Space Technology

Satellite Communications:
propagation, measurements, the radio channel
1.

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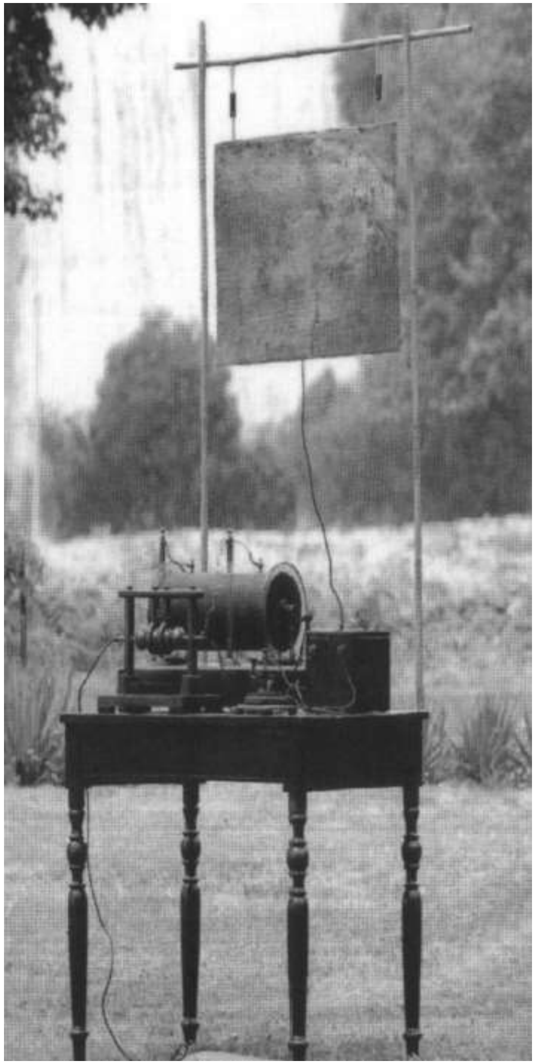
Radio communications – the beginning

- Faraday, Maxwell, Hertz, Tesla…
- 1895: signal transfer to 2400 m, born of radio



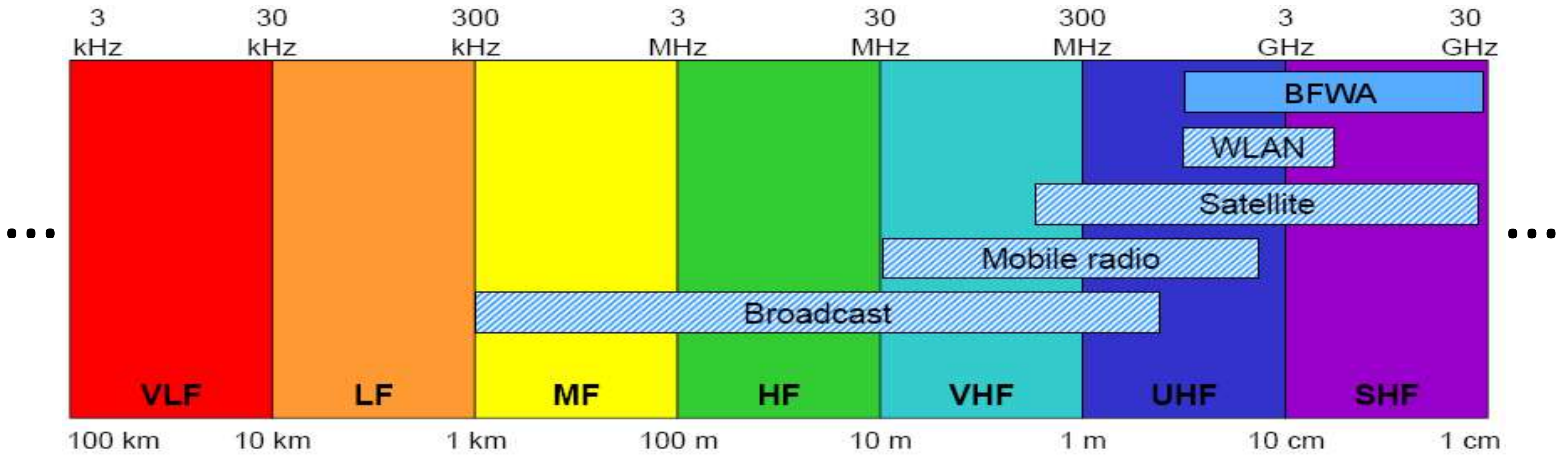
- Spark inductor
- Antenna and grounding
- Koherer
- Battery
- Bell

The signal: . . . = ‘S’

Guglielmo Marconi

1874-1937

The radio spectrum



Tremendously low frequency	**TLF**	< 3 Hz > 100,000 km	Natural and artificial electromagnetic noise
Extremely low frequency	**ELF**	3–30 Hz 100,000 km – 10,000 km	Communication with submarines
Super low frequency	**SLF**	30–300 Hz 10,000 km – 1000 km	Communication with submarines
Ultra low frequency	**ULF**	300–3000 Hz 1000 km – 100 km	Submarine communication, Communication within mines
Very low frequency	**VLF**	3–30 kHz 100 km – 10 km	Navigation, time signals, submarine communication, wireless heart rate monitors, geophysics
Low frequency	**LF**	30–300 kHz 10 km – 1 km	Navigation, time signals, AM longwave broadcasting (Europe and parts of Asia), RFID, amateur radio
Medium frequency	**MF**	300–3000 kHz 1 km – 100 m	AM (medium-wave) broadcasts, amateur radio, avalanche beacons
High frequency	**HF**	3–30 MHz 100 m – 10 m	Shortwave broadcasts, citizens' band radio, amateur radio and over-the-horizon aviation communications, RFID, Over-the-horizon radar, Automatic link establishment (ALE) / Near Vertical Incidence Skywave (NVIS) radio communications, Marine and mobile radio telephony

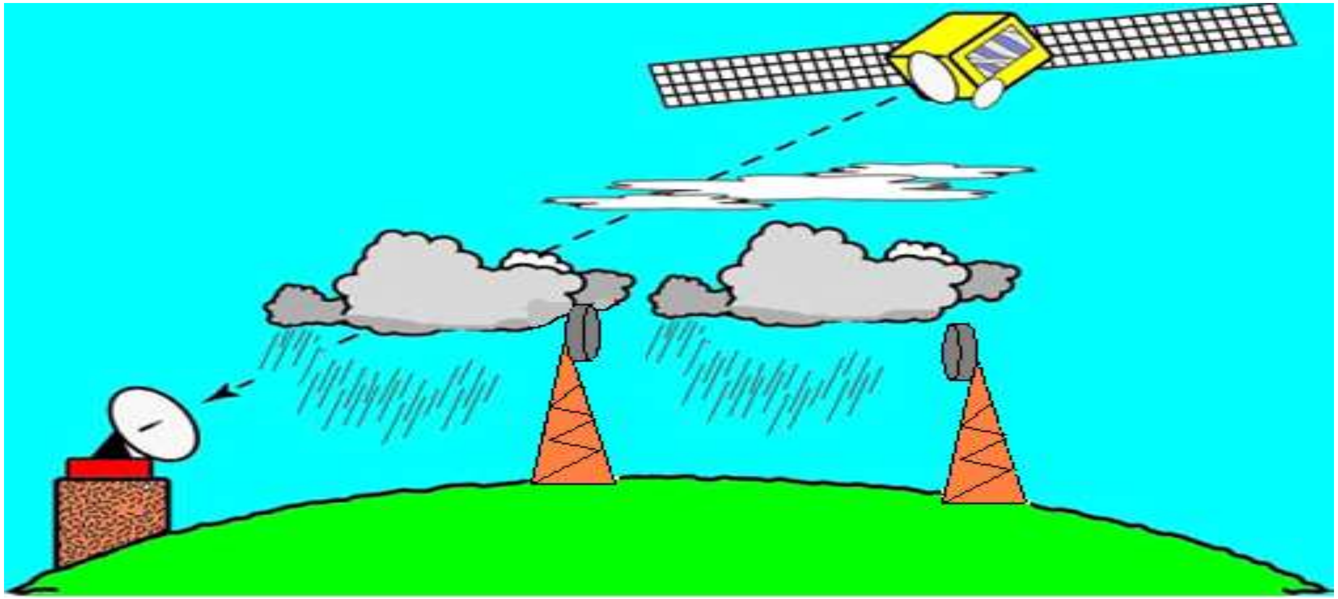
Very high frequency	**VHF**	30–300 MHz 10 m – 1 m	FM, television broadcasts and line-of-sight ground-to-aircraft and aircraft-to-aircraft communications. Land Mobile and Maritime Mobile communications, amateur radio, weather radio
Ultra high frequency	**UHF**	300–3000 MHz 1 m – 100 mm	Television broadcasts, Microwave oven, Microwave devices/communications, **radio astronomy**, mobile phones, wireless LAN, Bluetooth, ZigBee, **GPS and two-way radios such as Land Mobile**, FRS and GMRS radios, amateur radio
Super high frequency	**SHF**	3–30 GHz 100 mm – 10 mm	**Radio astronomy**, microwave devices/communications, wireless LAN, most modern radars, **communications satellites**, **satellite television broadcasting**, DBS, amateur radio
Extremely high frequency	**EHF**	30–300 GHz 10 mm – 1 mm	**Radio astronomy**, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner
Terahertz or Tremendously high frequency	**THz or THF**	300–3,000 GHz 1 mm – 100 μm	Terahertz imaging – a potential replacement for X-rays in some medical applications, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, sub-mm remote sensing, amateur radio

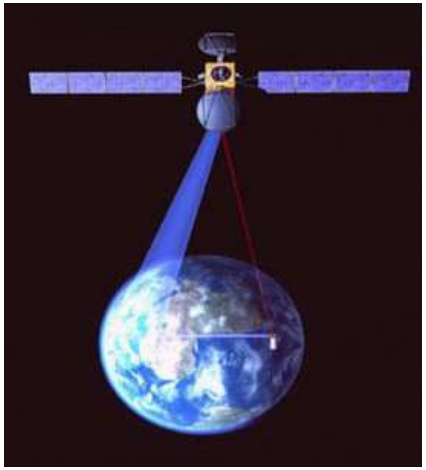
Frequency bands (ITU) - services

Band	Frequency range	Applications
L	1 to 2 GHz	Satellite, navigation (GPS, etc.), cellular phones
S	2 to 4 GHz	Satellite, SiriusXM radio, unlicensed (Wi-Fi, Bluetooth, etc.), cellular phones
C	4 to 8 GHz	Satellite, microwave relay
X	8 to 12 GHz	Radar
K_u	12 to 18 GHz	Satellite TV, police radar
K	18 to 26.5 GHz	Microwave backhaul
K_a	26.5 to 40 GHz	Microwave backhaul
Q	30 to 50 GHz	Microwave backhaul
U	40 to 60 GHz	Experimental, radar
V	50 to 75 GHz	New WLAN, 802.11ad/WiGig
E	60 to 90 GHz	Microwave backhaul
W	75 to 110 GHz	Automotive radar
F	90 to 140 GHz	Experimental, radar
D	110 to 170 GHz	Experimental, radar

Propagation

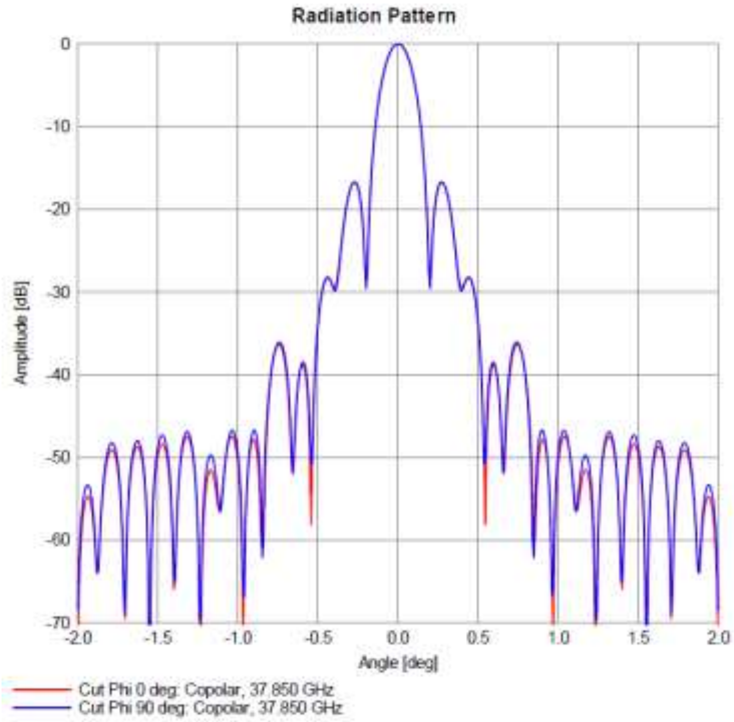
- Earth-Earth
- Earth- Satellite
- Satellite-Satellite





Antennas

- Satellite communications: often parabolic antennas
- Prime focus/offset/Cassegrain antenna
- Gain, beamwidth, directivity, lobes
- Effect of the surface quality



Alphasat station– Graz, Austria

Free space propagation(vacuum) 2/1

Received power at distance d; A_{RX} effective surface, isotropic antenna:

$$P_{RX}(d)_{[W]} = P_{TX} \frac{A_{RX}}{4\pi d^2}$$

Antenna gain (if not isotropic): G_{TX}

Gain of the receiver antenna: $\mathrm{G}_{\mathrm{RX}} = \frac{4\pi}{\lambda^2} \mathrm{A}_{\mathrm{RX}}$ (Stutzman és Thiele)

$$P_{RX}(d)_{[W]} = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi d} \right)^2$$

Free space propagation(vacuum) 2/2

On logarithmic scale:

$$P_{[dBm]} = 10\log\frac{P[W]}{0.001}$$

$$P_{RX}(d)_{[dBm]} = P_{TX\,[dBm]} + G_{TX\,[dB]} + G_{RX\,[dB]} + 20\log\left(\frac{\lambda}{4\pi d}\right)$$

Path attenuation:

$$\mathrm{a} = \frac{\mathrm{P_{TX}}}{\mathrm{P_{RX}}} = \left(\frac{4\pi \mathrm{d}}{\lambda}\right)^2 \frac{1}{\mathrm{G_{TX} G_{RX}}}$$

On logarithmic scale:

$$\mathrm{a} = 20\log\frac{4\pi \mathrm{d}}{\lambda} - \mathrm{G_{TX}^{[dB]}} - \mathrm{G_{RX}^{[dB]}}$$

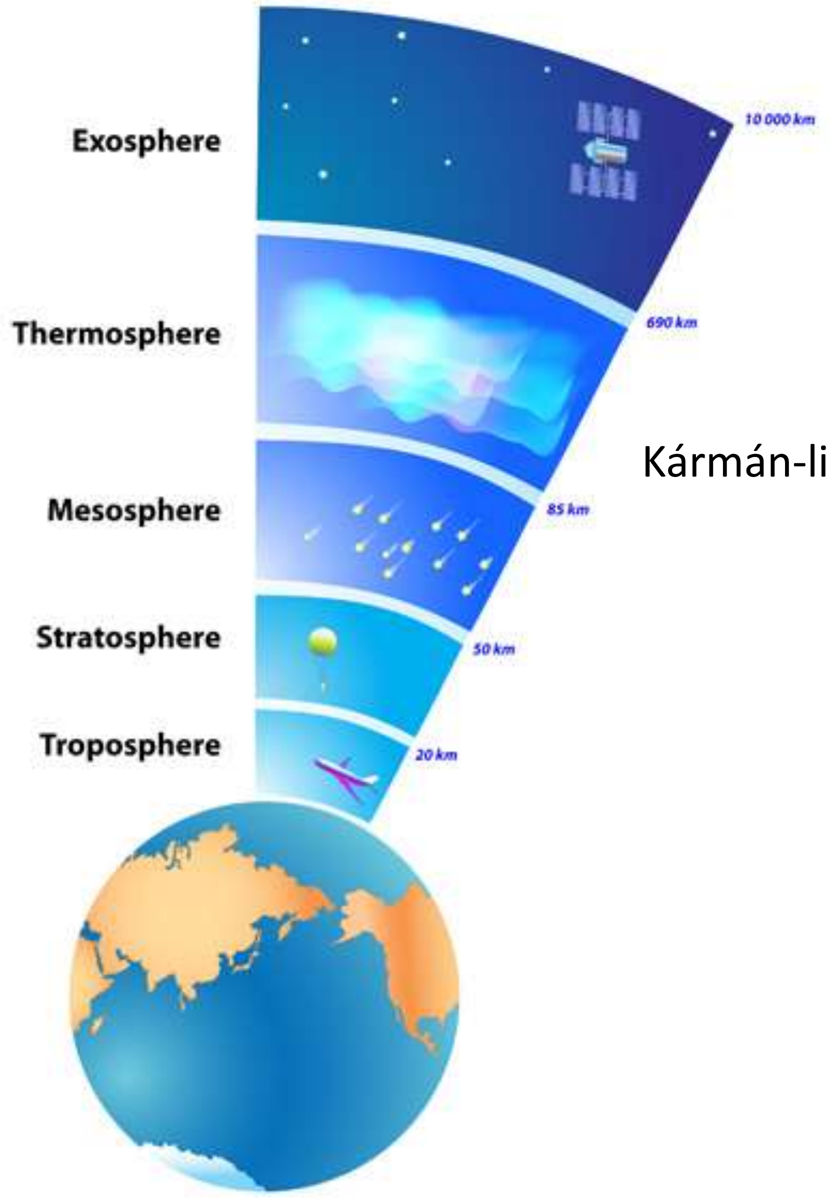
$$\mathrm{a^{[dB]}} = 32.44 + 20\log \mathrm{f^{[MHz]}} + 20\log \mathrm{d^{[km]}} - \mathrm{G_{TX}^{[dB]}} - \mathrm{G_{RX}^{[dB]}}$$

Example: Earth- Moon connection

384.400 km (average distance)

$$a^{[dB]} = 32.44 + 20\log f^{[MHz]} + 20\log d^{[km]} - G_{TX}^{[dB]} - G_{RX}^{[dB]}$$

The Earth’s atmosphere



Kármán-line (~100km)

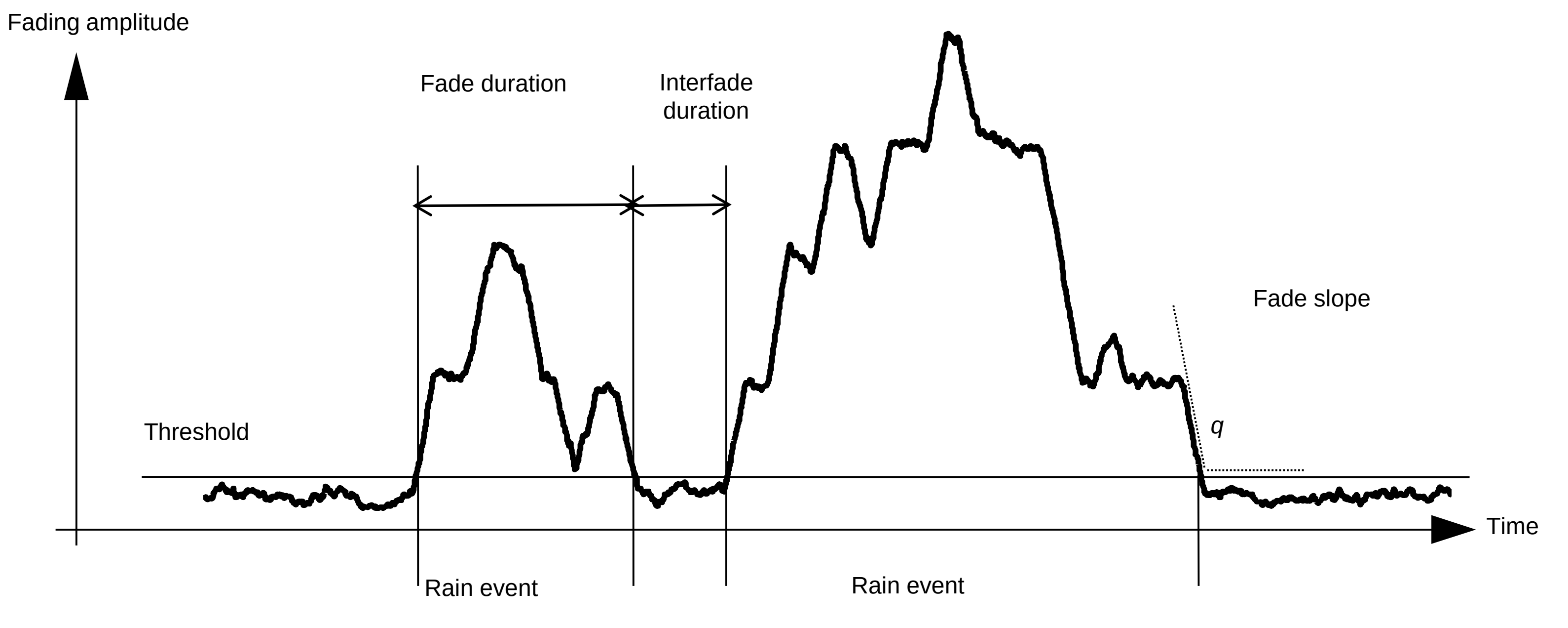
The fading

Fading: temporary variation of the path attenuation

The fading as stochasztic process

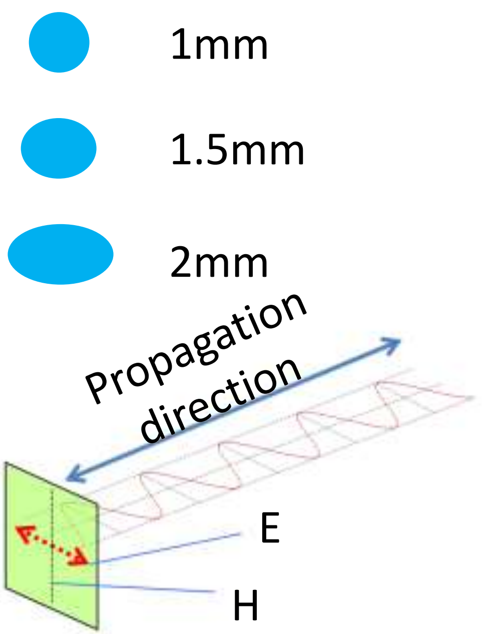
- Models: rain attenuation, multipath propagation, raincell movement, modelling the dynamic properties, channel models
- Distributions and time series generation

Dynamic properties of the fading:



Athmospheric attenuation

- **Attenuation of atmospheric gases**
  - oxigen molecule
  - water vapour
- **Precipitation attenuation**
  - rain
  - fog
  - snow
  - rain with snow (sleet)
  - ice



Horizontal polarization

Attenuation of the atmospheric gases

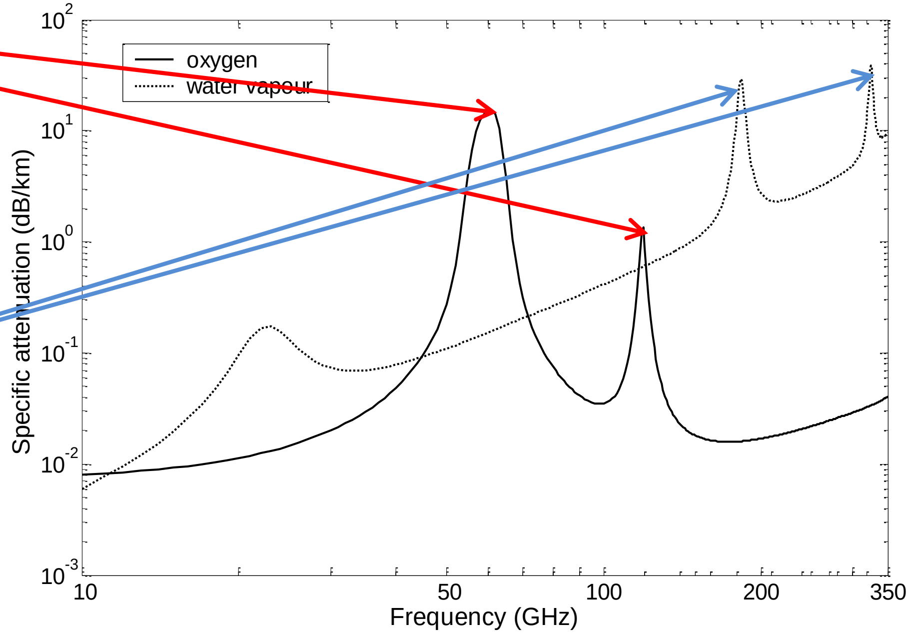
- Gases are absorbing energy
- Significant: above 15 GHz
- Caused by oxigen and water vapour

Oxigen absorption lines:

- 118,74 GHz
- 50 GHz - 70 GHz: multiple
- continous in lower frequencies

•Water vapour absorptions:

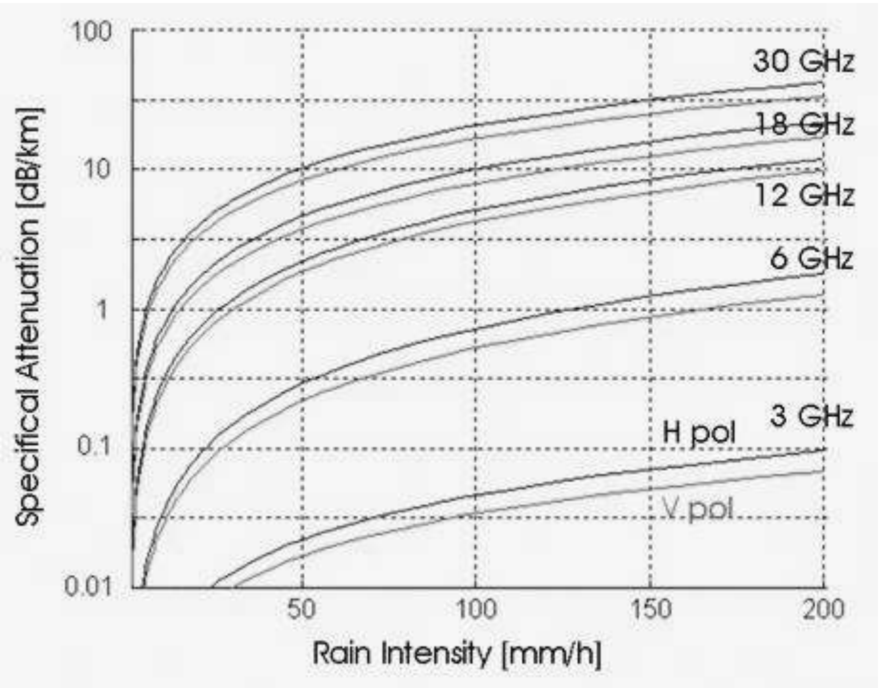
- 23,3 GHz
- 183,3 GHz
- 323,8 GHz
- and in infrared band



- Water vapour attenuation is proportional with concentration.

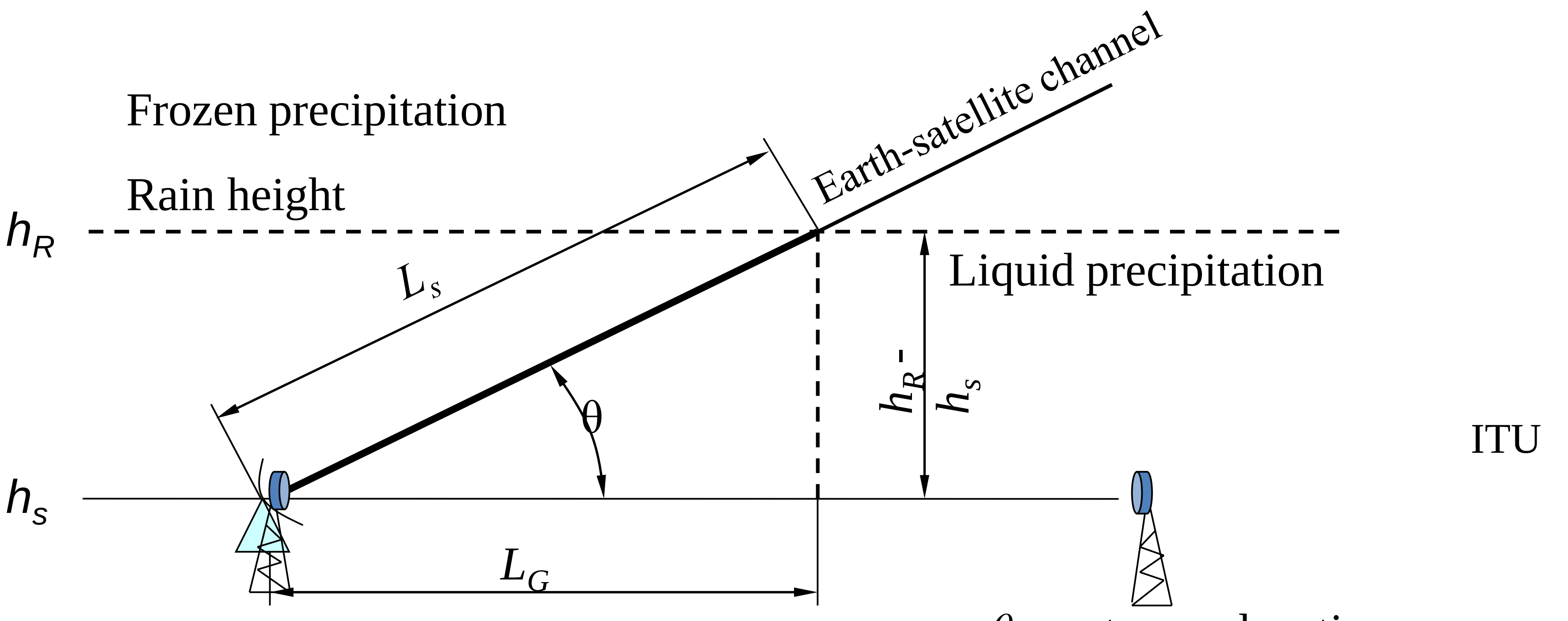
Standard concentration: 7,5 g/m^3

Attenuation caused by the precipitation



- **Rain**
  - attenuation depends on:
    - frequency
    - rain intensity [mm/h]
    - raindrop diameters
  - causes:
    - absorption
    - spreading
    - polarization changes
  - above10 GHz mainly at the attenuation maximums
  - horizontally polarized wave: more attenuation due to the raindrop shape
- **Ice, snow**
  - frozen water has smaller dielectric constant
  - attenuation is not significant
  - snow may cumulate on radome!
- **Fog**
  - rather on optics (wavelength, drop size)
- **Snow+rain** (sleet)
  - Special meteorological circumstances
  - Melting snow ha a water cloak

Earth-Earth and Earth-satellite path



θ – antenna elevation

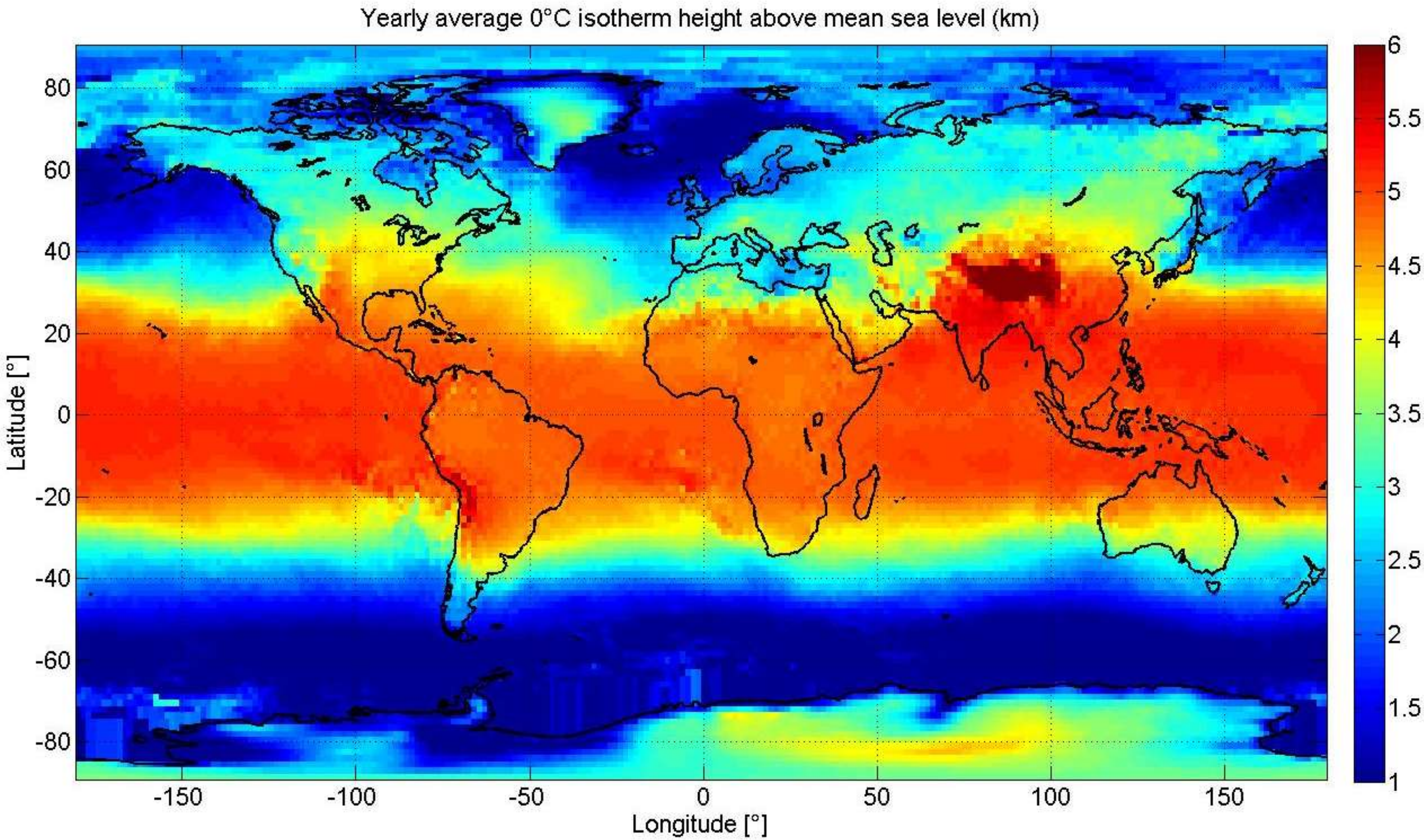
$L_G = Ls \cos\theta$ [km].

L_s – slant path,

L_G – horizontal path, h_R – effective rain height

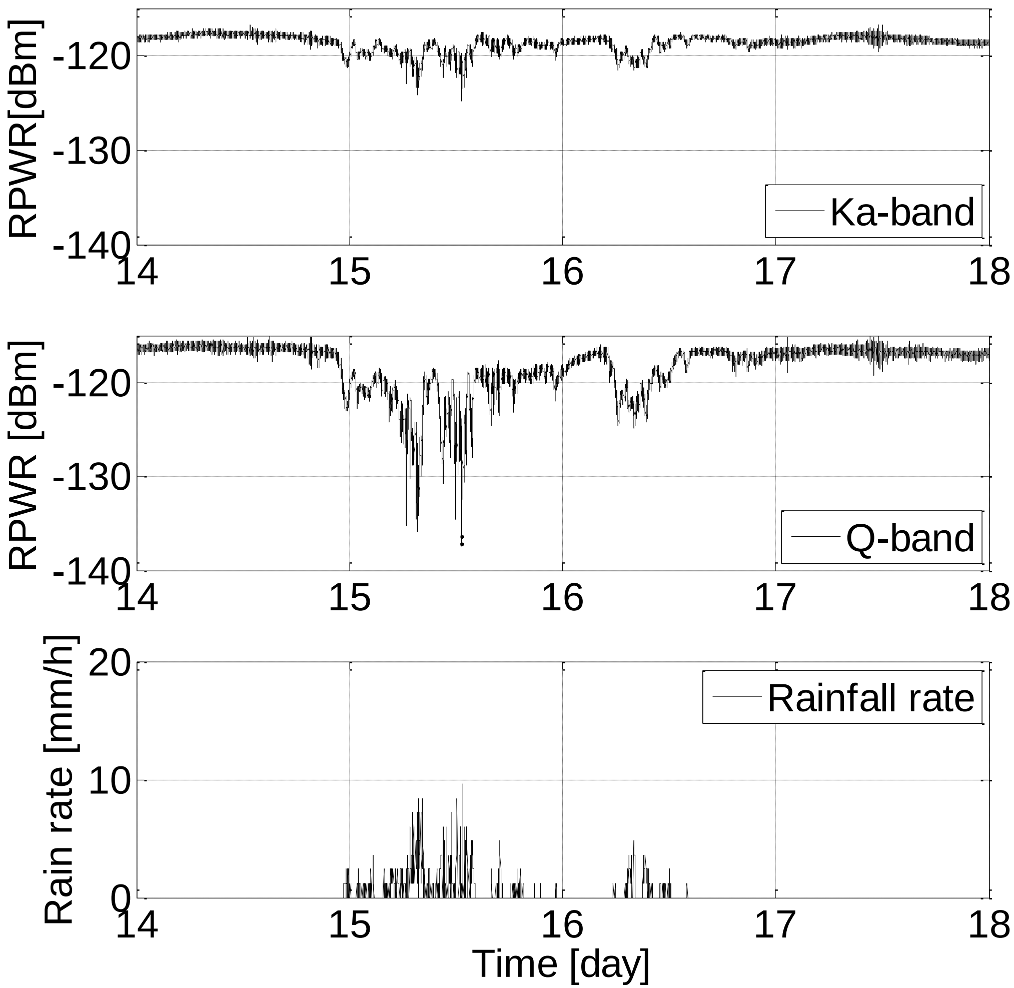
$L_s = (h_R - h_s)/\sin\theta$ [km], h_s – height of the station

Rain height: ITU-R P.839



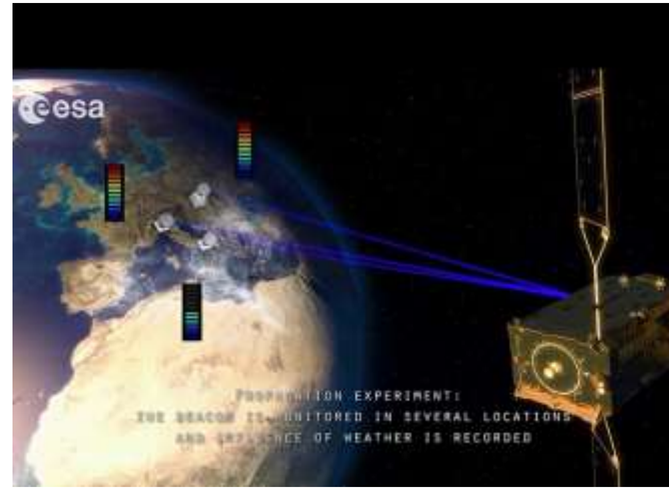
$$h_R = h_0 + 0.36 \text{ km}$$

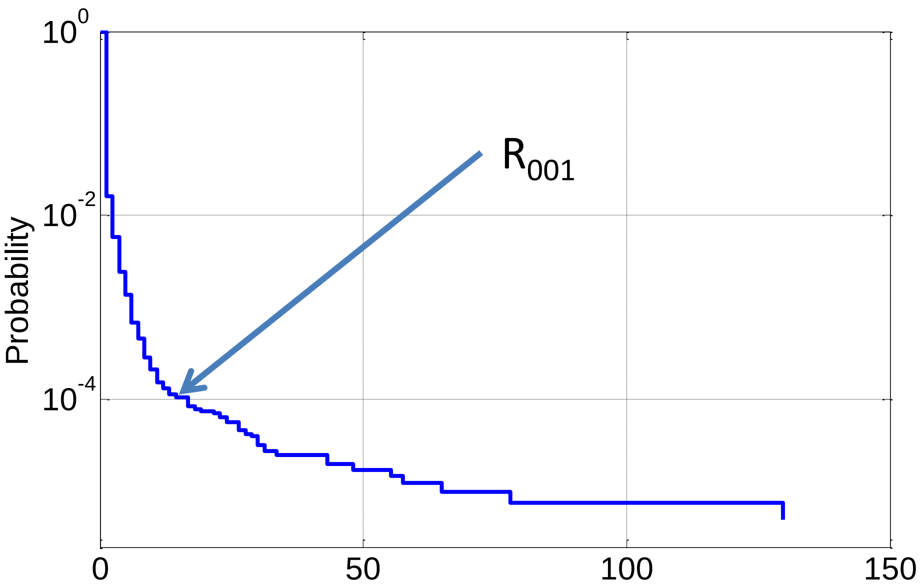
Typical received power time series (19.7/38.4 GHz, satellite)



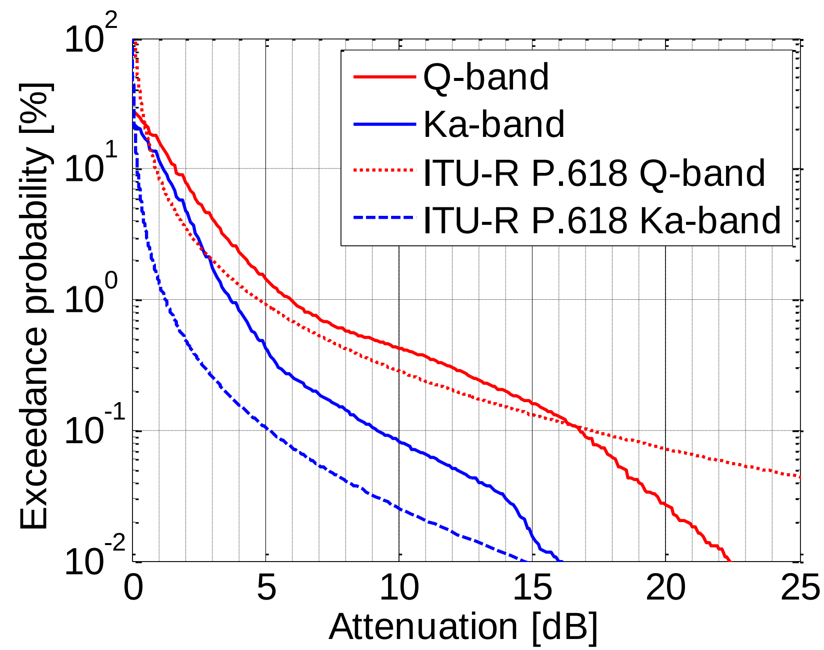
14-18 July, 2016

Distribution of rain intensity and attenuation



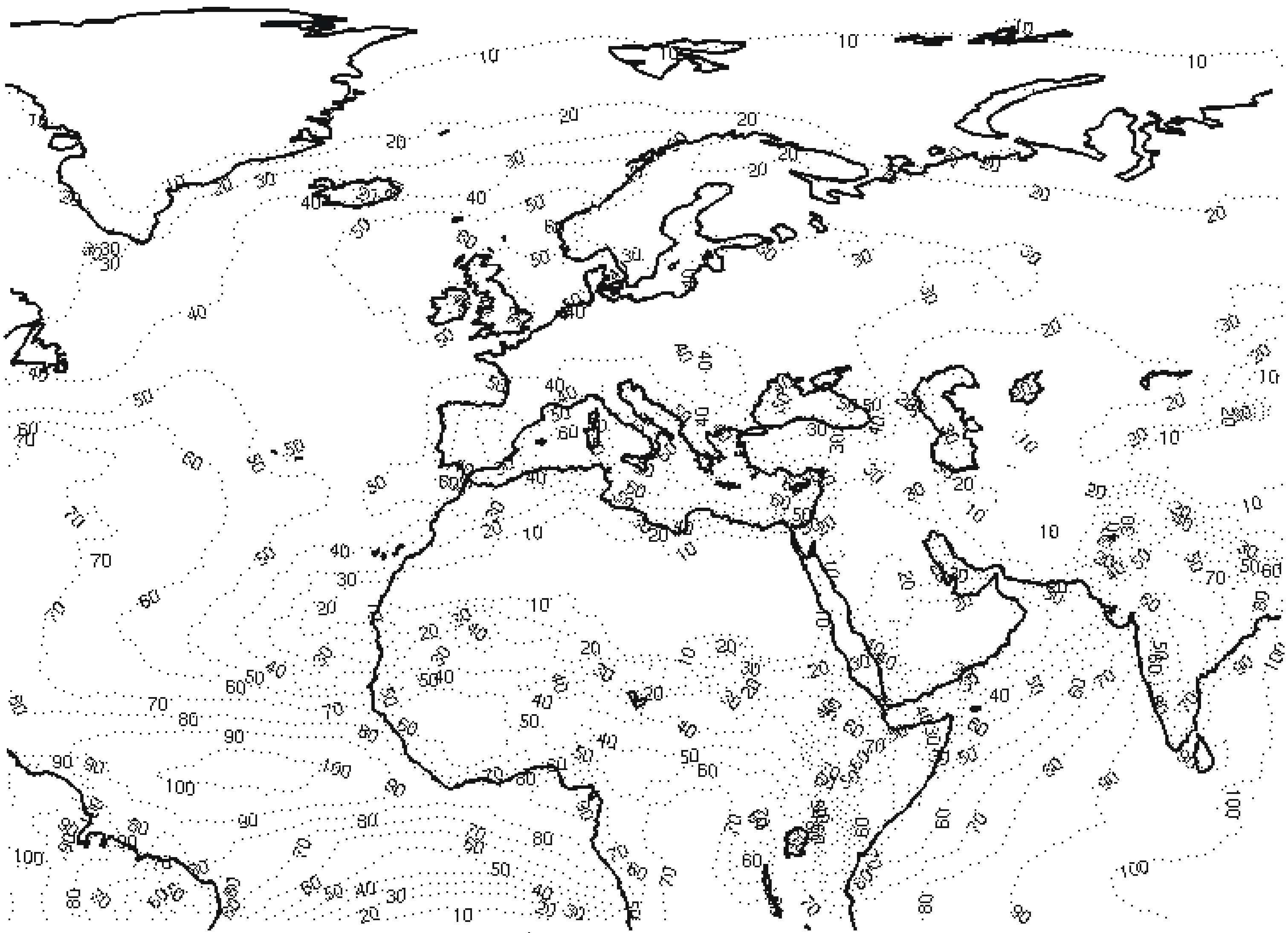


Budapest, 1 year statistics



Alphasat, Budapest, 2 years statistics

R_{001} according to ITU-R

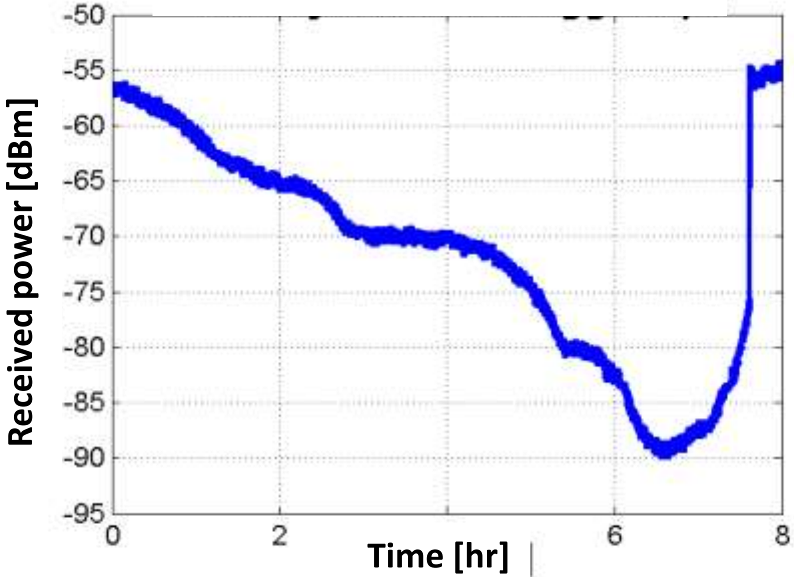


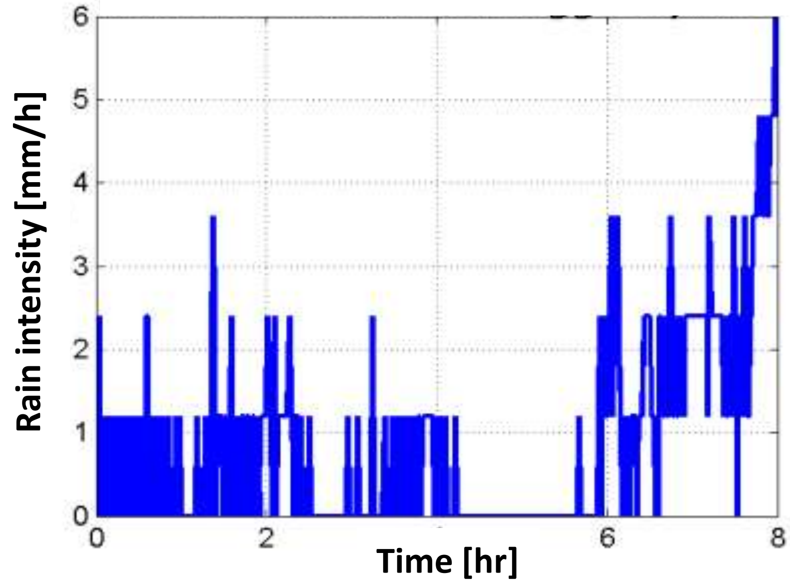
Wet snow (sleet) attenuation

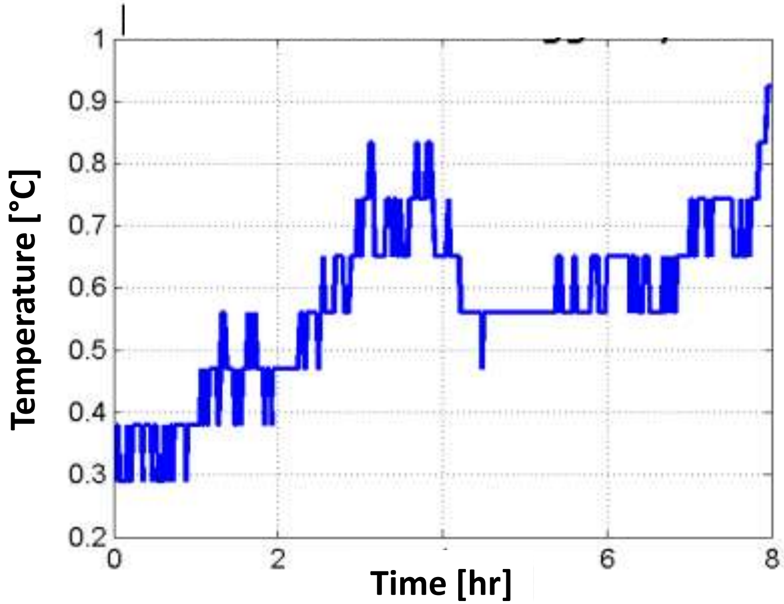
Circumstances:

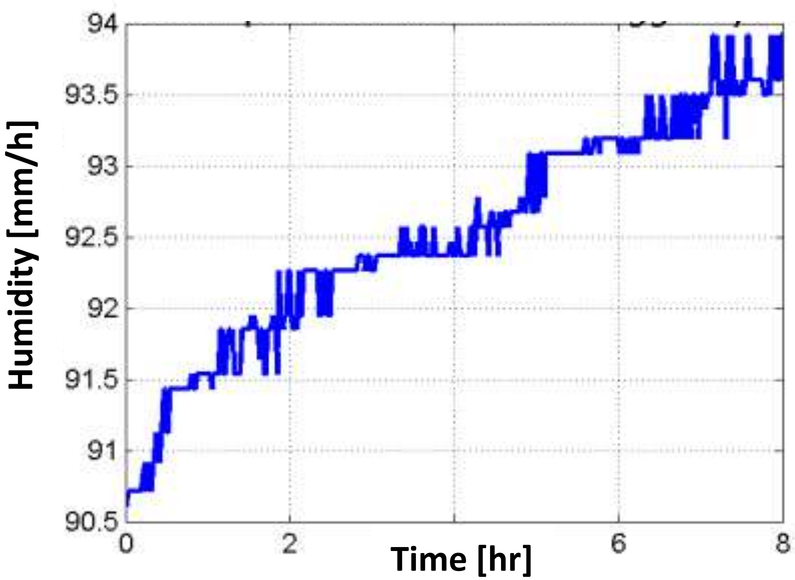
- temperature around 0 °C or between 1,6-6 °C
- humidity above 70%
- sleet max mixed with rain
- probably fog

Effects of sleet on microwave connections

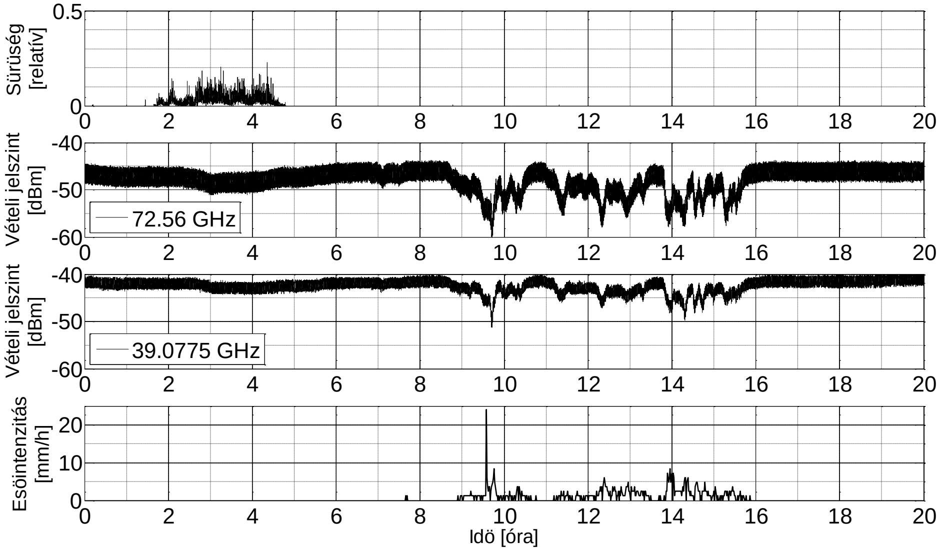


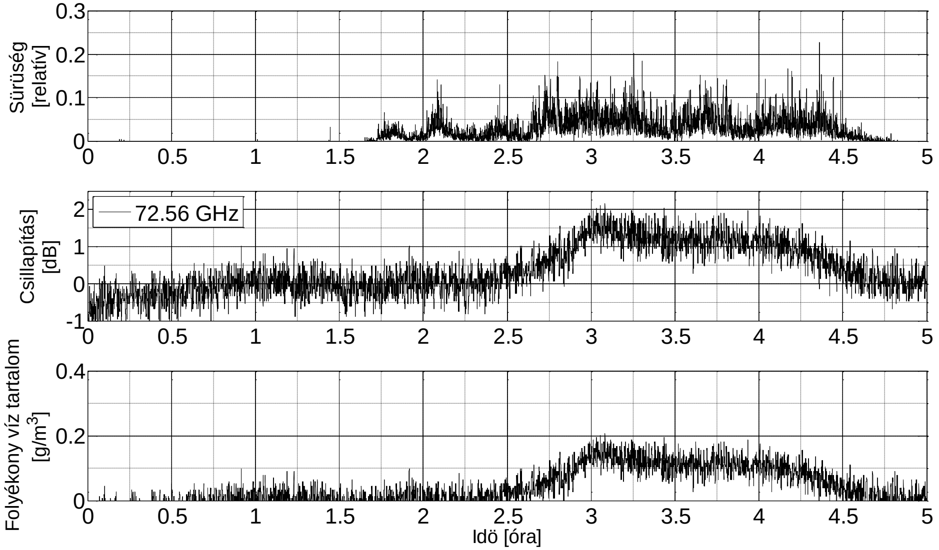




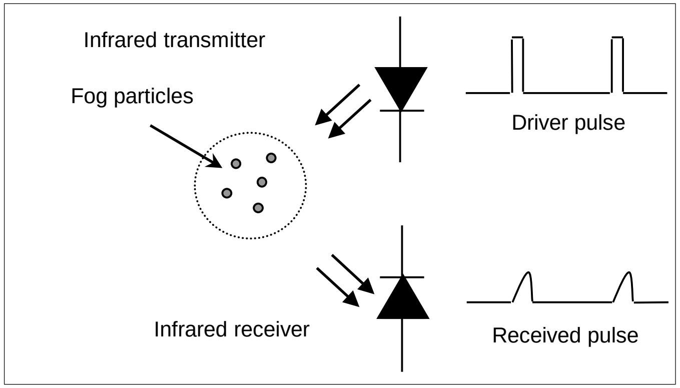


Effects of fog



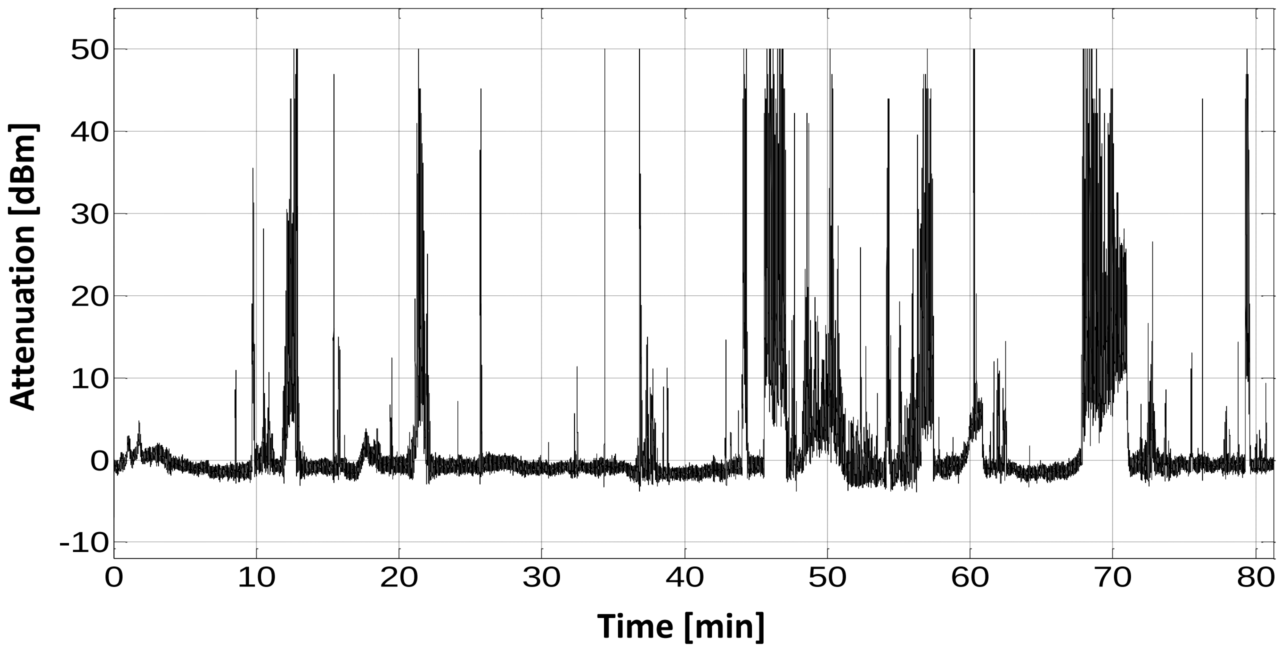


Fog density measurements:



Further effects

- Multipath propagation, reflexions
- Mobility
  - Transmitter (satellite) is moving
  - Receiver is moving (mobile phone, train, airplane, etc.)
  - Transmitter & receiver are moving (e.g. ad-hoc wireless network)
  - Doppler effects
- effects of shadowing (buildings, plants)



LMS attenuation, highway

Main topics / questions

- ❑ **Free space radiowave propagation: main parameters**
- ❑ **The antenna gain**
- ❑ **The fading**
- ❑ **Main atmospheric effects**