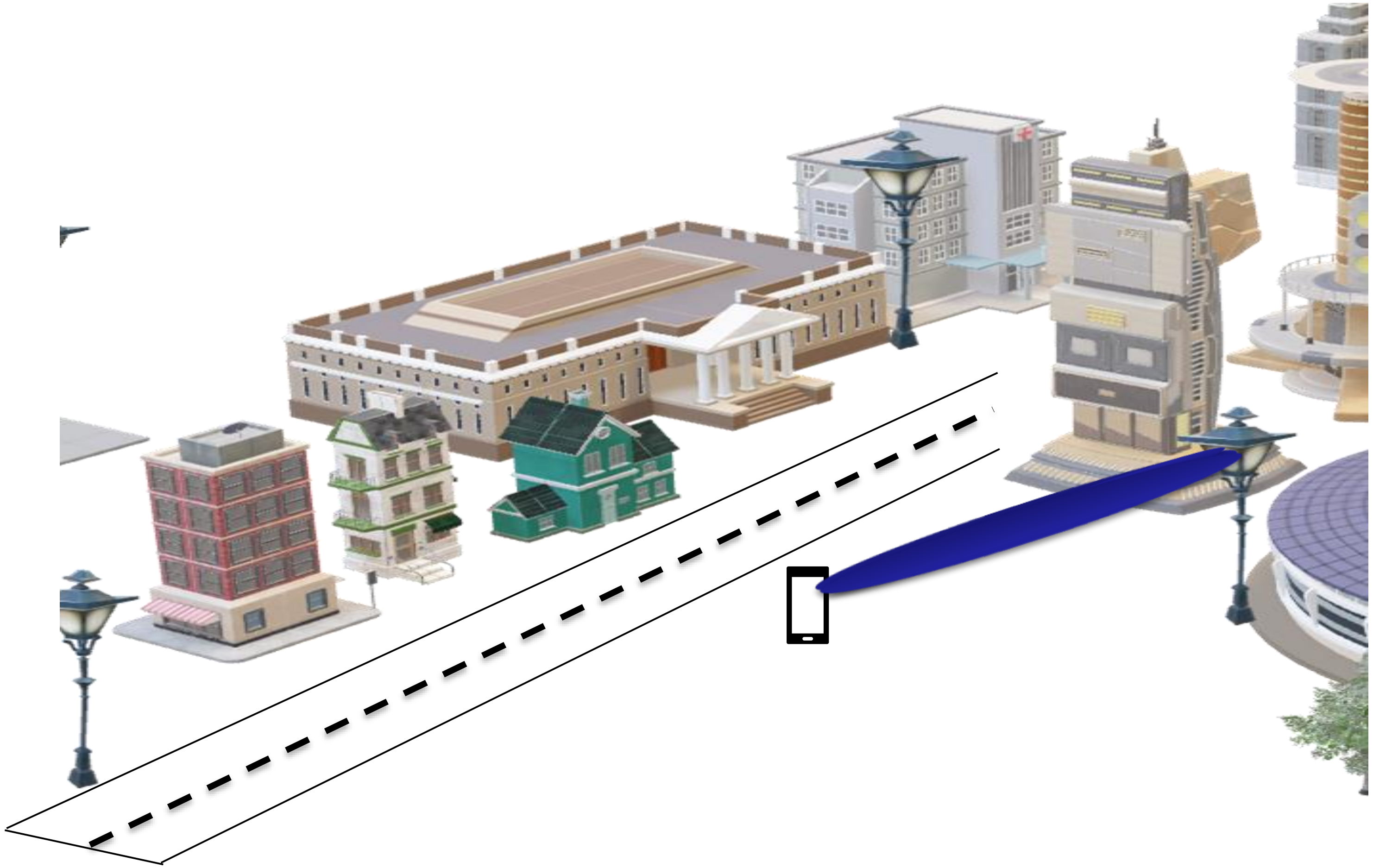


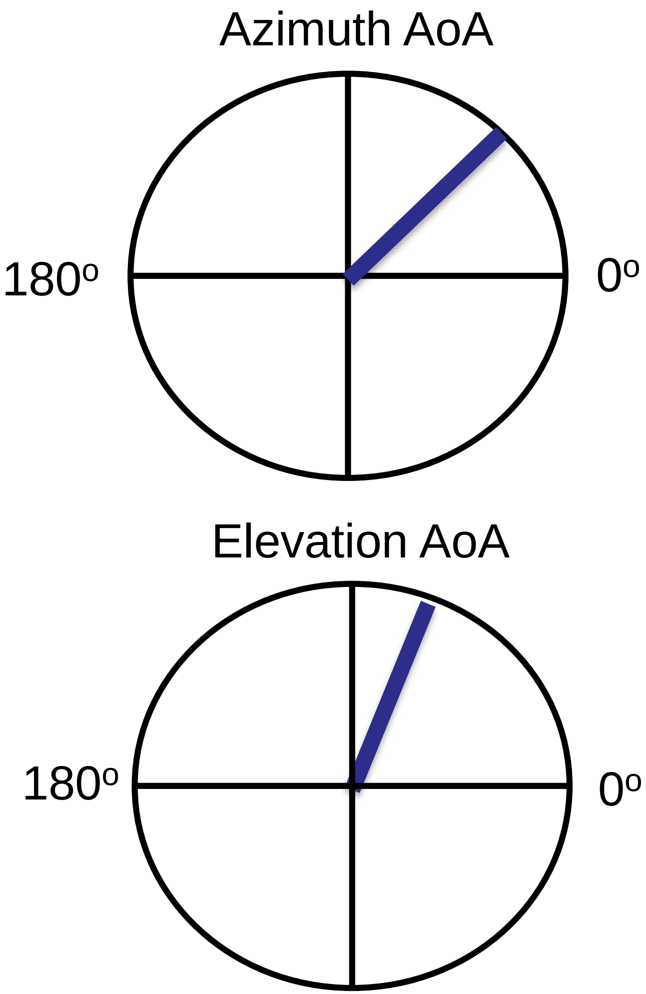
Again, Rayleigh distribution does not model the reflection. For Bath-Stone Ricain is a better fit



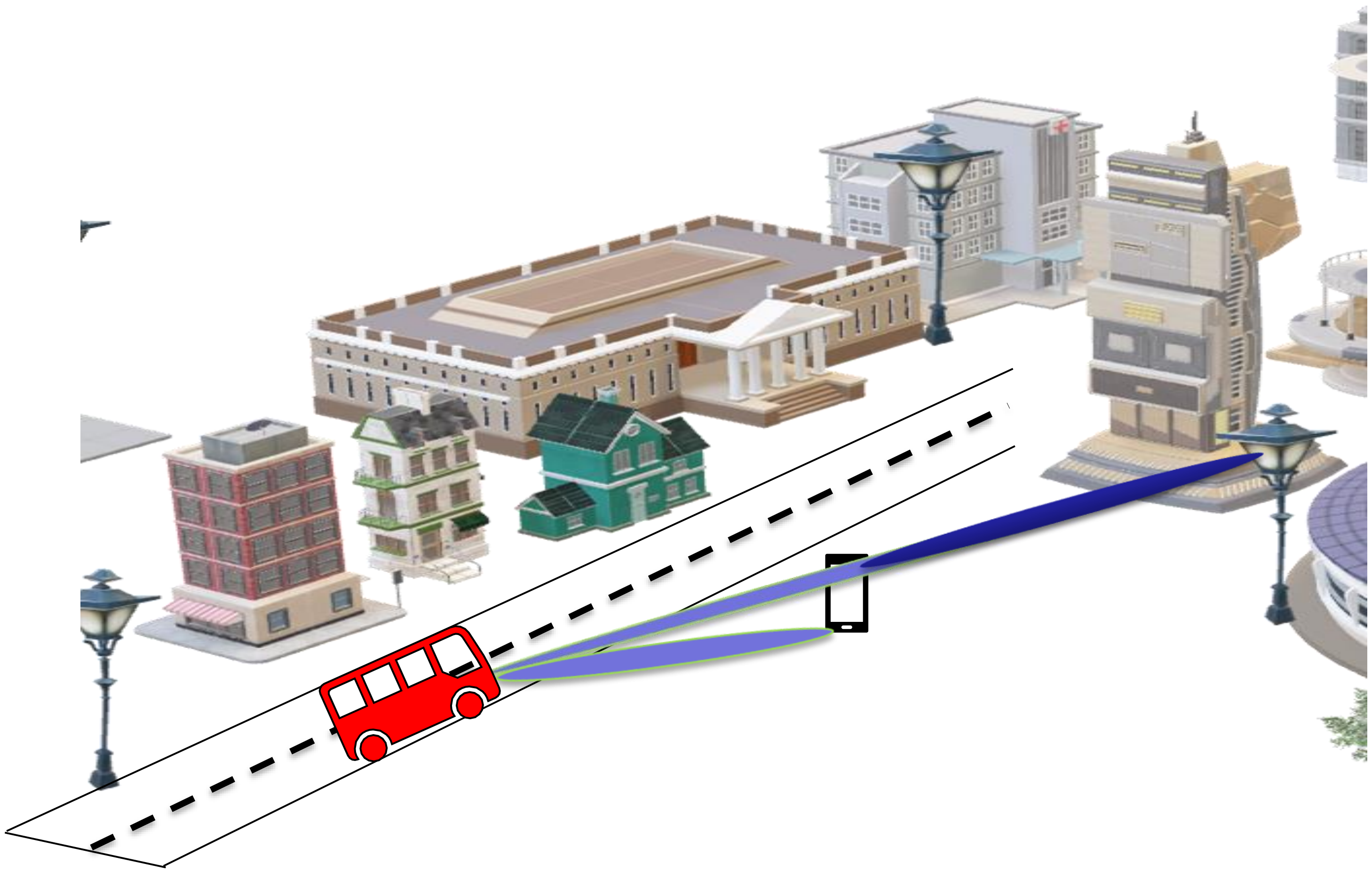
Rayleigh distribution provides an adequate fit for a rough surface (i.e. the dressed stone wall).

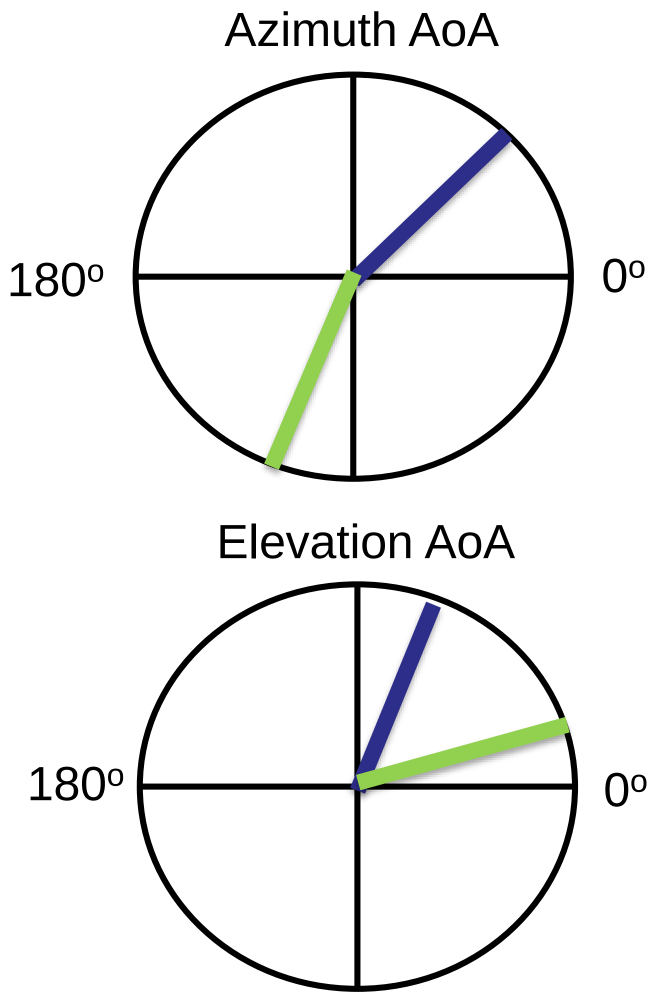
Emulation & Testing of Devices: One signal Line of Sight scenario



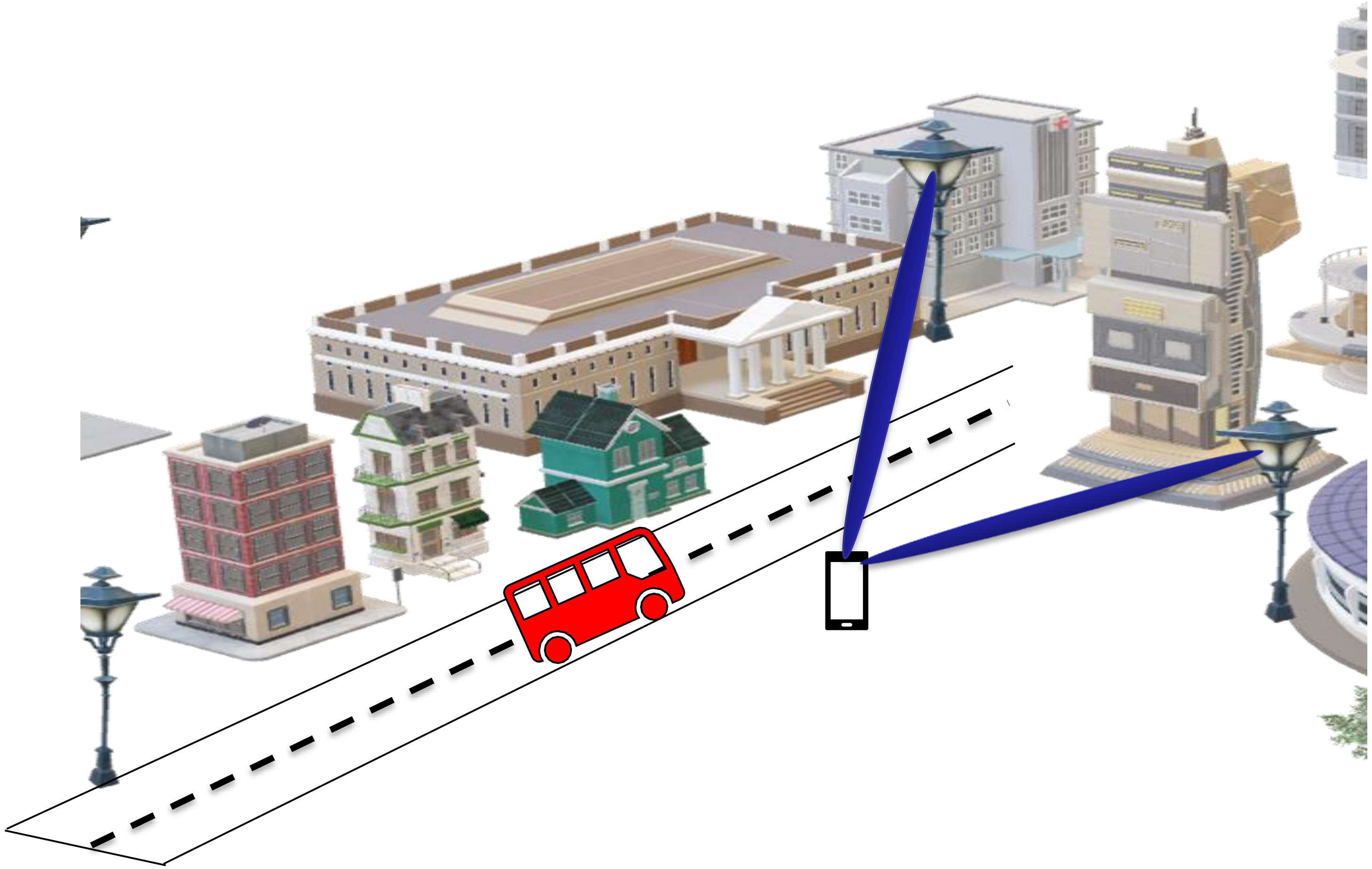


Emulation & Testing of Devices: Same signals with different Angles of Arrival

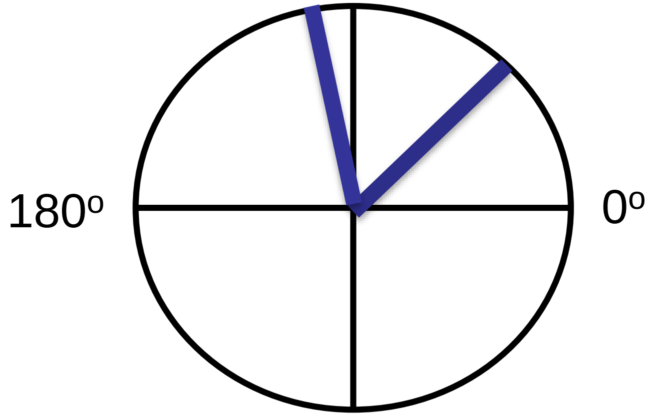




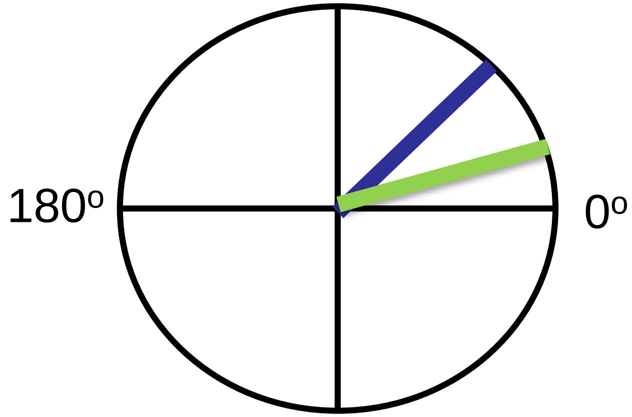
Emulation & Testing of Devices: Two signals with different Angles of Arrival



Azimuth AoA

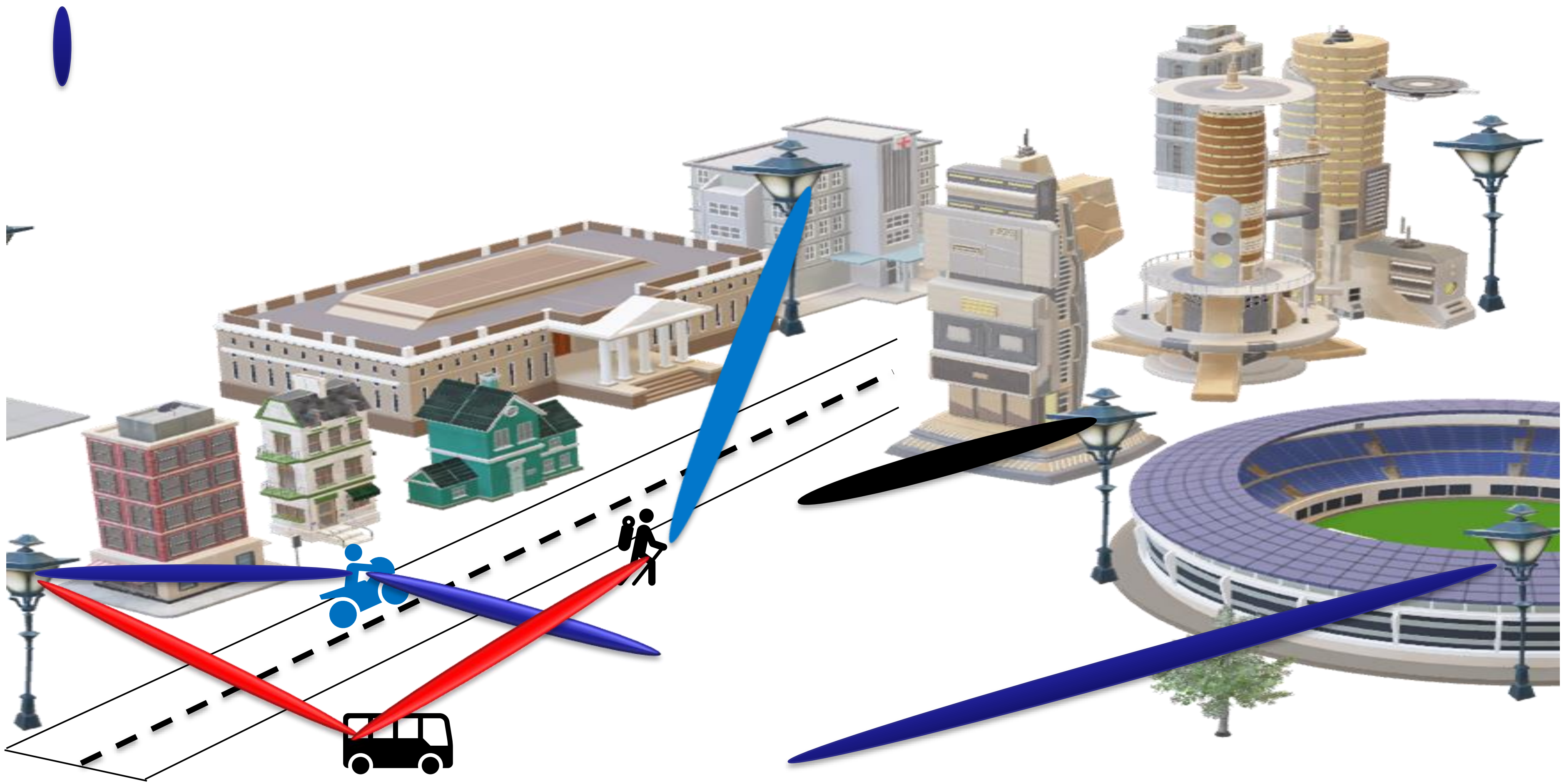


Elevation AoA



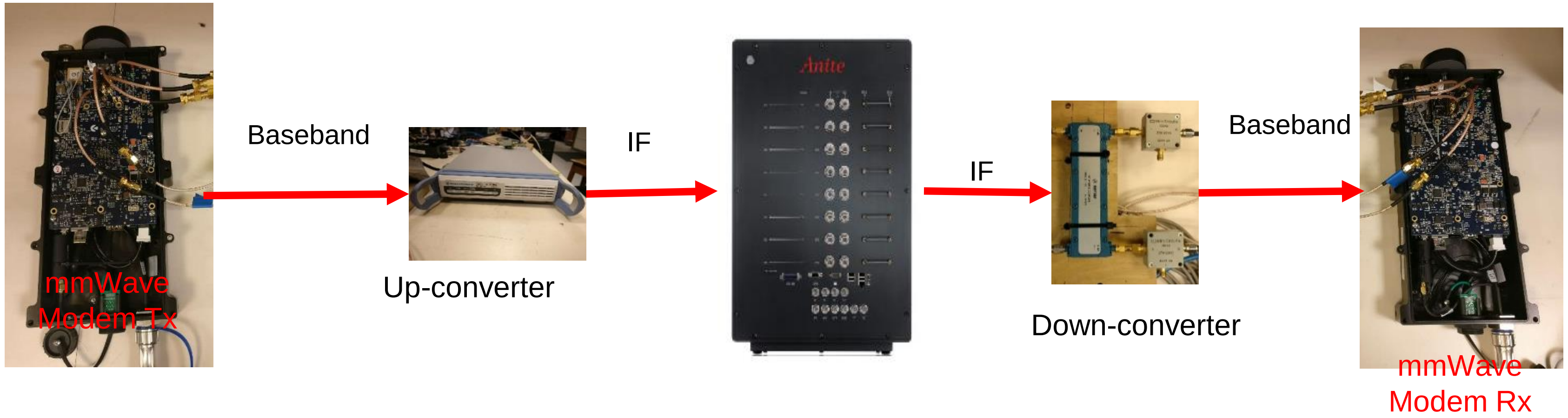
Emulation & Testing of Devices: Real-life Dynamic environment

- Search BS's
- Acquiring BS's
- Tracking beams
- Feedback
- Refinement
- Switch



Conducted testing

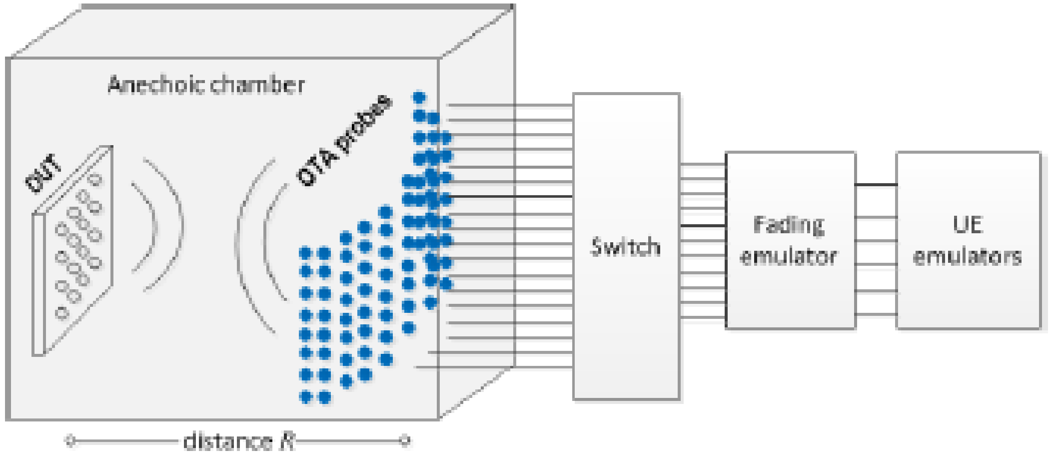
- Frequently used for sub 6GHz devices as channel bandwidths are < 160MHz making digital emulation feasible
- Bristol’s wideband ‘millimetre’ solution at a sub 6GHz IF



- Lacks ability to test RF hardware and beamforming functions !

Simplified Sectored MPAC OTA test method

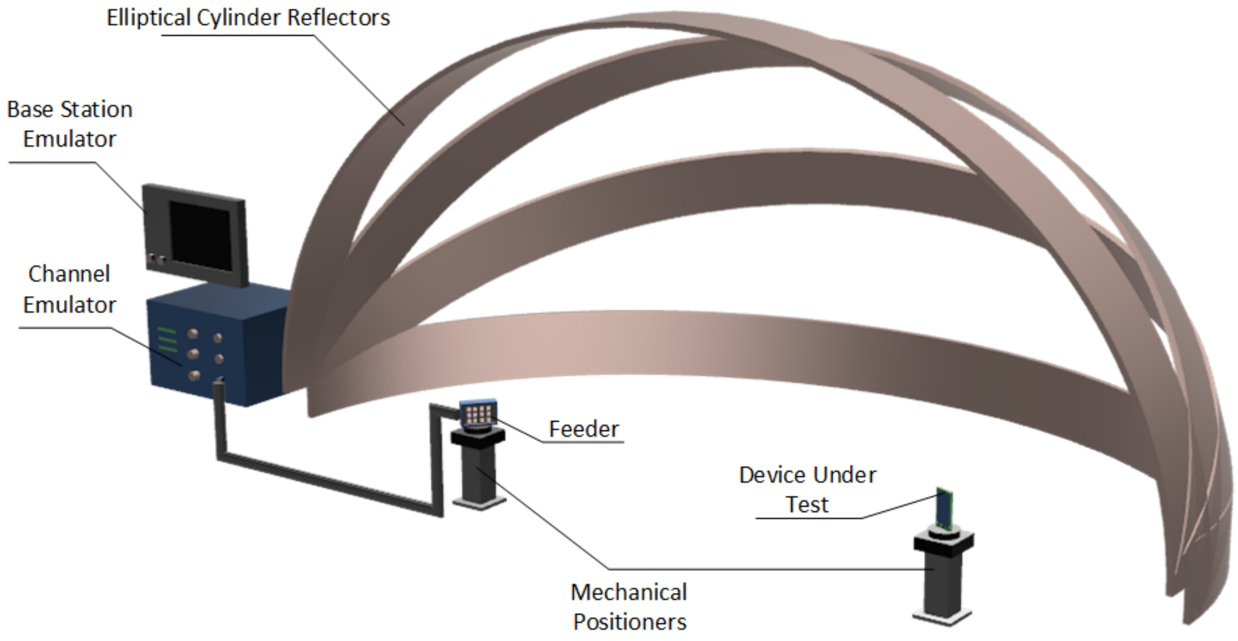
- Emulate only one sector of the 3D sphere
  - To reduce cost, ie 120º azimuth, 60º elevation
- Probes equidistant to DUT
  - Achieves amplitude and phase coherence
- Only few probes of the many probes (#8) need to be illuminated
  - Sparse nature of channel
  - Control over PAS
- Sectored approach isn't full 3D
- No cost effective solutions for antenna switching as yet!



Source: Over-the-air Radiated Testing of Millimeter-Wave Beam-steerable Devices in a Cost- Effective Measurement Setup
Fan Wei; Kyösti Pekka; Rumney Moray; Chen Xiaoming & Pedersen Gert.

Bristol's Millimetre Wave 5G OTA Testing

- Exploits reflective property of ellipse:
  - ✓ Any ray leaving one focal point will be reflected and pass through the other focal point.
- Set of Elliptical Cylinder Reflectors used to:
  - ✓ Emulate **3D spatially dynamic** environments.
  - ✓ Emulate between **1 to 3 simultaneous** signals.
  - ✓ Optimised for the ***Dynamic Spatial Testing*** of **Beam Management functions, Radio Resource Management (RRM) and Receiver Demodulation**
- Minimal number of mechanically moving parts
- Inherently supports two-way communication
- Promising initial measured results
- Cost-effective implementation



D. Reyes, M. Beach, E. Mellios, M. Rumney, 'Novel Over-the-Air test method for 5G mmWave devices with beam forming capabilities', COST IRACON TD(18)08001, Podgorica, Montenegro, Oct 2018

Take Aways:

- Increased path loss compared to sub 6GHz systems
  - Use of directional antenna or array antenna to mitigate loss is essential
- Directional antenna elements at both ends of the link
  - Less ‘spatial’ excitation of potential reflectors (Sparse Channel)
  - Surface roughness impacts nature of specular reflection
  - Results indicate channels are more spatially dynamic than sub-6GHz
  - Spatial filtering => Opportunities for Spectrum Sharing
- Novel and cost effective OTA methodology for spatially dynamic signals
  - Exploits reflective property of an ellipse
  - Supports multi-source excitation of device from different angles
  - Supports spatially dynamic testing of RRM and Demod.