Satellite channel losses

pointing, rain fade, sun outages

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Various losses on “air interface”

Including:

- Free space loss on path to satellite in link budget.
- Loss from mispointed dishes.
- Rain fade and slant through atmosphere.
- Noise from sun outages.

- Not covering cable, connector or splitter losses in detail.

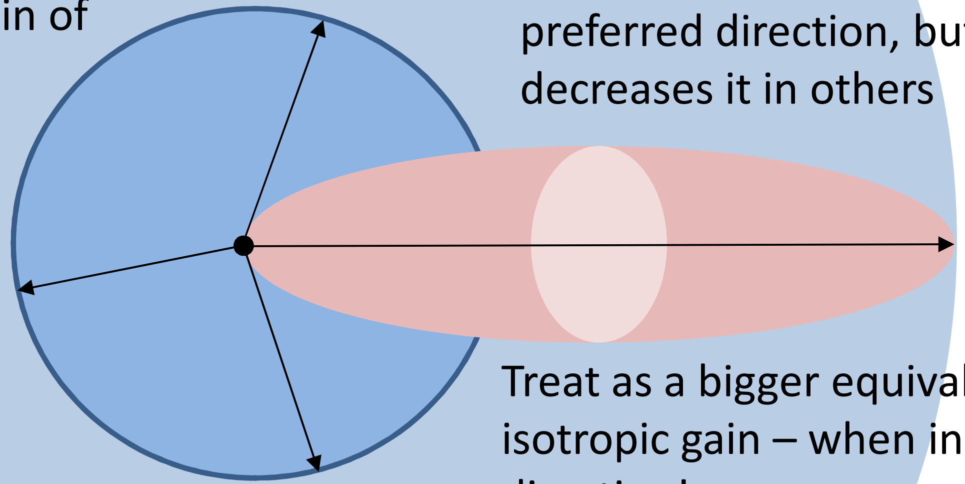
- But must introduce working with link budgets first.
- Provides a framework for considering all the losses in.

Start with gain at transmitter antenna

- Gain G is not uniform; antennas are deliberately directional. Pretend gain is uniformly spherical - but really only in the useful direction.
- This is *Equivalent Isotropic Radiated Power*.

Isotropic radiation from point source has gain of 1 in all directions

Antenna increases gain in preferred direction, but decreases it in others



Treat as a bigger equivalent isotropic gain – when in this direction!

EIRP Equivalent Isotropic Radiated Power

- Power out of Block UpConverter (BUC) is P_{TX}
- Transmission gain is G_{TX}
- EIRP = $P_{TX}G_{TX}$
- in dB, EIRP = 10 log P_{TX} + 10 log G_{TX}

- P is expressed in dBW (relative to 1W); G is just a multiplier in dB. So EIRP is *really* in dBW.

  (dBm is relative to 1mW, i.e. 1W/1000, so equivalent dBm value is 30 more. 1 dBW = 30 dBm.)

- power flux density PFD is EIRP / $4\pi r^2$ in W/m^2
  where r is distance from dish
  and we're in the peak beam.

- Gain G = *antenna efficiency* $(\pi D/\lambda)^2$; D is diameter of dish.

Free space loss (FSL)

- $L_{FS} = (4\pi R/\lambda)^2$
- R to (and from...) geostationary orbit is LARGE.
- Around 200dB loss up, another 200dB down.
- Distance to geostationary orbit doesn't change *that* much with latitude; up to 1.3dB increase in free space loss. Bit more with longitude offset.
- More in slant path losses through air – later.
- $L_{FS} = \mathit{20} \log (4\pi R/\lambda)$

    (because *squared, so adding twice*)

Power at receiver

- Power at receiver is $EIRP(G_{RX})/L_{FS}$

  $= P_{TX}G_{TX}G_{RX}/L_{FS}$

  $= P_{TX}G_{TX}\, \mathit{efficiency}_{RX}(\pi D_{RX}/\lambda)^2 / (4\pi R/\lambda)^2$

  cancel the common terms top and bottom...

  $= EIRP \times \mathit{efficiency}_{RX} D_{RX}^2 / 16R^2$

- *So depends on the receiver dish area from G_{RX}*
- *But also depends on transmit dish area, as EIRP contains G_{TX}!*
- because $EIRP = P_{TX}G_{TX} = P_{TX}\, \mathit{efficiency}_{TX} (\pi D_{TX}/\lambda)^2$

Power at receiver #2

- ***but*** satellite has amplifier and receiving and transmitting antenna with EIRP – really two separate links, with (slightly) different λ and noises, amplifier in middle. Even so, EIRP from transmitter dish still drives the received power.
- So can do budgets for each uplink and downlink and combine them. Or, do FSL over up+down 2R, and just multiply by satellite gain/losses as *very crude* approximation.
- Oversimplified! Many ‘right’ ways to handle this for satellites in the link budget calculations.

More detailed worked example

- Transmit Ku-band dish of D=16m, radiating P_T of 100W (or 20dBW) from 200W BUC, at uplink frequency f = 14 GHz, downlink frequency 10 GHz.
- $c = f\lambda$. Assume efficiency of antennas is 0.6.
- G_{TX} = *efficiency* $(\pi D/\lambda)^2$; $\lambda = c/f$

  $= 0.6(16m\ \pi\ 14 \times 10^9 Hz/3 \times 10^8 m/s)^2$

  = 3.301,448.5 = 65.2 dB
- EIRP = $P_{TX}G_{TX}$ = 20 dBW + 65.2 dB = 85.2 dBW

Worked example #2

- Say satellite transponder adds 90 dB power+gain. G_{SAT} = 90 dB.
- 1.8m receive antennas on ground and satellite. 0.6 efficient.
- Power at receiver is $EIRP(G_{SAT}G_{RX})/L_{FS}$

$= EIRP + G_{SAT} + G_{RX} - L_{FS\text{-uplink}} - L_{FS\text{-downlink}}$ all in dB

- G_{RX}= efficiency $(\pi D/\lambda)^2$ $= 0.6(1.8\text{ m } \pi\ 10 \times 10^9\text{Hz}/3 \times 10^8\text{ m/s})^2$

$= 21{,}318.3$

$= 43.3$ dB

$L_{FS} = (4\pi R/\lambda)^2$

$L_{FS\text{-uplink}} = (4\pi 40{,}000{,}000\text{m}/\lambda)^2$

$= (4\pi 40{,}000{,}000\text{m} \times 14 \times 10^9/3 \times 10^8\text{m})^2$ using $\lambda = c/f$

$= 5.5 \times 10^{20}$

$= 207.4$dB $L_{FS\text{-downlink}} = 204.5$ dB the same way

Worked example #3

Power = EIRP+ G_{SAT} + G_{RX} – $L_{FS\text{-}uplink}$ – $L_{FS\text{-}downlink}$ all in dB

Add the G's, subtract the L's. Filling in:

85.2 dBW + 90 dB + 43.3 dB – 207.4dB – 204.5 dB

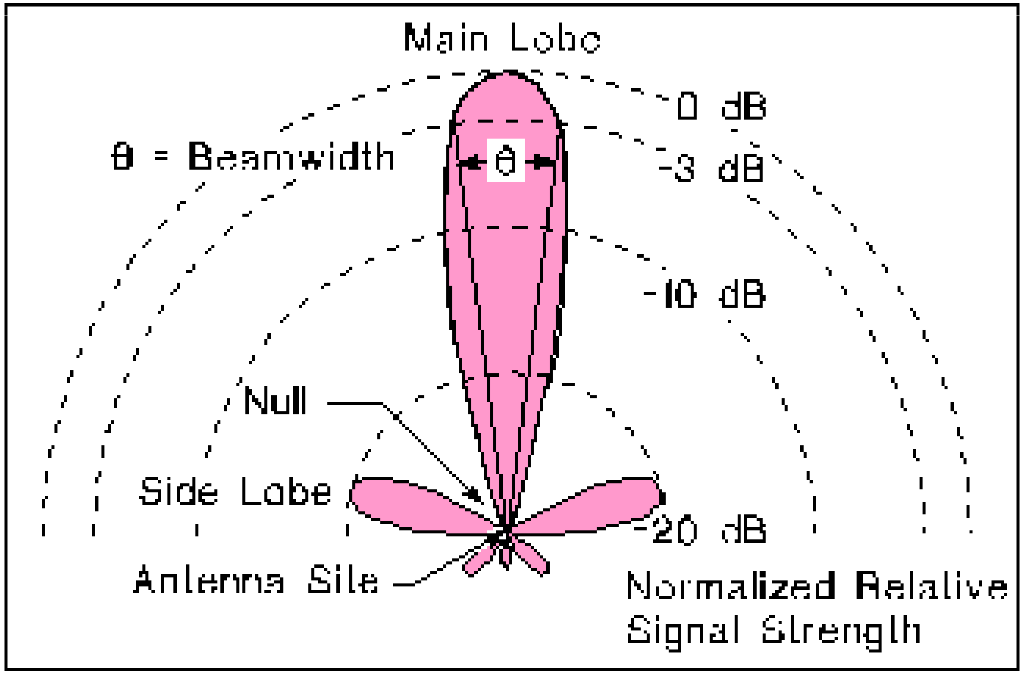
= -193.4 dBW

... or a bit over 200dB less than we started with.

- ~400dB of free space loss to and from the satellite has been compensated for somewhat by gain and power.
- Also two noise temperatures from two receive antennas, on satellite and at earth station, across receive bandwidth, not considered here.
- Need to consider pointing loss, atmospheric slant path loss, rain fade, and many other losses as well.
- But this gives a flavour of how to do much more complex and detailed link budget calculations.

Pointing

- Previous assumed perfect alignment. Power lost in misaligning dishes is function of angle α from centre of beam.
- 3dB (half power) beamwidth $\theta_{3dB} = 70\lambda/D$ degrees
- α_T is offset angle.
- loss $L_p = 12(\alpha_T/\theta_{3dB})^2$
- Subtract this loss



beamwidth

ATIS Telecom Glossary

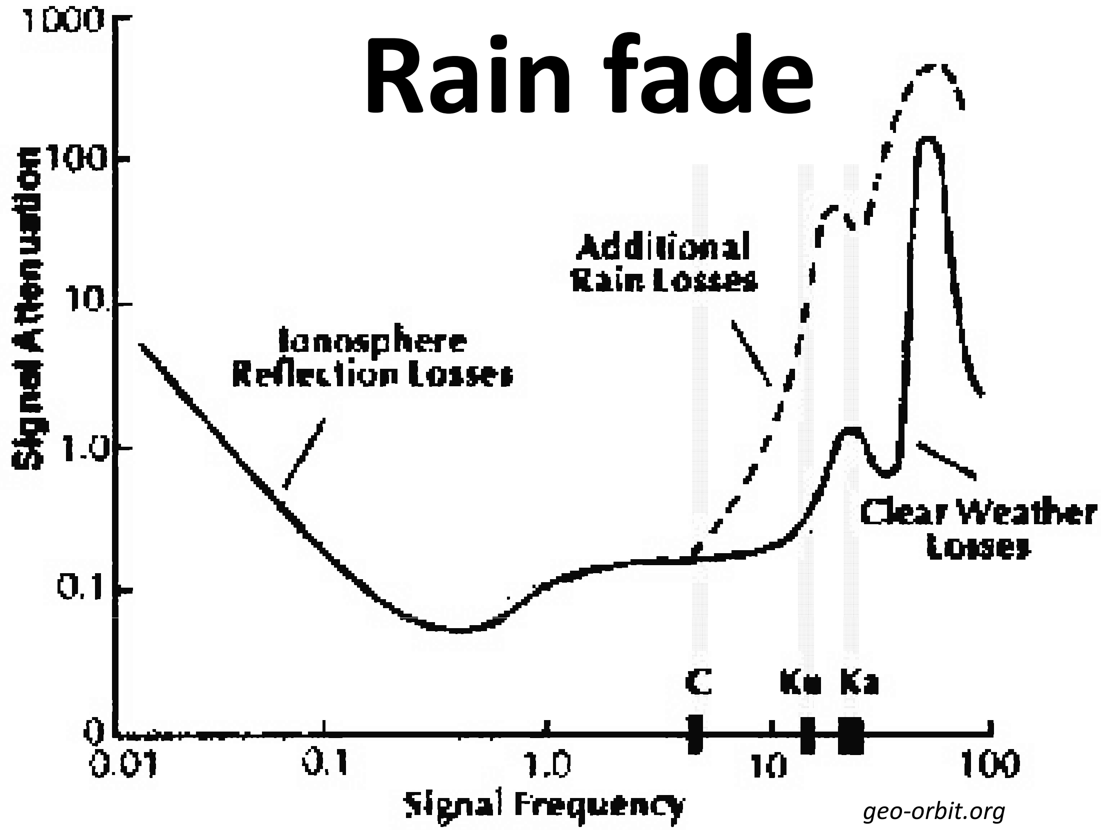
Pointing losses

$$\text{loss } L_p = 12(\alpha_T/\theta_{3dB})^2$$
$$L_p = 12(\alpha_T D/70\lambda)^2$$
$$= 0.00245\ (\alpha_T D/\lambda)^2$$

- Pointing loss is proportional to $(D/\lambda)^2$
- Pointing loss is proportional to area of dish.
- Worse with bigger dishes or at lower frequencies.
- This is why big dishes must track the satellite... their θ_{3dB} angle regions are much narrower.
- Lower-frequency Rx hit (slightly) more than higher Tx.
- Also, if linear polarisation mismatch:

  20 log(cos *angle of rotation*).

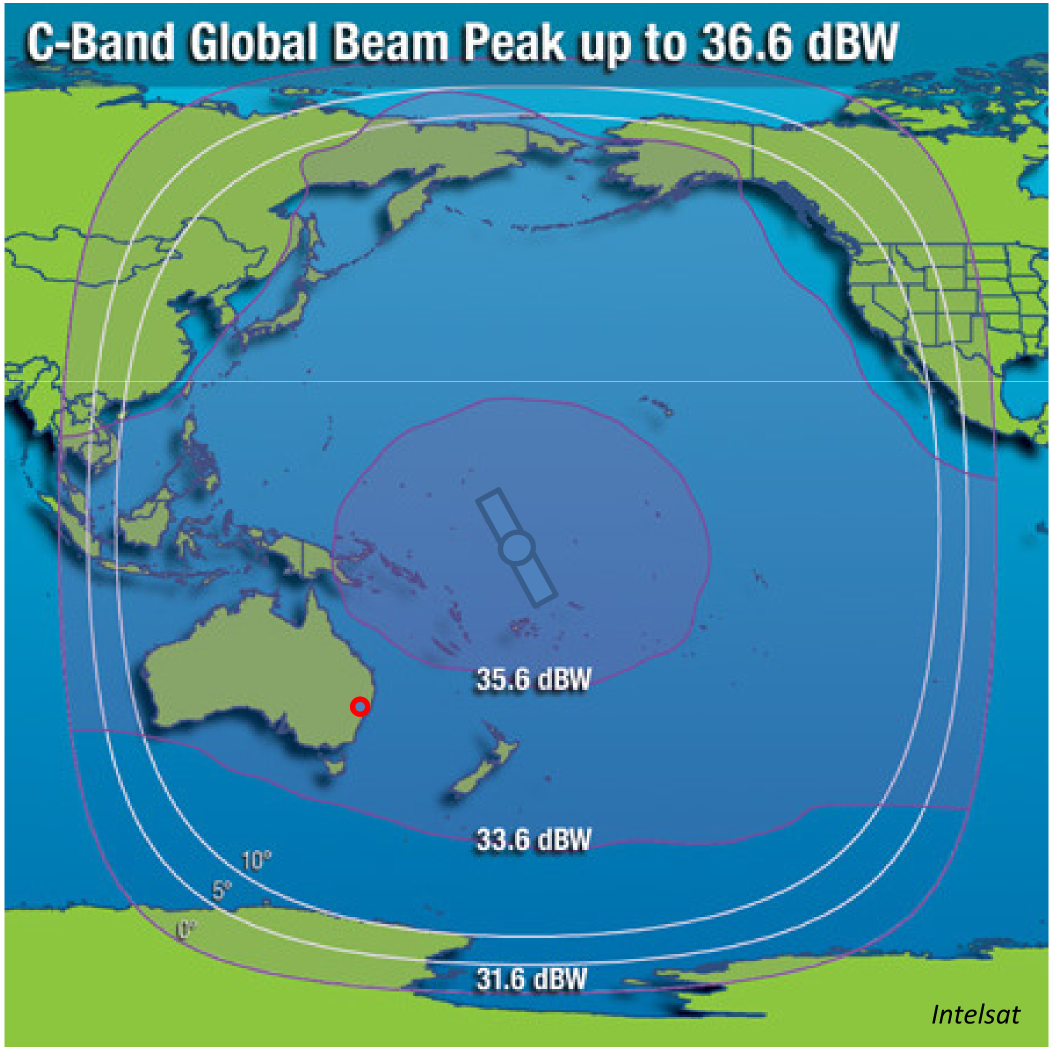
Rain fade



- Frequency dependent, worse at Ku- and Ka-band.
- Greater loss at higher frequencies.
- Receive Rx at site (lower *f* into smaller dish) hit (slightly) less than Tx from site.

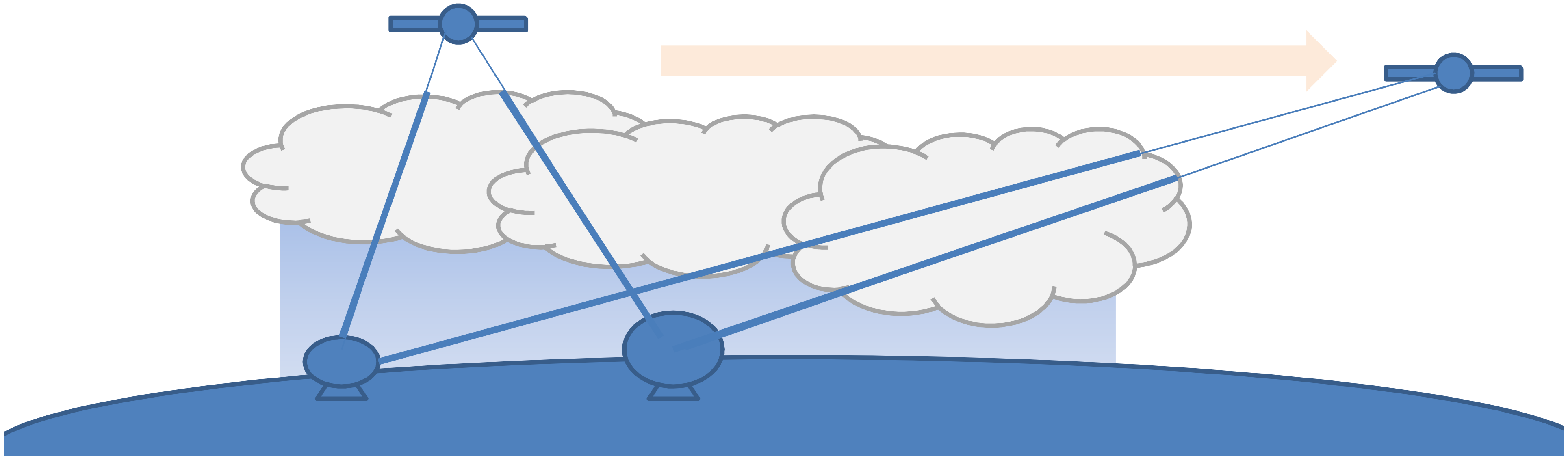
Sydney to IS-18

- Losses close to 3dB each way (half the strength!) from hub in Sydney, not at nadir (directly below).
- add FSL, atmos, offpeak.
- As elevation angle is lower (40 deg) and slant path is longer than a dish at nadir, rain in Sydney can have increased effect.
- On other hand, hub at nadir in Pacific leads to cyclones, connectivity/ maintenance problems...



Elevation angle matters

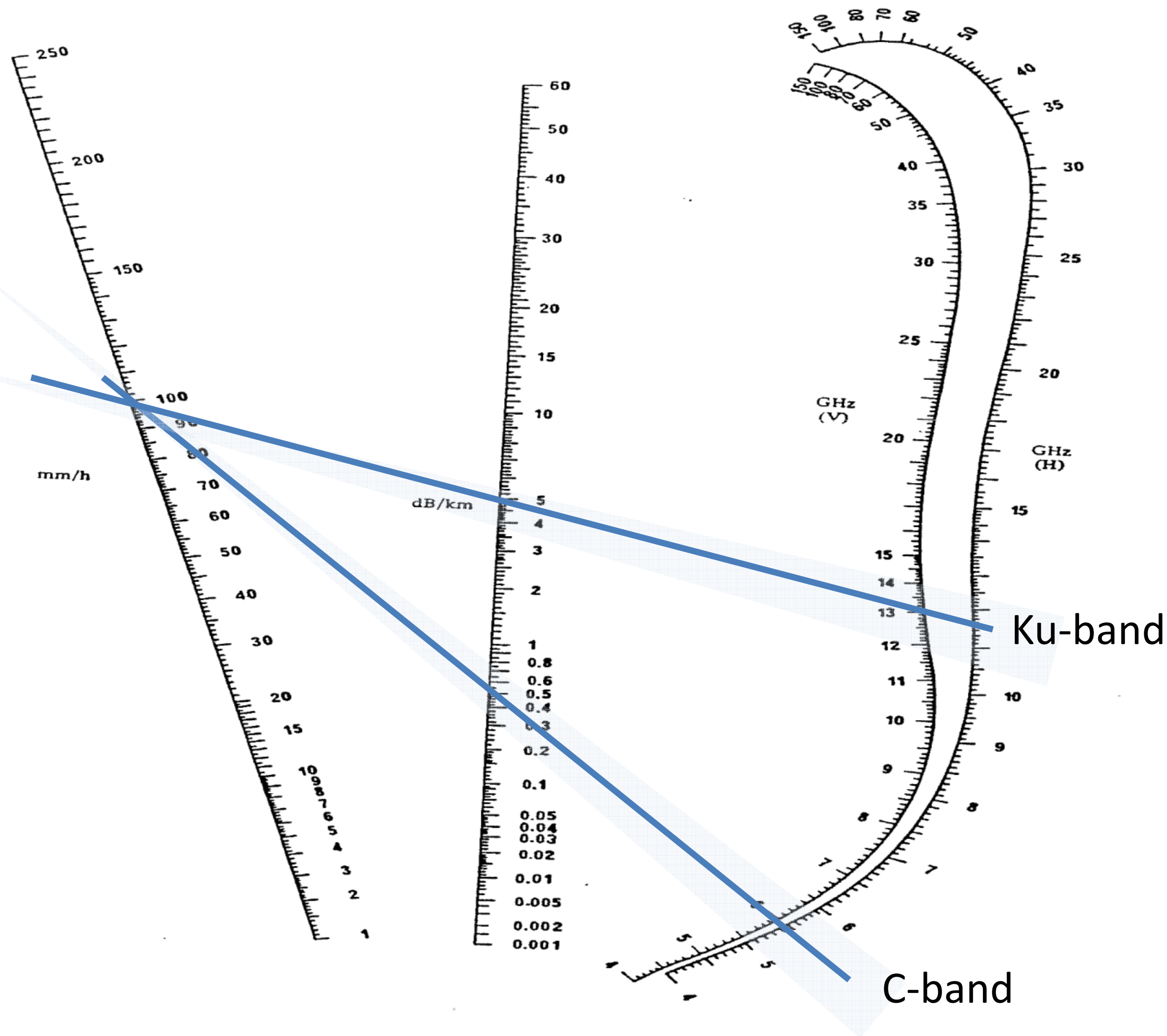
- Rain fade also depends on elevation angle through atmosphere – our satellites are often low on horizon. Low elevation angle means long slant path through rain and high attenuation, so rain has more of an effect than you might expect.



Fun with nomograms

Example demonstrates non-linear relationship.

Same rate of rain leads to very different dB/km attenuation at different frequencies. Then multiply by slant distance.



ITU CCIR report 721

Compensating for rain fade

- **Expensive:** Adaptive coding and modulation (ACM). Allows individual terminals experiencing rain fade to adjust their rates by changing outbound and reporting signal quality to the hub to adjust rate back.
- **Cheaper:** uplink power control. Just boost signal from the hub based on measured strength of satellite beacon. Useful when raining at the hub as it benefits all receivers, but less useful when rain at just a few remote sites.
- **Cheapest?** Get operators to change modcod manually. (Actually opportunity cost: they could be doing something else, service suffers during time to react. Capex *vs* opex.)

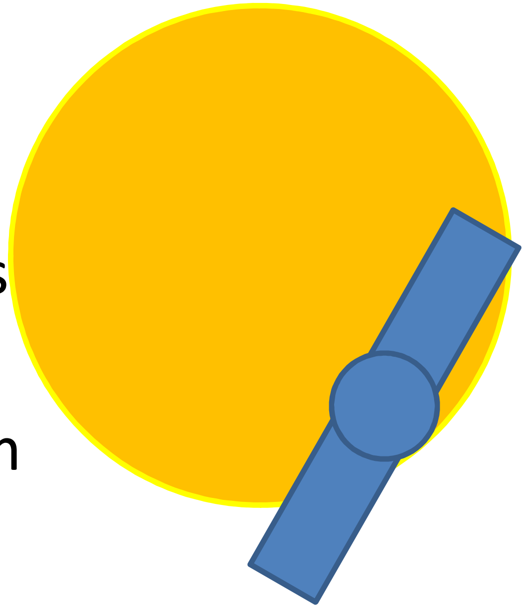
Rain fade: Ku- and C-band

- **High Ku-band rain attenuation** demands ACM; frequent changes, large losses span several modcod jumps, operators can’t keep up.
- ACM not always sufficient, outage protection not guaranteed. Improving coding (e.g. introducing LDPC low density parity check coding) improves efficiency and margins, which helps decrease outages.
- 7-9 dB margin at Ku-band, due to higher rain fade
- **C-band rarely needs ACM.** Rain loss not often close to dB change from a single modcod jump, so if margin was set right, it should be greater than any loss and service remains unaffected.
- Typically 3dB margin at C-band.

Other effects related to rain fade

- Could place hub in desert to avoid rain fade. But sandstorms still cause loss with slant path.
- High-altitude ice crystals – cross-pol effects.
- Faraday effect: ionosphere rotates signals, affecting linear polarisations.
- Refraction: variation in atmospheric layers and refraction at boundaries leads to scintillation, varies with temperature. (Also why stars flicker.)
- Ground multipath effects – caused by buildings, low elevation angles. Signal reflects, but takes slightly longer to get there than straight path, so is slightly delayed. Self-interference, basically.

Sun outages



- Satellite is a point source. Sun is much bigger, stronger, noisier.
- At equinoxes (20 March/22 September), Sun's path takes it around equator.
- Sun appears behind satellite as viewed from Earth station dish as Earth rotates.
- Once a day behind the satellite from the hub. Once a day for each remote dish.
- Smaller dishes see more of the sky, so sun only has to be *near* satellite. Longer outage period per day, outages over more days.
- Some modems have trouble recovering lock afterwards. How good would you feel after ten minutes staring into the sun?


International Space Station
transit of the Sun
geostationary satellites are smaller and
farther away than ISS – point sources.
Thierry Legault


YES!
IN FACT, THIS IS ROCKET SCIENCE
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Thankyou!