# Millimetre Wave and Short-Range Propagation

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# Outline

1. Why Mm wave band
2. Candidate frequency bands
3. Working Groups
4. Possible use scenarios: Point to point and point to multi-point
5. Propagation in the mm wave band
6. Wideband channel functions, and extraction of relevant channel parameters such as delay spread, and Doppler spread
7. Estimation of channel parameters

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# Mm wave band

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MM wave band (1 cm-1 mm): Extra High Frequency (EHF) 30-300 GHz

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Research is focussed on > 6 GHz to 100 GHz

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# Primary motivation

– Projected increase in mobile data traffic

– Availability of large contiguous spectrum in the mm wave band

– RF and transceiver design challenges for carrier aggregation < 6 GHz

– Small wavelength enables beamforming through the use of large antenna arrays

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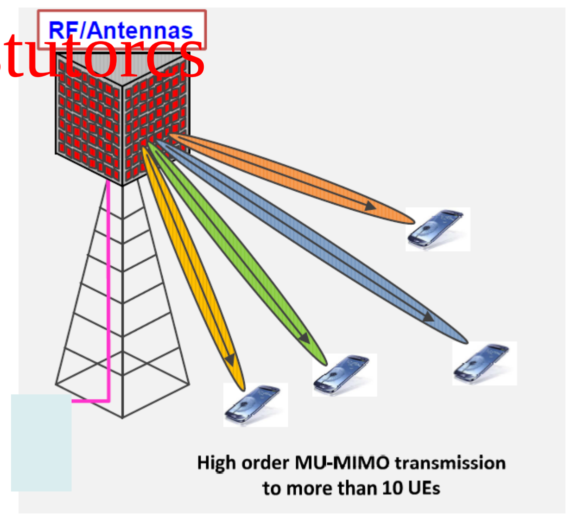


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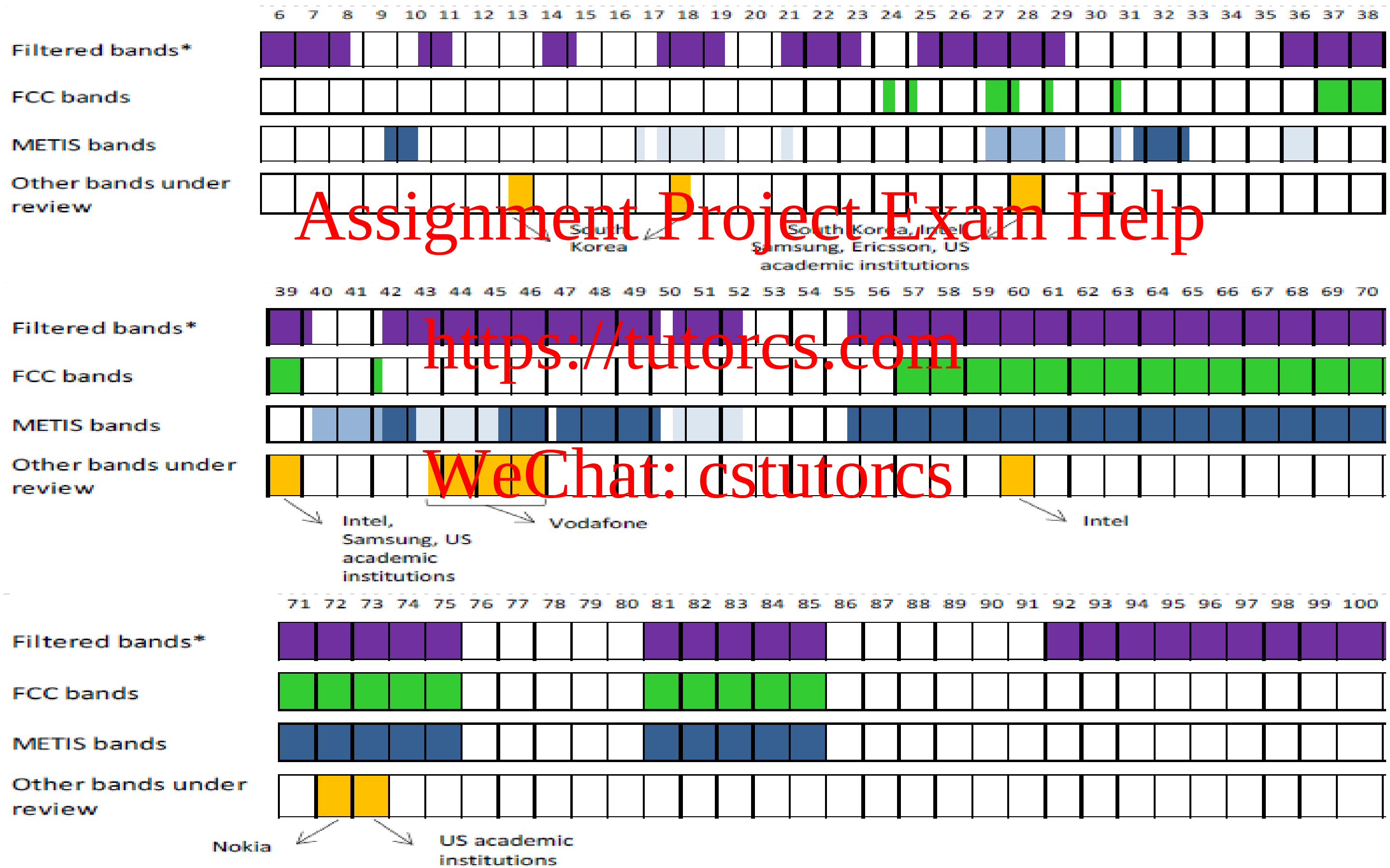
# Summary of bands identified by Ofcom as having potential for 5G

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# Ofcom frequency bands > 6 GHz

| **Frequency Range** | **6-20 GHz** | **20-40 GHz** | **40-60 GHz** | **60-100 GHz** |
|---|---|---|---|---|
| Specific bands identified | 10.125-10.225<br>10.475-10.575 | 31.8-33.4 | 40.5-43.5<br>45.5-48.9 | 66-71 |
| Potential bandwidth | 2 x100 MHz | 1.6 GHz | 5.8 GHz | 5 GHz |

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# WRC15 bands

| WRC15 Band (GHz) | Designation |
|---|---|
| 24.25-27.5 | I |
| 31.8-33.4 | II |
| 37-43.5 | III |
| 45.5-50.2 | IV |
| 50.4-52.6 | V |
| 66-76 | VI |
| 81-86 | VII |

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# Working Groups

1. IEEE 802.11 Next Generation 60 GHz ISM band (NG60) Study Group

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2. NIST formed the corner alliance for 5G mm wave-channel model Next Generation 60 GHz IEEE 802.11 TGay

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3. ITU: CG 5 on Radio Measurement Equipment and CG6 on channel modelling above 6 GHz

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# NG60 Indoor P2P Scenarios

| Applications and Characteristics | Propagation conditions | Throughput |
|---|---|---|
| **Ultra Short Range (USR) Communications**<br>-Static,D2D,<br>-Streaming/Downloading | LOS <10cm | ~10Gbps |
| **8K UHD Wireless Transfer at Smart Home**<br>-Uncompressed 8K UHD Streaming | LOS, NLOS <5m | >28Gbps |
| **Augmented Reality and Virtual Reality**<br>-Low Mobility, D2D<br>-3D UHD streaming | LOS, NLOS <10m | ~20Gbps |

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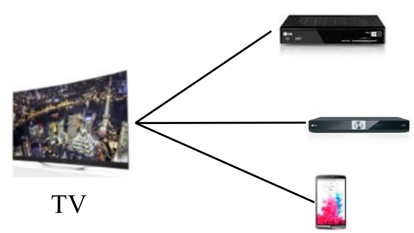


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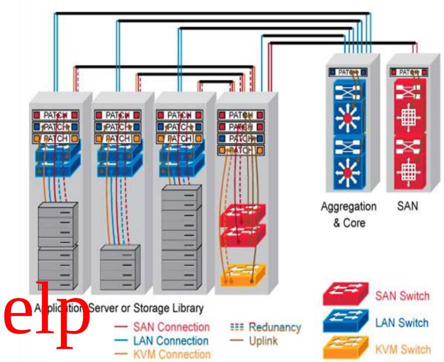
# NG60 Indoor P2P/P2MP Scenarios

| | | |
|---|---|---|
| **Data Center NG60 Inter-Rack Connectivity**<br>-Indoor Backhaul with multi-hop* | LOS <10m | ~20Gbps |
| **Video/Mass-Data Distribution/Video on Demand System**<br>- Multicast Streaming/Downloading<br>- Dense Hotspots | Indoor, LOS/NLOS<br><100m | >20Gbps |

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Train


Bus

Aeroplane

Class room


Exhibition

Conference

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# NG60 Outdoor P2P/P2MP Scenarios

| Applications and Characteristics | Propagation conditions | Throughput |
|---|---|---|
| **Mobile Front-hauling** | Outdoor, LOS <200m | ~20Gbps |
| **Wireless Backhauling with Single Hop** -Small Cell Backhauling with single hop | Outdoor, LOS <1km | ~20Gbps |
| **Wireless Backhauling with Multi-hop** -Small Cell Backhauling with multi-hop | Outdoor, LOS <150m | ~2Gbps |

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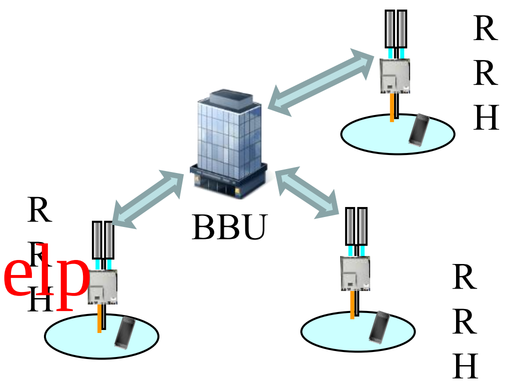
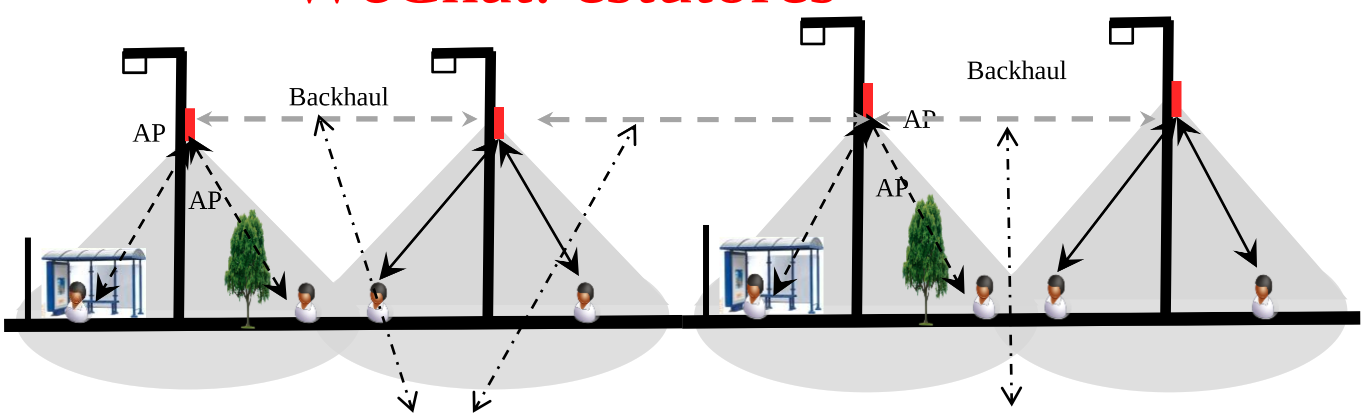



RRHs (Remote Radio Heads)
Base Band Unit (BBU)




Multi-hop Single hop

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# Radio Propagation of mm waves

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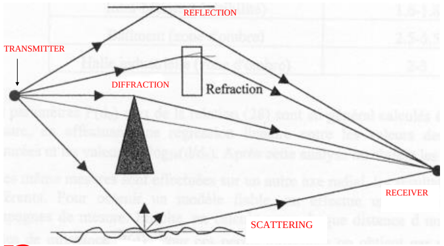
# Propagation mechanisms




***Line of sight (LOS)***

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***Reflection*** smooth surface with very large dimensions with respect to the wavelength

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***Diffraction*** transmission path is obstructed by a dense body with large dimensions compared to the wavelength or by a surface with large irregularities.

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***Scattering*** wave incident on surface with dimensions on the order of a wavelength or less). Irregularities such as in tropospheric scatter.

***Refraction*** : variations of refractive index such as in the troposphere and in the ionosphere. light in a prism.  Important for HF frequencies

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# Measured penetration loss

Frequency dependence of penetration loss

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Three wall partition between antennas

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| 900 MHz | 11.4 GHz | 28.8 GHz |
|---|---|---|
| 18.9 dB | 26 dB | 36.2 dB |

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Report by the
National Telecommunications and Information Administration, US

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# mm wave penetration loss

| Frequency 60 GHz | Plastic 0.8 cm | Plywood 0.8 cm | Wood 1.8 cm | Tampered glass 0.7 cm |
|---|---|---|---|---|
| Vertical polarisation | 3.44 dB | 6.09 dB | 9.24 dB | 4 dB |
| Horizontal polarisation | 4.04 | 5.42 | 8.48 | 3.97 |

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IEEE 802.11 report on Transmission and Reflection Measurements

# Diffraction and scattering models

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# mm wave band diffraction loss

Empirical model from measurements at 28 GHz for $90^o$ edge around a building:

$L = 6.5\,dB \quad 0 \geq \theta_d > 0.1^o$

$L = 5 ln\theta_d + 18 \quad 0.1^o \geq \theta_d > 5^o$

$L = 0.74\theta_d + 75 \quad 5^o \geq \theta_d \geq 40^o$

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No difference between different brick or concrete

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# Rain scattering in mm wave

Rain drop scattering. **Rayleigh criterion**

$\pi D/\lambda$ <<1 where D is the diameter of the particle

$\pi nD/\lambda$ <<1 where n is the refractive index.

Example: D=1mm, at 60 GHz with n=1:

$\pi nD/\lambda = 0.2 << 1$

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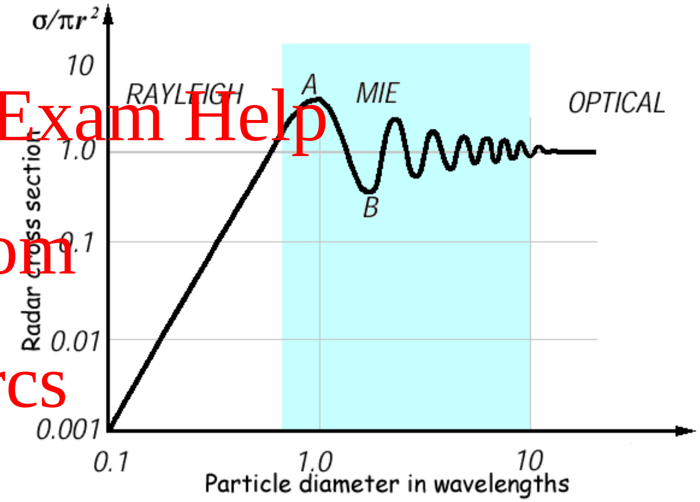
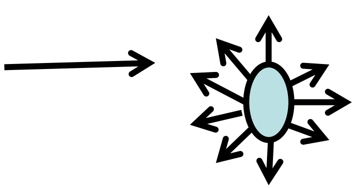
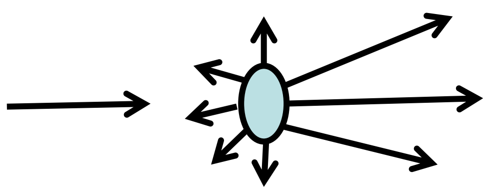


Rayleigh scattering



Mie scattering

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# Scattering loss

Scattering power to free space

$$10 \log \left(P_r^{scat} / P_r^{fs}\right) = 40 \log f + 16 \log R + 10 \log V + 10 \log S - 20 \log d - 81 \qquad \text{dB}$$

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f is the frequency in GHz

R is the rain rate in mm/hour

V is the common volume in $km^3$

S is a correction for non Rayleigh effects above 10 GHz

S=0 for f<10 GHz, f>10 GHz 10log S = R0.4 4x10-3 (f - 10)1.6

d distance between transmitter and receiver

# Specifics of propagation characteristics in mm band

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## Gaseous and rain Absorption

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# ITU-R recommendations

ITU-R P676-10: Gaseous absorption

Model input parameters:

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temperature, ambient pressure, and water vapour density.

Use can be made of

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ITU-R P.836-5 water vapour density

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ITU-R P1510 mean annual surface temperature

ITU-R P.840-6: Fog absorption

ITU-R P838-3: Rain absorption

ITU-R P 837-6: Rain rates

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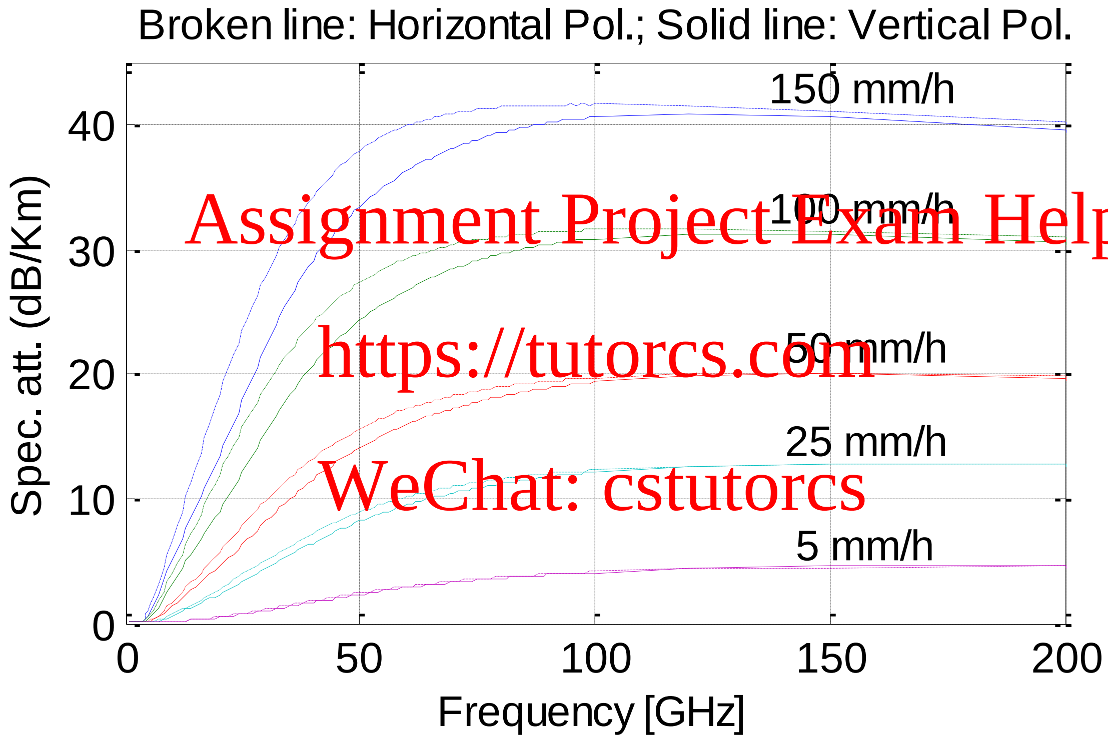
# Rain attenuation model ITU-R P838-3

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At 60 GHz

Rain:10 dB/km at 25 mm/hr increasing to 30 dB/km at 100 mm/hr rainfall

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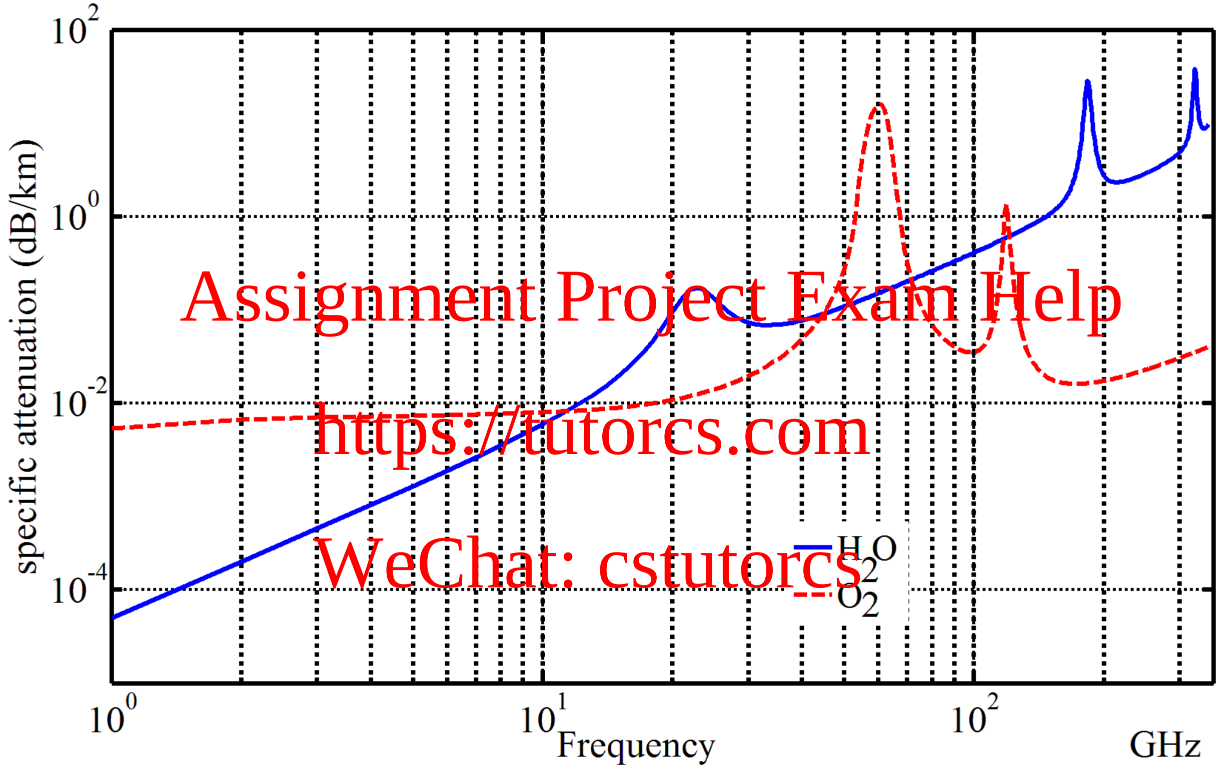
# Gaseous absorption

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Gaseous: 0.3-0.5 dB/km for frequencies up to 38 GHz
and 70-100 GHz
maximum at 60 GHz of 15 dB/km

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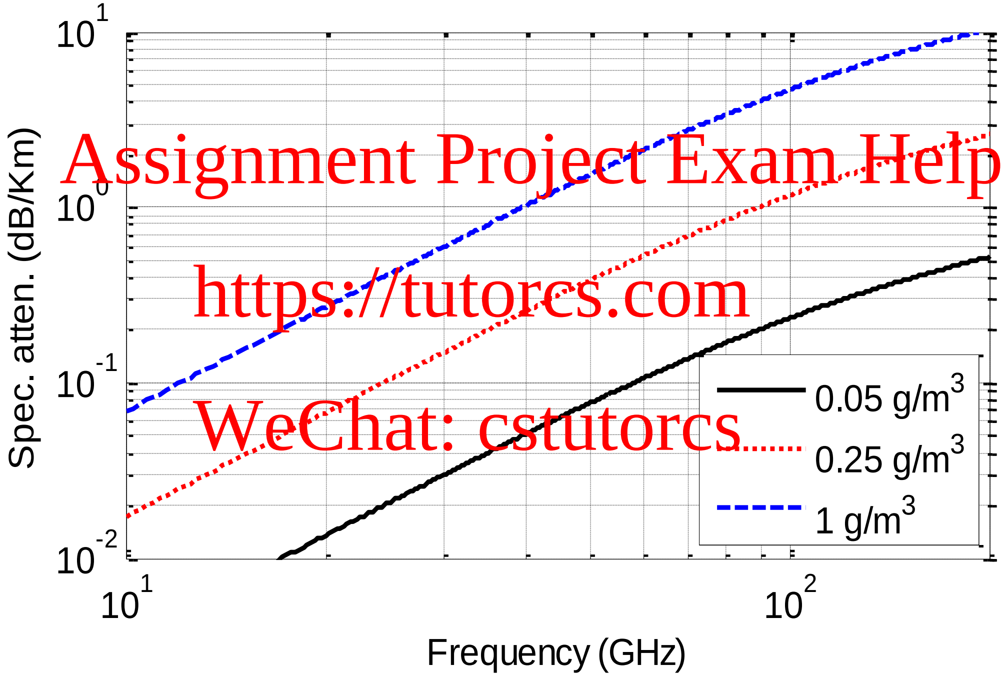
# Fog absorption

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as high as 5dB/km at 100 GHz for 1g/m$^3$

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# Propagation in the built environment

mm wave band

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# ITU-R Study Group 3 Correspondence Groups

- CG 3K-6: ITU-R P.1238-10 and ITU-R P. 1411-10 Model harmonization of path loss models (Samsung Korea)

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- CG 3J-3K-3M-8: ITU-R P. 2109-1 Building entry loss model (UK)

- CG 3K-3M-12: ITU-R P. 2108-0 Clutter loss prediction (Ofcom, Intel)

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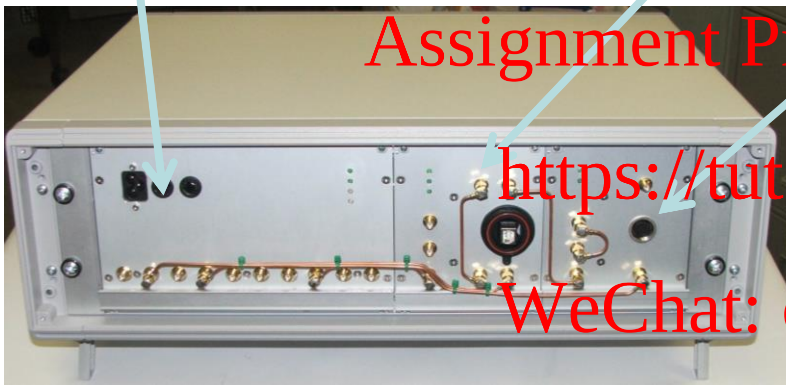
# FMCW Channel Sounder

Rubidium unit

DDS and 2.2-2.95 GHz



4.4-5.9 GHz and

14.5-16 GHz

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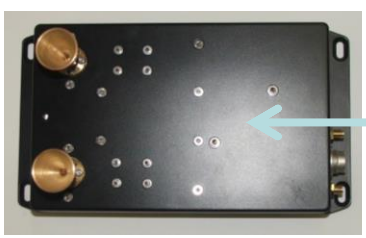
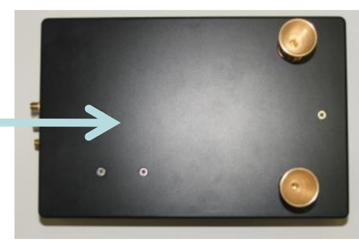


mm Transmitter

mm Receiver



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# WRC15/WRC19 frequency bands

| WRC15 Band (GHz) | Bandwidth (GHz) |
|---|---|
| 24.25-27.5 | 3.25 |
| 31.8-33.4 | 1.6 |
| 37-43.5 | 6.5 |
| 45.5-50.2<br>45.5-47, 47.2-48.2 | 4.7<br>1.5, 1 |
| 50.4-52.6 | 2.4 |
| 66-76<br>66-71 | 10<br>5 |
| 81-86 | 5 |

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With 14.75 GHz harmonized worldwide, ~ 85% of global harmonization

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# CG 3K-6: ITU-R P 1411Environments

1. Urban very high rise: high density 10’s floors

2. Urban high rise: several floors over rooftop propagation

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3. Urban low rise/suburban: 3 storey

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4. Residential: single/double storey

5. Rural: small houses large gardens

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# Outdoor mm wave measurements


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# Outdoor mm wave measurements

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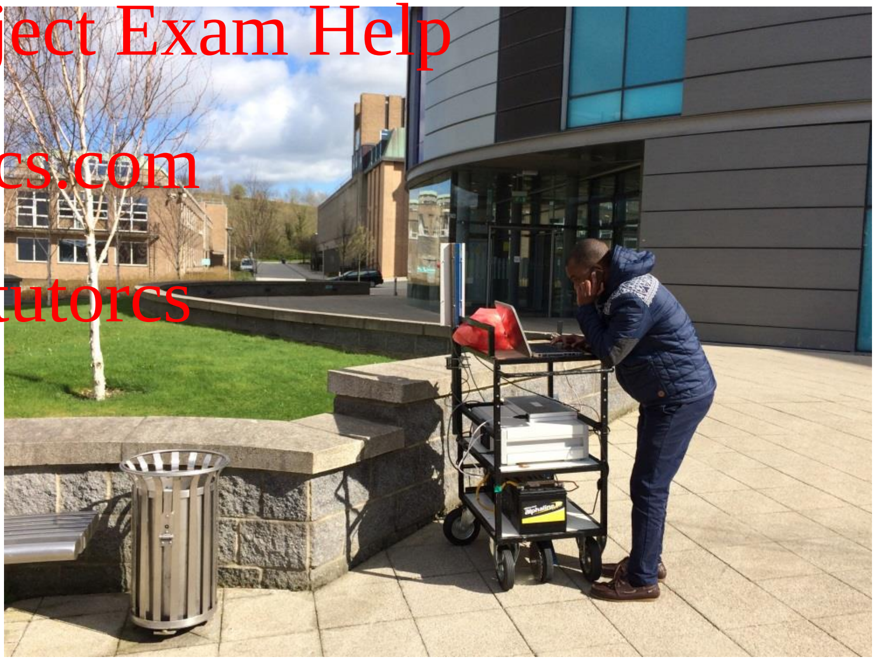


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# Path loss model

Single frequency vs multiple frequency

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$$PL_{logDist}(d) = 10\alpha \log_{10}(d) + \beta \; dB$$

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$$PL(d, f) = 10\alpha \log_{10}(d) + \beta + 10\gamma \log_{10}(f) \; dB$$

with an additive zero mean Gaussian random variable $N(0, \sigma)$ with a standard deviation $\sigma$ (dB)

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# Environments: UK, Japan, Korea

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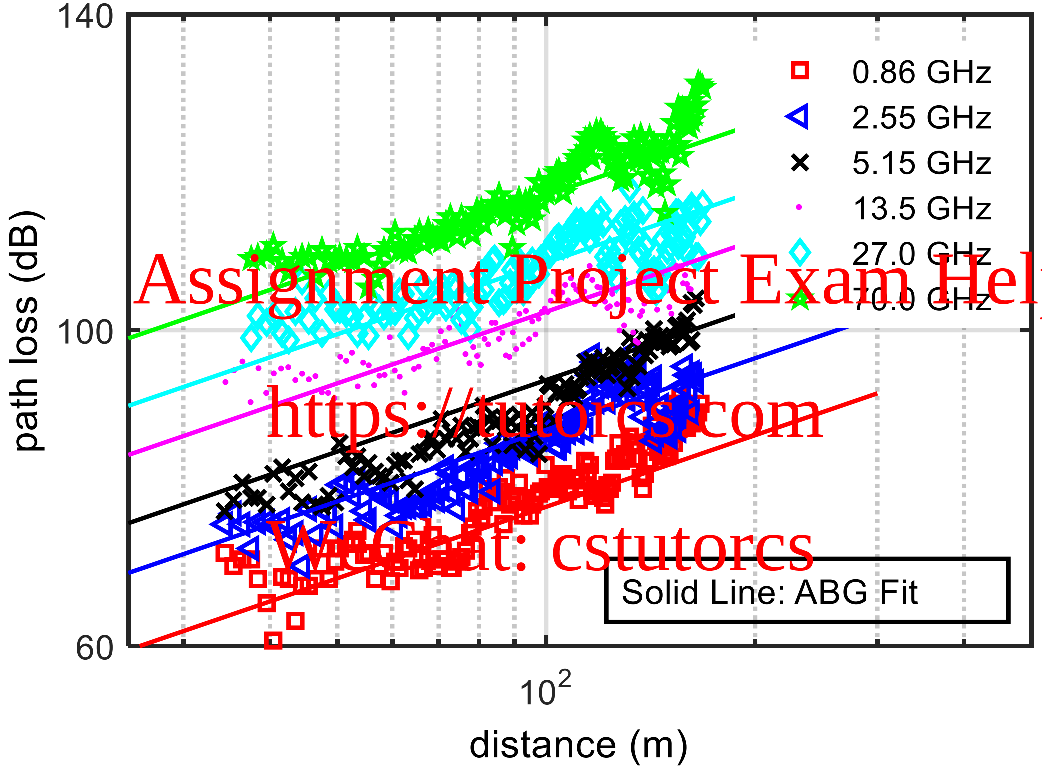
# Multi-band Residential NLOS Measurements

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***AGB***

***(α, β, γ, σ)***

3.01, 18.8, 2.07, 3.07

# Adopted model for below rooftop

| Frequency range (GHz) | Distance range (m) | Type of environment | LoS/ NLoS | α | β | γ | σ |
|---|---|---|---|---|---|---|---|
| **0.8-73** | **5-660** | **Urban high-rise, Urban low-rise/ Suburban** | **LoS** | **2.12** | **29.2** | **2.11** | **5.06** |
| **0.8-38** | 30-715 | Urban high-rise | NLoS | 4.00 | 10.2 | 2.36 | **7.60** |
| **10-73** | **30-250** | **Urban low-rise/ Suburban** | **NLoS** | **5.06** | **-4.68** | **2.02** | **9.33** |
| **0.8-73** | **30-170** | **Residential** | **NLoS** | **3.01** | **18.8** | **2.07** | **3.07** |

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# ITU-R 1238-10 measurement scenarios

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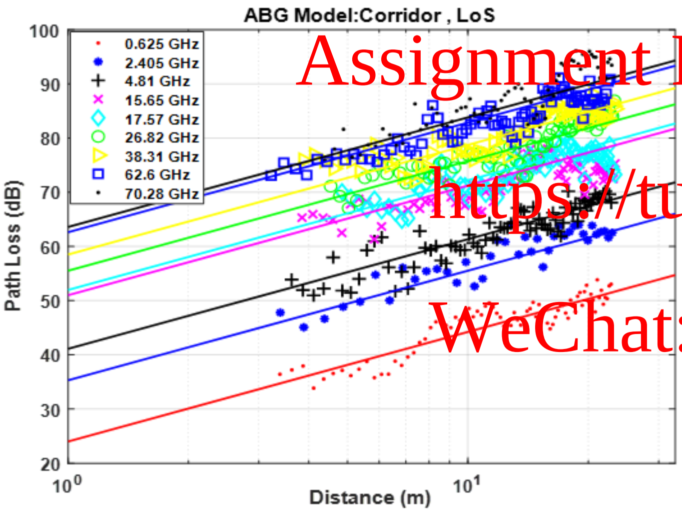
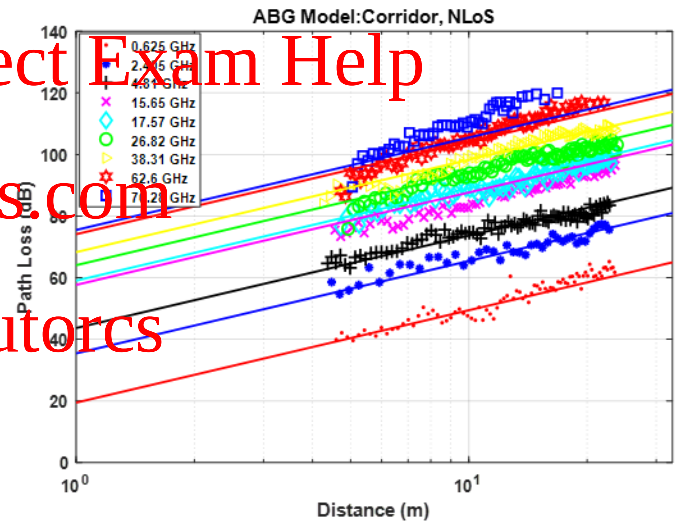
Indoor  Ceiling height to user,
Tx=2.35 m, Rx=1.5 m

# Towards a new model: corridor

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# Adopted model for 1238-11

| Environment | LoS NLoS | Frequency range (GHz) | Distance range (m) | $\alpha$ | $\beta$ | $\gamma$ | $\sigma$ |
|---|---|---|---|---|---|---|---|
| Office | LoS | 0.3–83.5 | 2–27 | 1.46 | 34.62 | 2.03 | 3.76 |
| | NLoS | 0.3–82.0 | 4–30 | 2.46 | 29.53 | 2.38 | 5.04 |
| Corridor | LoS | 0.3–83.5 | 2–160 | 1.63 | 28.12 | 2.25 | 4.07 |
| | NLoS | 0.625–83.5 | 4–94 | 2.77 | 29.27 | 2.48 | 7.63 |
| Industrial | LoS | 0.625–70.28 | 2–101 | 2.31 | 24.52 | 2.06 | 2.69 |
| | NLoS | 0.625–70.28 | 5–108 | 3.79 | 21.01 | 1.34 | 9.05 |

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# CG 3J-3K-3M-8: ITU-R P. 2109-1 Building entry loss model

Building classification

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- Thermally-efficient: metallised glass, foil-backed panels
- Traditional’ buildings without such materials

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# Type of properties measured

## Traditional

## Modern

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Victorian House

80s build

Üserhuus

Weinerberger-E4

Building Research Establishment (BRE) in Watford, UK

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# CG 3K-3M-12: Clutter loss prediction
# ITU-R P. 2108 Clutter Loss Measurements UK


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# Combined Clutter Loss and BEL Wideband Measurement Scenario


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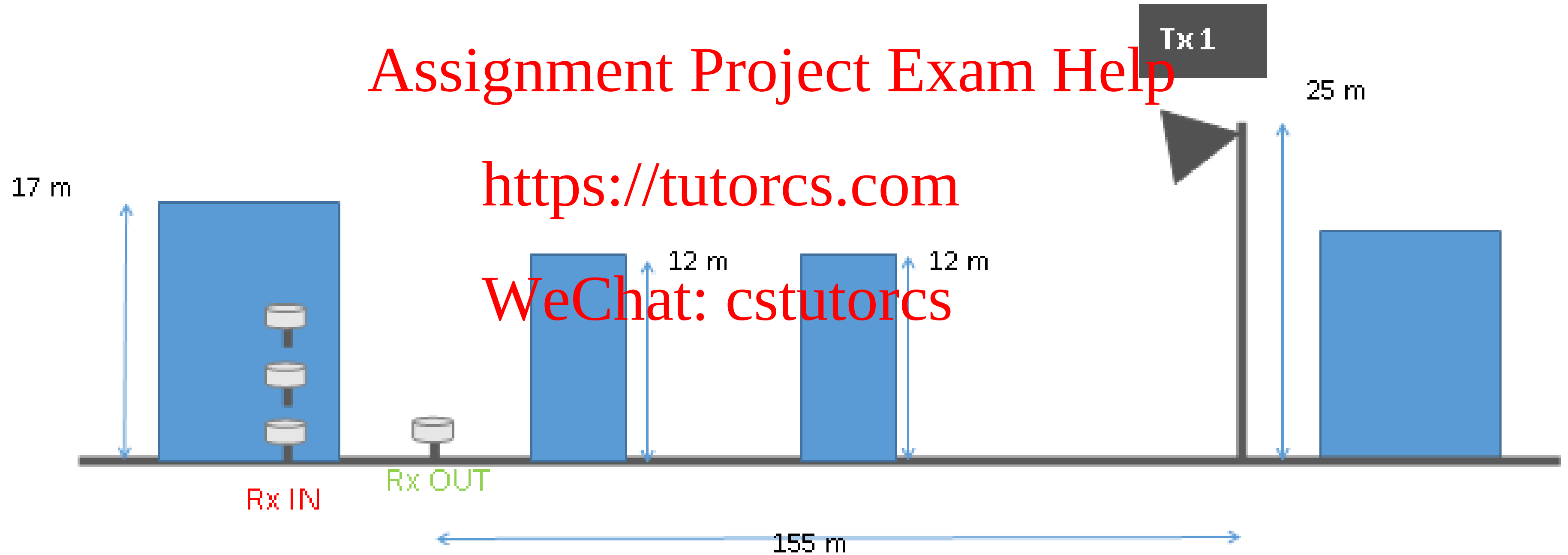
# Combined Clutter and BEL measurements

FIGURE 5

**Scenario side view**

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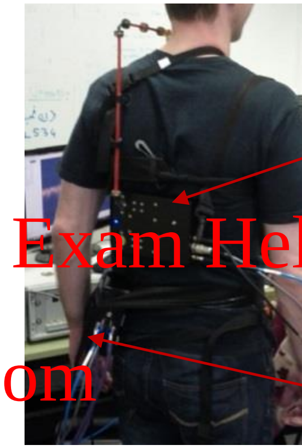
# Measurement scenarios

On body: dismounted soldier



Transmitter

Receiver

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Indoor: WiFi

TX=2.35 m, Rx=1.5 m

Outdoor:

back haul building to building,
lamp post to user, cellular

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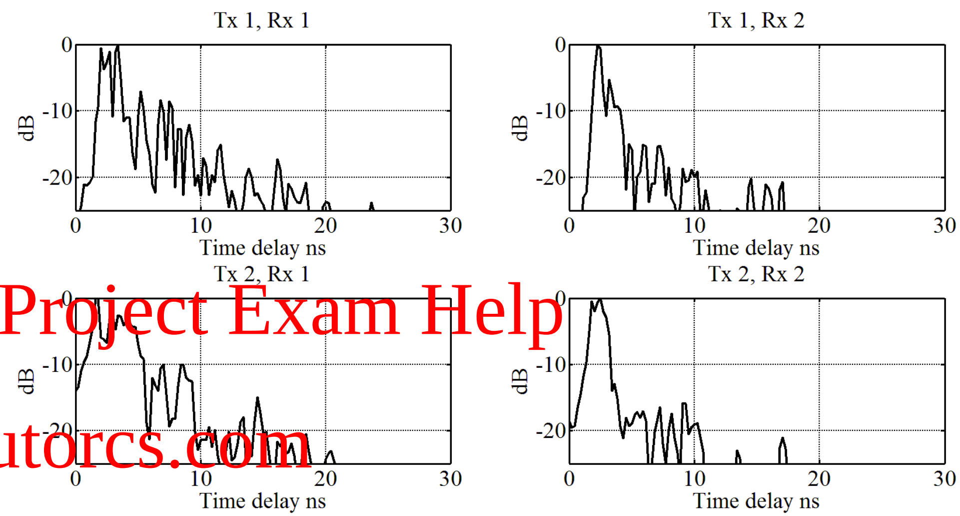
# Example of Measurements

Outdoor scenario ~79 m
~22 cm (0.76 ns)
Median MIMO capacity at
SNR=30 dB ~13.2b/s/Hz
vs
17 b/s/Hz theoretical
Rms~2.2 ns 20dB for 90%

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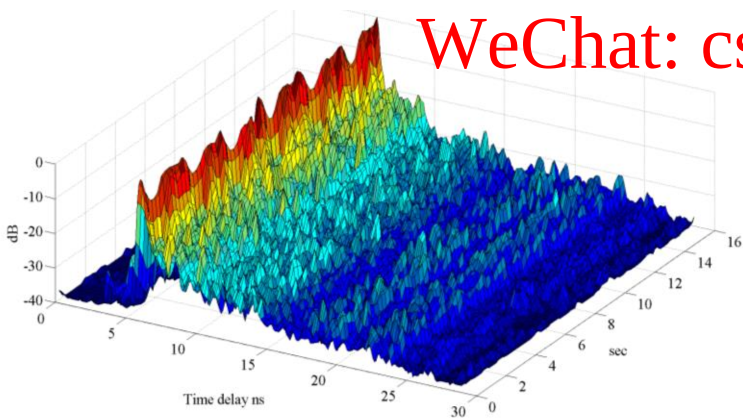


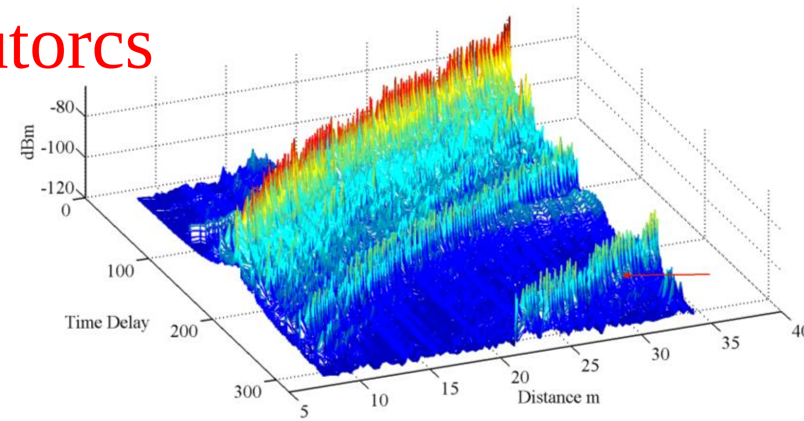


On body

Indoor

rms 0.69 ns at 20dB vs 10.65 at 30 dB ns

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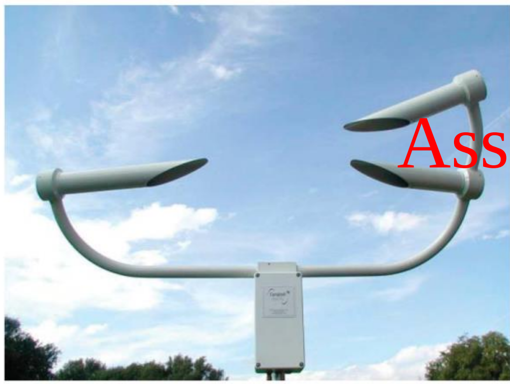
# Impact of precipitation



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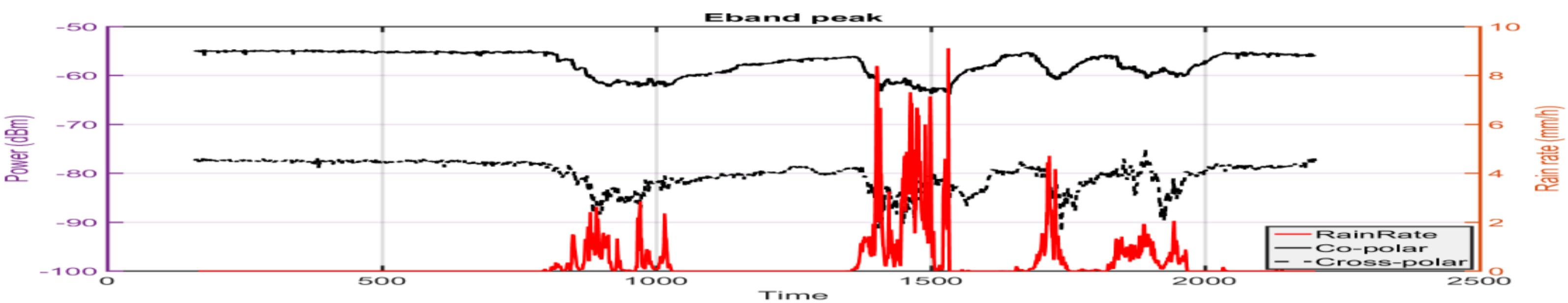


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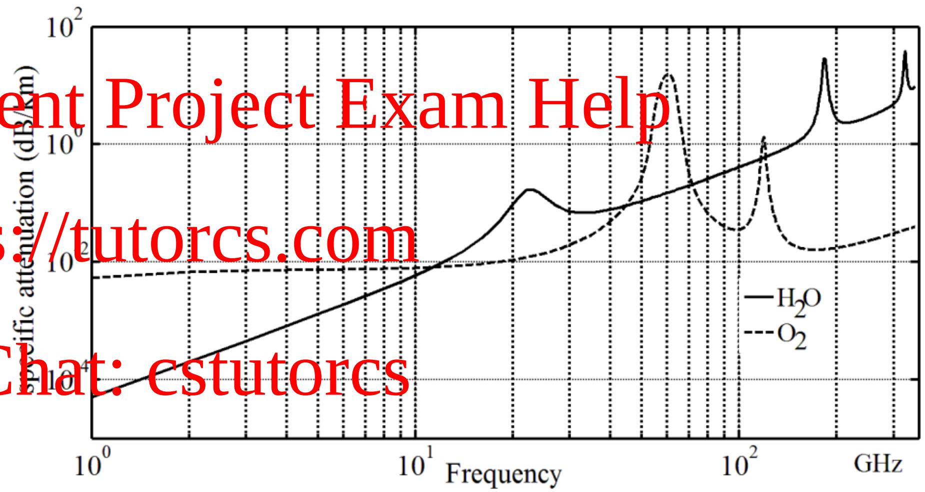
# Future plans: 5G/6G

- **WRC23:** 140-170 GHz, and 235-300 GHz




- **Models**: Indoor, outdoor, Precipitation measurements

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