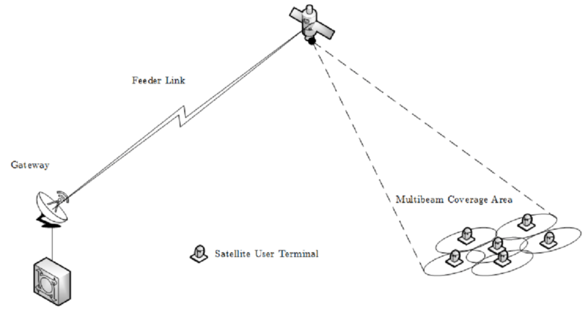
mmWave – Unlocking the potential of LEO satellites for Global Data Connectivity

Dr Tudor Williams, Director of Technology

High Data Rates in Non-Terrestrial Comms

- Move from GEO to MEO/LEO
- Soaring Bandwidth Requirements
- Leo constellations as part of the 5G/6G Communications Network
  - 50,000 satellites in the next 10 years
- Satellite Feeder Links
  - Existing Ka Band
  - Future Q/V Band?
  - Future W-Band (71-86GHz)?



Next Generation Feeder Links

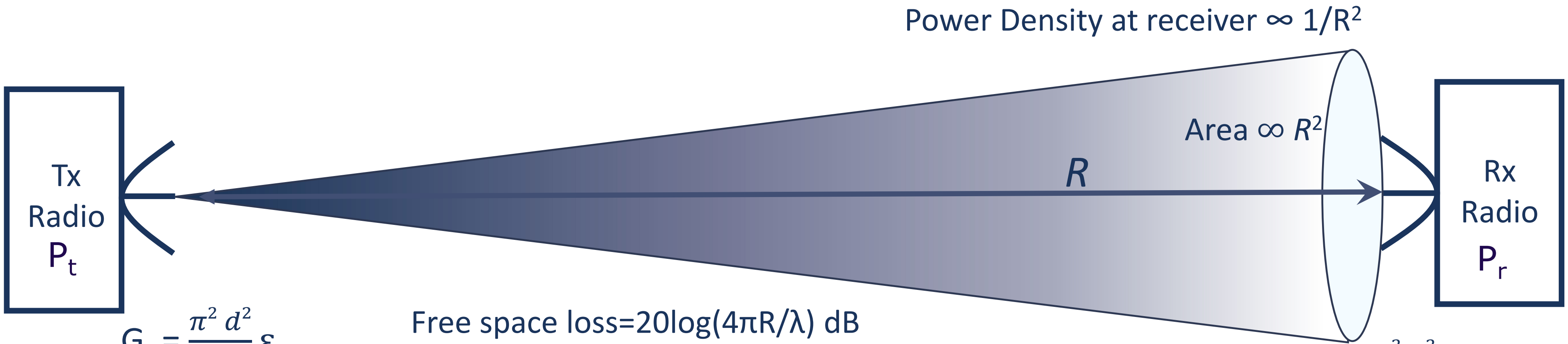
Larger channel at W-band two 5GHz channels 71-76/81-86GHZ with typical 2GHz channel BW
Q-Band

Relates to maximum data rate improvement from 3.2 GB/s to 12.8 GB/s

Are Q/V or W-Band Feasible??

Link Budget - Free Space Loss

filtronic
Innovation in RF technology



$$G_t = \frac{\pi^2 d^2}{\lambda^2} \varepsilon$$

Free space loss=20log(4πR/λ) dB

Increases with the square of the distance and square of the frequency

$$G_r = \frac{\pi^2 d^2}{\lambda^2} \varepsilon$$

$$P_r = P_t + G_t + G_r + 20\log_{10}\left(\frac{\lambda}{4\pi R}\right) - Attenuation_{Rain} - Attenuation_{Atmosphere}$$

The Friis transmission equation

Where

P_r = Power at receiver dBm

P_t = transmit power int antenna dBm

G_t = Tx Antenna gain dBi

G_r = Rx Antenna gain dBi

R distance between Tx and Rx m

λ = wavelength in m

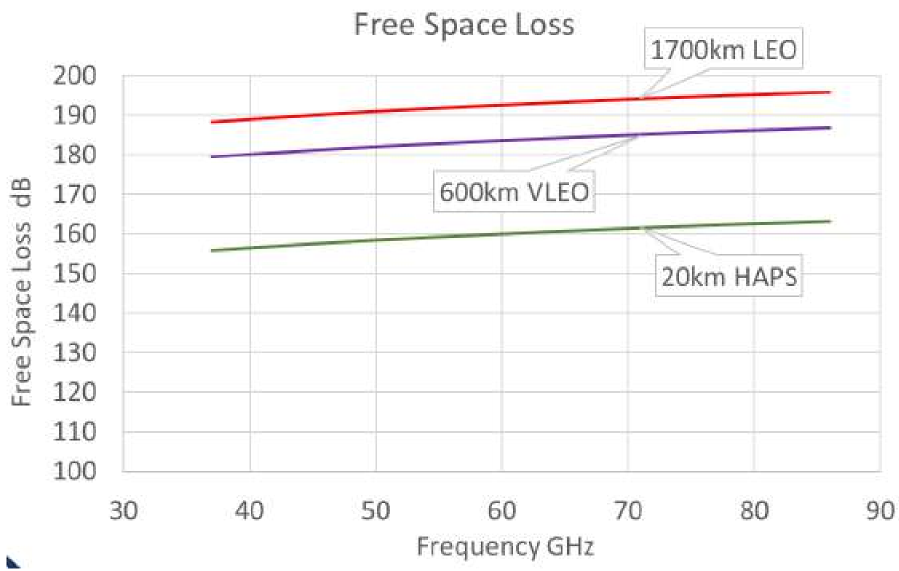
d= Antenna diameter

ε= Antenna efficiency (includes feeder loss & implementation losses)

Link Budget - Free Space Loss

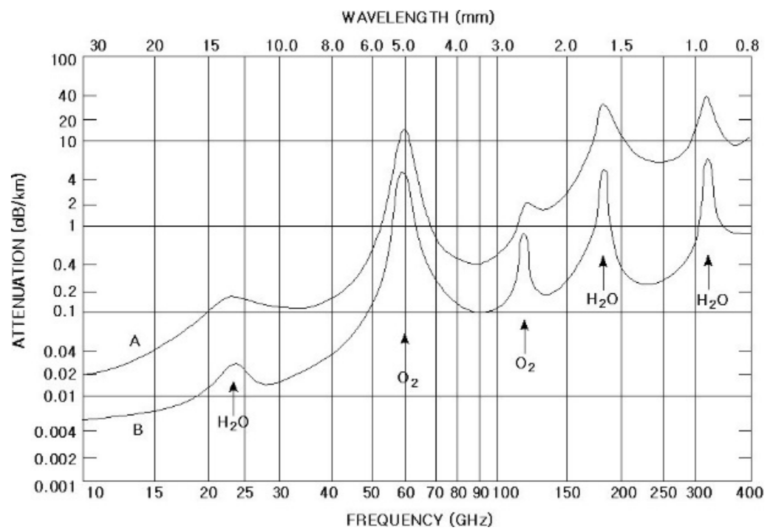
filtronic
Innovation in RF technology

- Free space loss shown for 3 scenarios, HAPS, VLEO and LEO
- 20 km for HAPS, 600 km for VLEO and 1700 km for LEO
- Note the altitude will vary for different constellations, e.g. lowest altitude for Gen 2 space-X constellation is 328 km
- For VLEO Q-Band @37.5GHz loss is 180 dB moving to 71GHz would give 184 dB loss



Link Budget - Atmospheric Losses

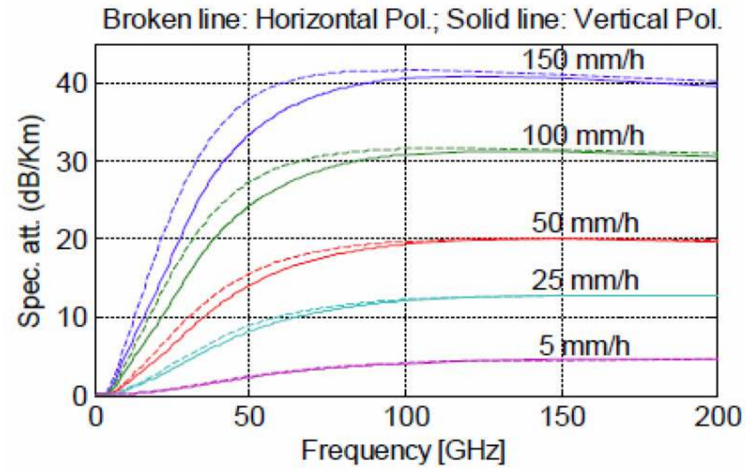
- Another Significant source of attenuation over frequency
- Significant peaks at 22 GHz due to water and at 63 GHz due to oxygen, making transmission for a long link length impossible at this frequency
- Attenuation will vary with elevation angle as this affects path length through lower atmosphere
- Assuming 60^o elevation for a VLEO orbit (600 km), loss would be 0.35 and 2.3dB for 37.5 GHz and 71 GHz respectively

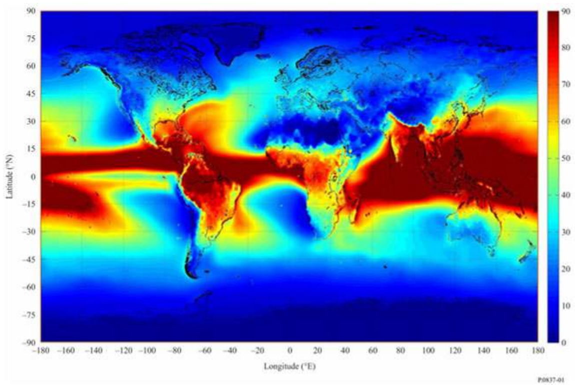


Link Budget - Rain Losses

filtronic
Innovation in RF technology

- Significant influence on transmission loss, again influenced by elevation angle
- ITU publishes statistical data on rain zones that can be used for calculation
- Availability is a critical criteria when calculating loss
- Satellite constellations, reduced requirements, particularly for mesh networks.



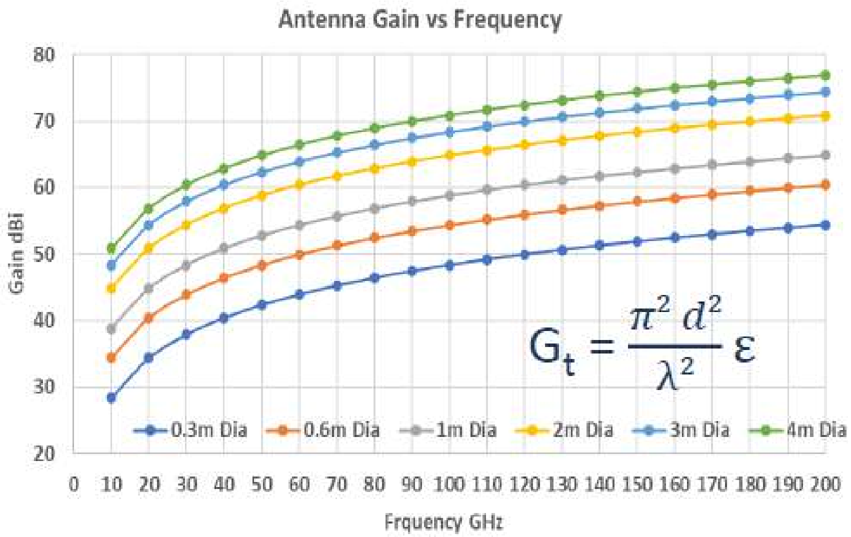


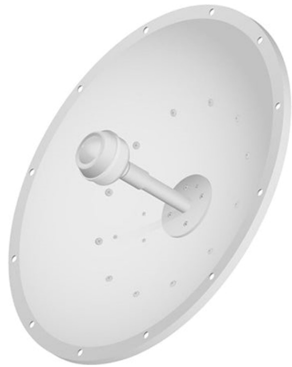
Availability %	Loss at 37.5GHz (dB)	Loss at 71GHz (dB)
99.99	32.88	60.1
99.5	5.13	10.43
99	3.32	6.88
95	1.07	2.32

VLEO (650 km) loss Vs availability (32mm/h)

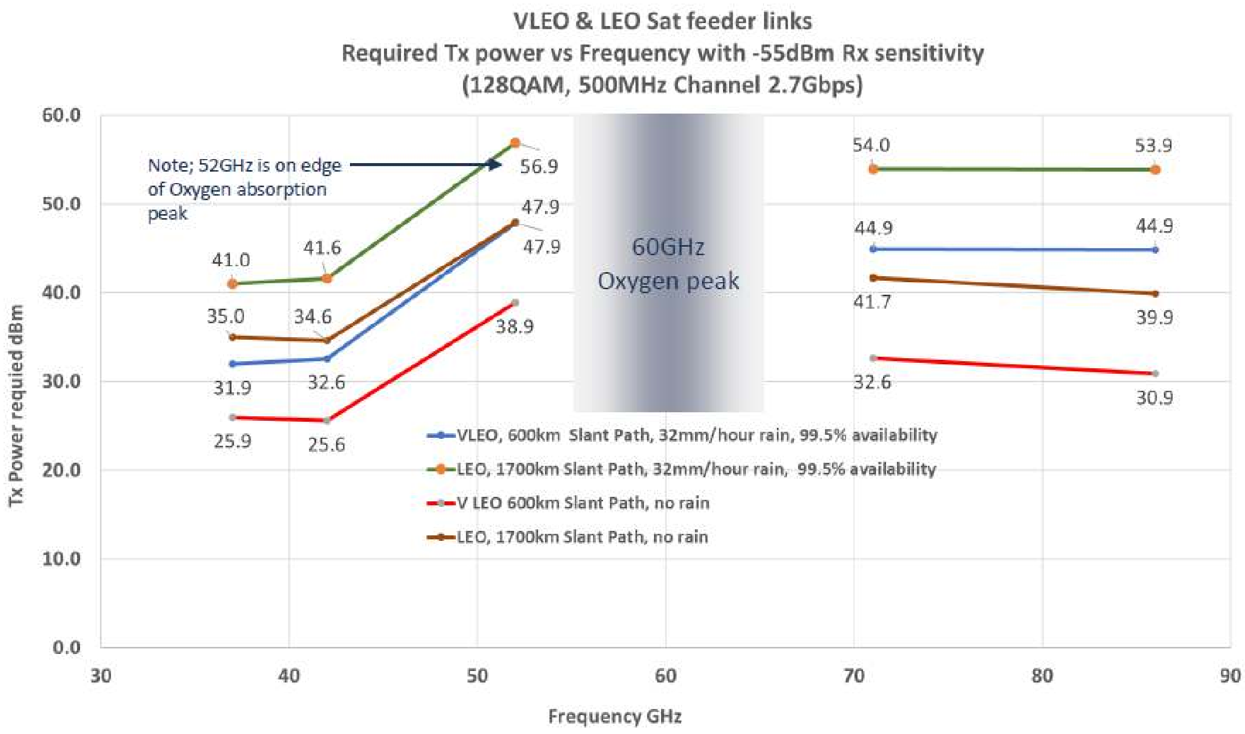
Link Budget - Antenna Gain

- Unlike all other parameters, this time we can get more gain at higher frequency for the same size dish
- Recover some of the performance lost in other parameters
- For the same 0.3m dish on the satellite gain improves by 5.5 dB





Link Budget - Required Tx Power Vs Frequency



In a like for like scenario Q-band would appear to be a clear winner –

At VLEO <2W of output power required at Q-Band compared to over 10W at W-Band

But what about using the additional bandwidth?

Link Budget – Payload Power
Adaptive modulation with 99.5% Availability

filtronic
Innovation in RF technology

- If no inter satellite links, could also drop to lower order modulation when poor conditions encountered.

500MHz Channel

Condition	64 QAM (2.4Gb/s) Tx dBm	16 QAM (1.6Gb/s) Tx dBm	4 QAM (800MB/s) Tx dBm
Clear Sky	20.1	14.0	7.1
Cloud/No rain	24.0	17.9	11.0
12mm/hr	30.2	24.0	17.2
22mm/hr	32.2	27.1	20.2
32mm/hr	35.7	29.5	22.7

2000MHz Channel

Condition	64 QAM (9.6Gb/s) Tx dBm	16 QAM (6.4Gb/s) Tx dBm	4 QAM (3.2GB/s) Tx dBm
Clear Sky	26.1	20	13.1
Cloud/No rain	30	23.9	17
12mm/hr	36.2	30.1	23.2
22mm/hr	39.2	33.1	26.2
32mm/hr	41.7	35.6	28.7

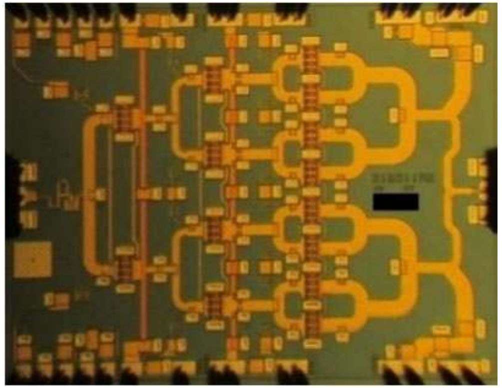
Adaptive modulation W-Band

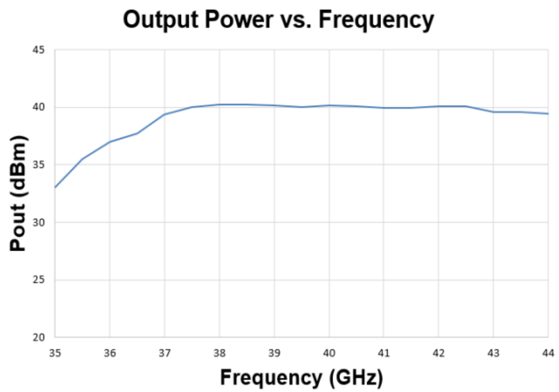
- Assume we have 5W HPA 35dBm, assume 3.5dB back of for linear gives max power of 31.5dBm, as conditions change would be possible to maintain >3.2GB/s link, with peak data rate of 11.2GB/s. Calculation to maintain 99.5% availability.

Condition	64 QAM (9.6Gb/s) Tx dBm	16 QAM (6.4Gb/s) Tx dBm	4 QAM (3.2GB/s) Tx dBm
Clear Sky	26.1	20	13.1
Cloud/No rain	30	23.9	17
12mm/hr	36.2	30.1	23.2
22mm/hr	39.2	33.1	26.2
32mm/hr	41.7	35.6	28.7

Q-Band Technology

- Limited MMICs available at high power but GaN technology starting to stretch to these frequencies
- One example is OMMIC who claim a 10W MMIC using their 0.1um GaN on Si process
- Viable to support the required power levels

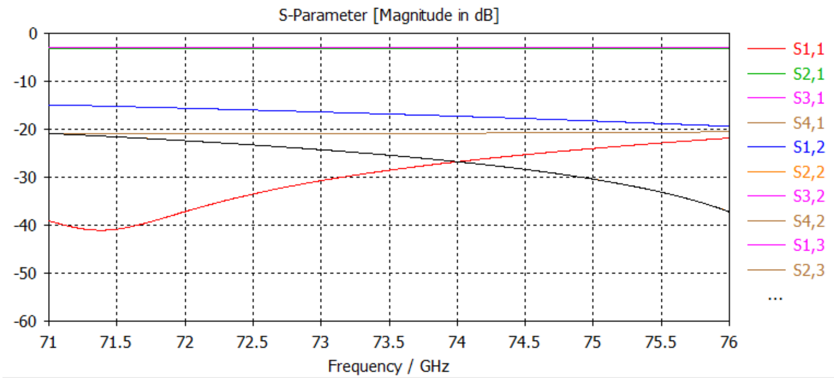


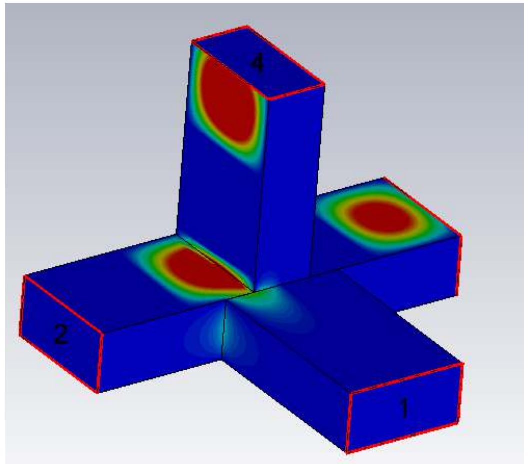


E-Band Technology

filtronic
Innovation in RF technology

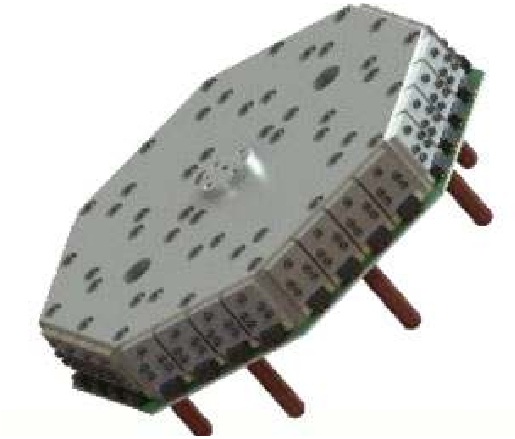
- Commercially available MMICs at E-band limited to around 0.5W output power
- Processes improving but will only give incremental improvement
- GaN processes starting to become available but no commercial offerings yet…….
- Necessity for low loss compact combining

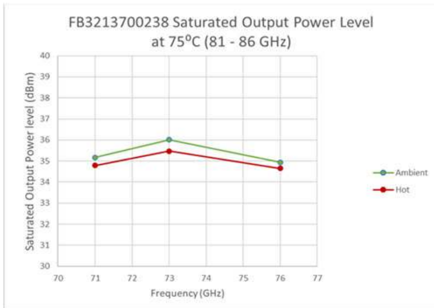




E-Band Technology

- Approach is scalable for any integer factor of 2 MMICs
- Filtronic have commercial product combining up to 8 MMICs giving 35/36 dBm
- Currently working on versions combining up to 32 MMICs with our next generation E-Band MMICs we expect to reach power levels exceeding 41dBm





Conclusion

filtronic
Innovation in RF technology

- Considered Link budget and translated to realistic output power specifications for Q and E-Band power amplifiers required for future satellite feeder links. Both bands are practical.
- Q-band is viable using off the shelf technology and expect to see more players able to deliver power from GaN in the near future expanding potential design space.
- W-band needs low loss combining, already have solutions to 35 dBm and working on solutions beyond 10W.
- W-Band Very attractive particularly in an adaptive modulation approach.