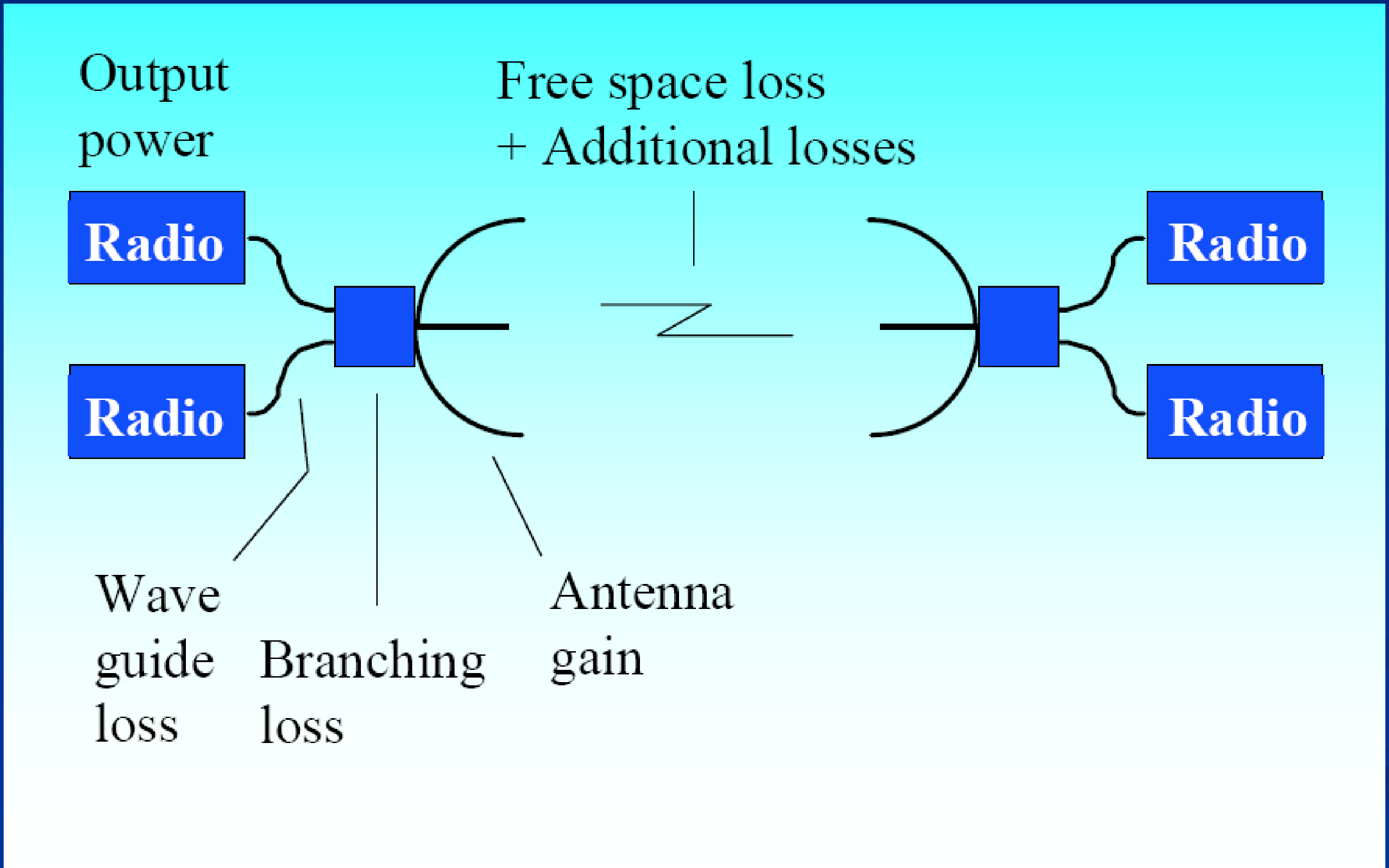
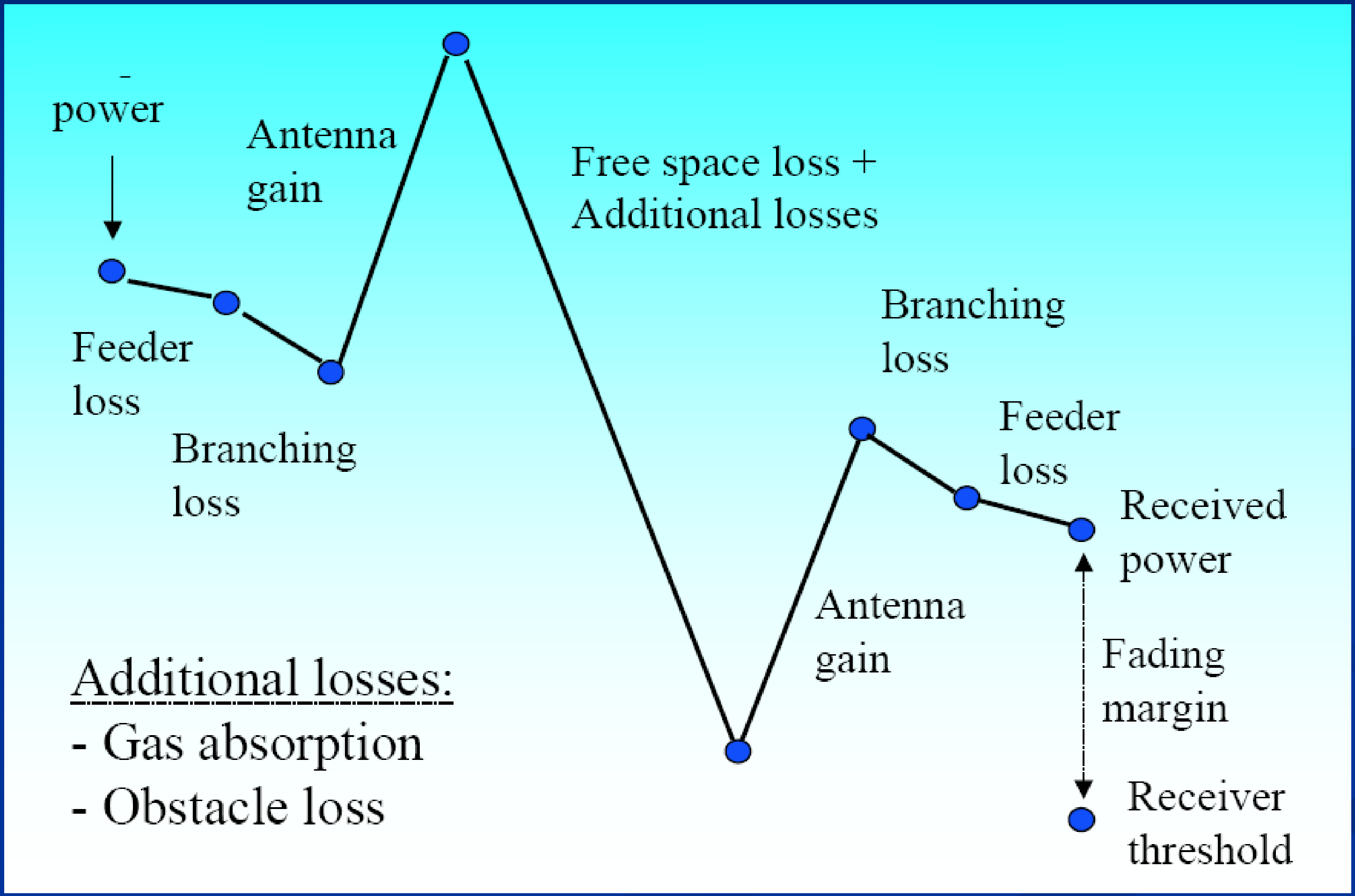
Microwave Link Theory

General Configuration



Link Budget



-
power
Antenna
gain
Free space loss +
Additional losses
Feeder
loss
Branching
loss
Branching
loss
Feeder
loss
Received
power
Antenna
gain
Fading
margin
Receiver
threshold
Additional losses:
- Gas absorption
- Obstacle loss

Fading Margin

- **Fading margin:**

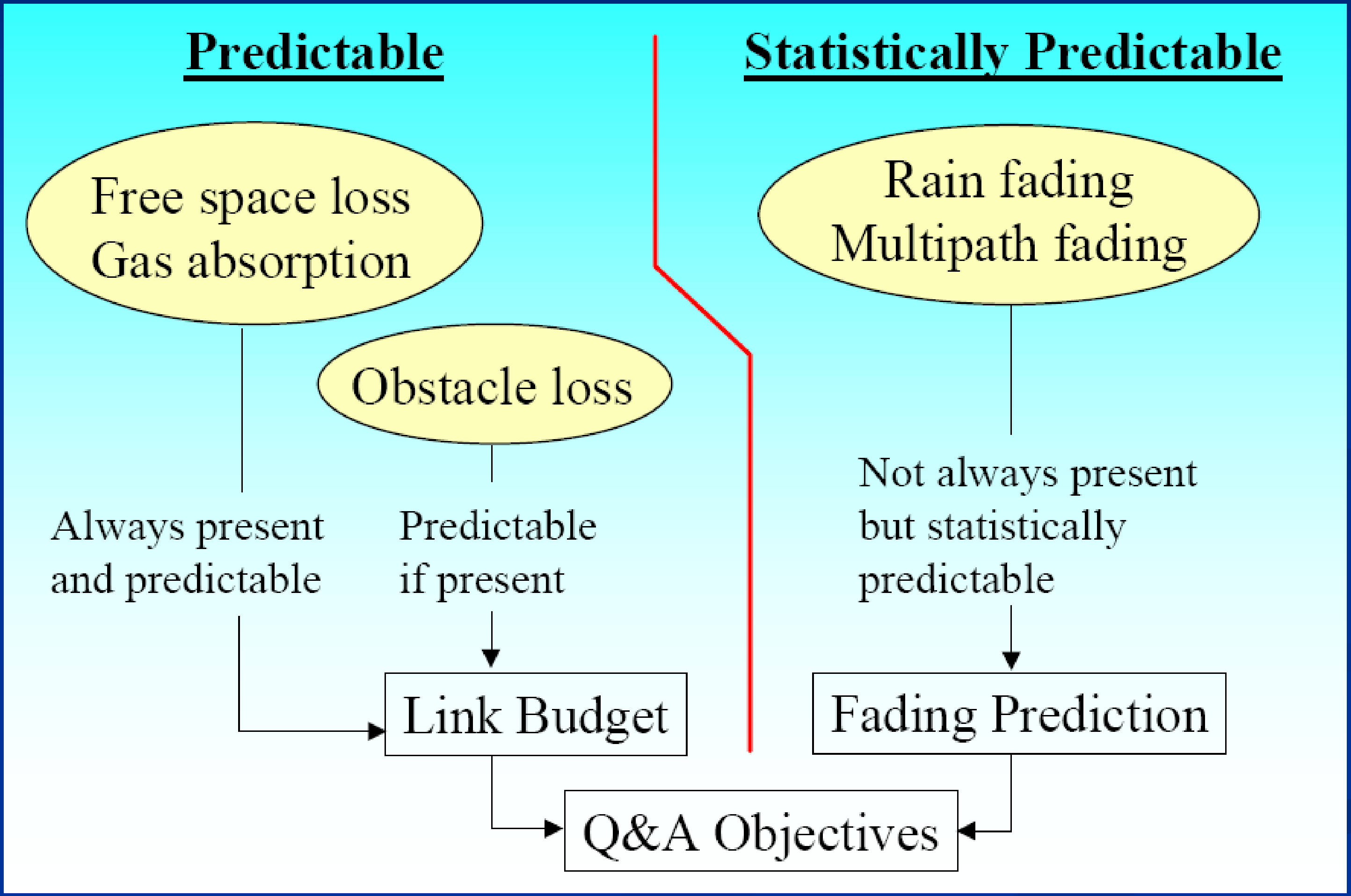
"Safety" margin. Should be large enough to guarantee that quality and availability objectives are met during fading conditions.

Typical value ~ 40 dB

Fading

- Fading
  - Multipath fading
    - Flat fading
    - Frequency selective fading
  - Rain fading

Hop Calculations



Free Space Loss

$$Afs = 92.4 + 20 \log d + 20 \log f$$

d: distance [km]

f: frequency [GHz]

Link Budget, Exercise

1) Calculate the fading margin for a 7 km MINI-LINK 15-E hop with 4x2 Mbit/s capacity, standard output power and 0.6 m antenna.
2) Calculate the fading margin for a 7 km MINI-LINK 15-E hop with 4x2 Mbit/s capacity, high output power and 1.2 m antenna.
3) Calculate the fading margin for a 5 km MINI-LINK 23-E hop with 2x8 Mbit/s capacity and 0.3 m antenna. Assume a feeder loss of 0.5 dB and no branching loss.

Link Budget, Exercise

$L_{rx}=L_{tx}+ 2G_{ant} -2A_{feeder}-A_{fs}$

$M=L_{rx}-L_{tresh}$

Link Budget, Exercise

1) Standard output power = *Ltx* = 18 dBm

Rec. threshold 10-3 = *Lthresh* = -87 dBm

Rec. threshold 10-6 = *Lthresh* = -83 dBm

Antenna gain = *Gant* = 36 dBi

L_{rx}=18+2*36-(92.4+20 log15+20 log7)=-43.8dBm

$M(10^{-3})=L_{rx}-L_{tresh}=-43.8-(-87)=43.2dB$

$M(10^{-6})=L_{rx}-L_{tresh}=-43.8-(-83)=39.2dB$

Link Budget, Exercise

2) High output power = *Ltx* = 25 dBm

Rec. threshold 10-3 = *Lthresh* = -87 dBm

Rec. threshold 10-6 = *Lthresh* = -83 dBm

Antenna gain = *Gant* = 42 dBi

$M(10^{-3})=L_{rx}-L_{tresh}=-24.8-(-87)=62.2dB$

$M(10^{-6})=L_{rx}-L_{tresh}=-24.8-(-83)=58.2dB$

Link Budget, Exercise

3)Standard output power = *Ltx* = 20 dBm

Rec. threshold 10-3 = *Lthresh* = -83 dBm

Rec. threshold 10-6 = *Lthresh* = -79 dBm

Antenna gain = *Gant* = 35 dBi

$M(10^{-3})=L_{rx}-L_{tresh}=-44.6-(-83)=38.4dB$

$M(10^{-6})=L_{rx}-L_{tresh}=-44.6-(-79)=34.4dB$

Gas Absorption

Gas Absorption

- Oxygen
- Water vapour

Should be considered for f > 10 GHz.

$$A_{gas} = \gamma_{gas} . d$$

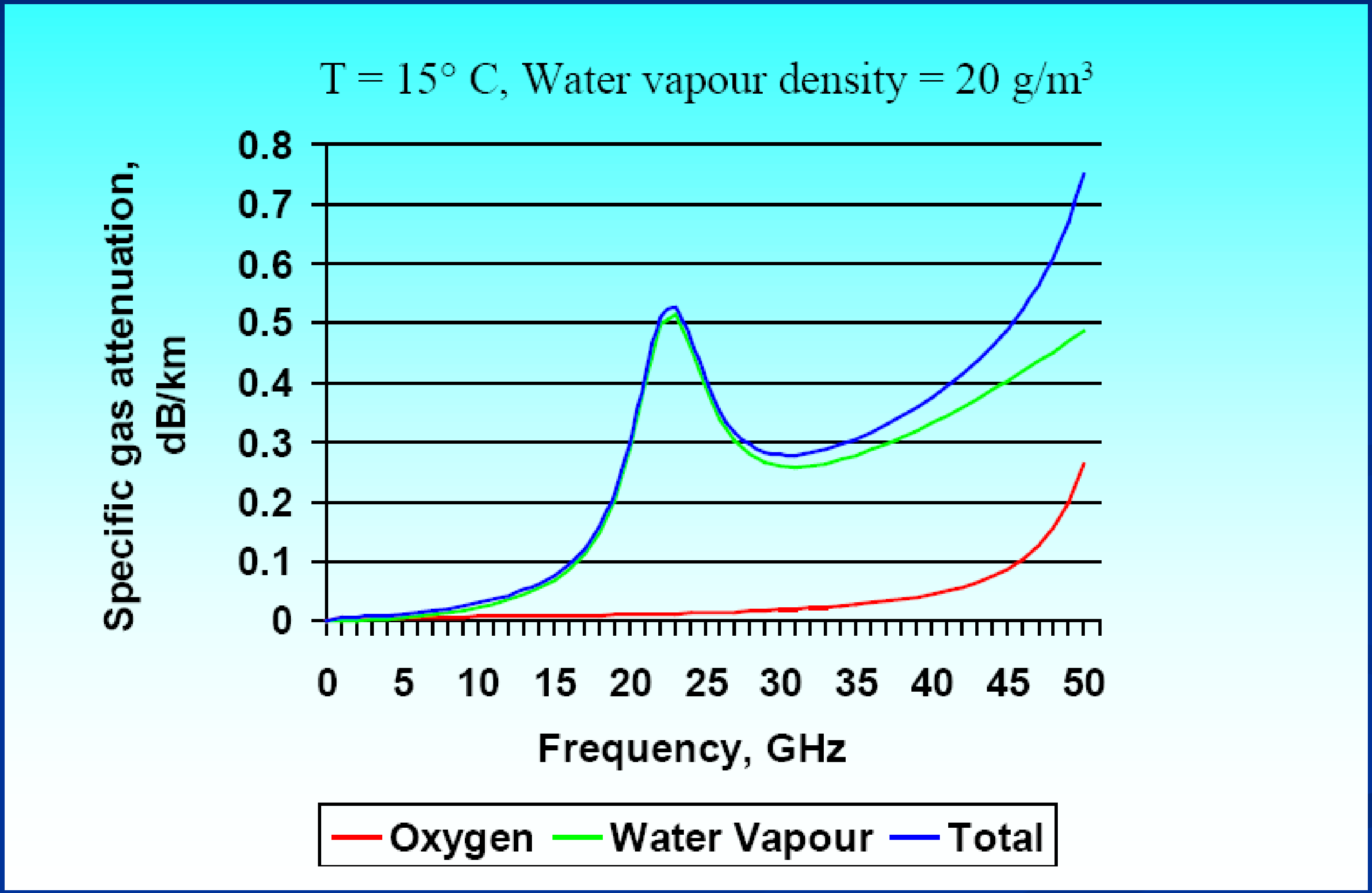
$\gamma_{air:}$: Specific attenuation for dry air [dB/km]

Where

$$\gamma_{gas} = \gamma_{air} + \gamma_{w}$$

$\gamma_{w:}$: Specific attenuation for water vapour [dB/km]

Gas Absorption, contd.

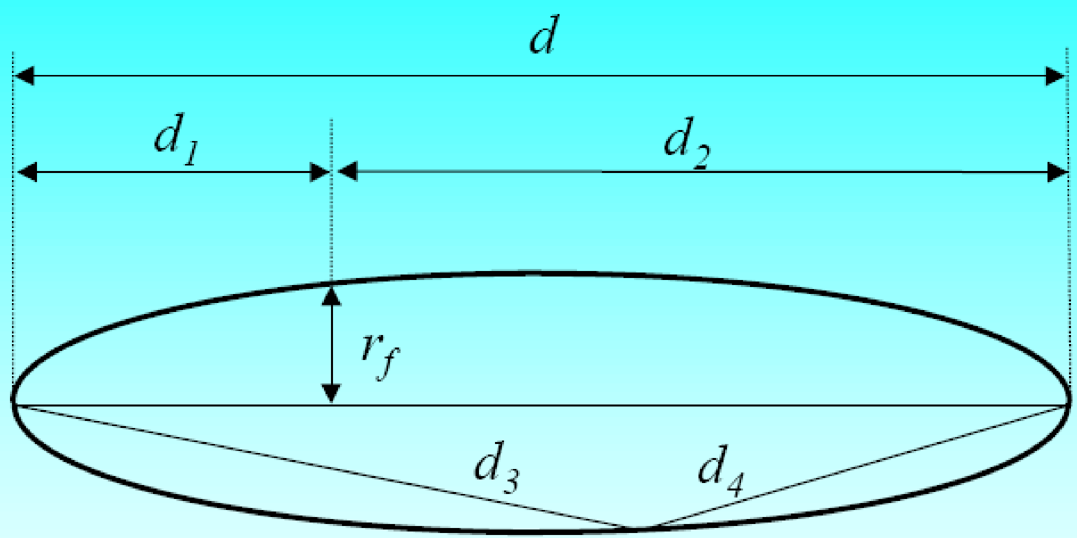


The Fresnel Zone

- The radiated power is distributed in a zone surrounding the direct line-of-sight.

The Fresnel Zone

The Fresnel Zone, contd.



Def:

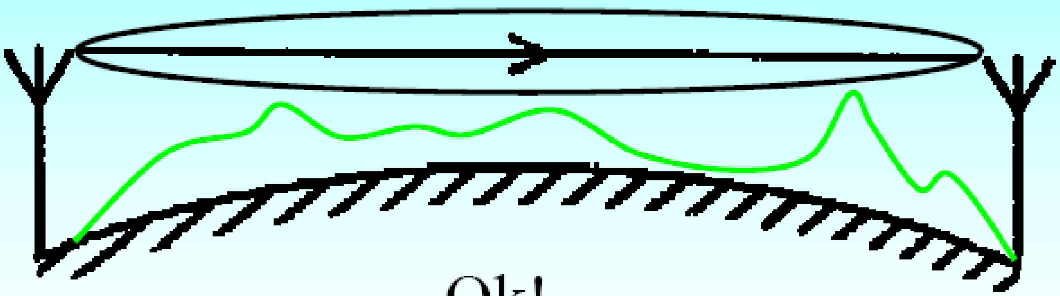
$$d_3 + d_4 - d = \lambda / 2 \qquad r_f = 17.3\sqrt{\frac{d_1 \cdot d_2}{f \cdot d}}$$

d [km], r_f [m], f [GHz]

The Fresnel Zone, contd.

<u>Design objective:</u>

Full clearance of the Fresnel zone.



Ok!

The Fresnel Zone, Exercise

f = 15 GHz

k = 4/3

d = 10 km

f = 15 GHz

k = 4/3

d = 20 km

Calculate the Fresnel zone radius at mid path.

The Fresnel Zone, Exercise

10 km:

$r=17.3\sqrt{(5*5/15.10)}=7$ m

20 km:

$r=17.3\sqrt{(10*10/15.20)}=10$ m

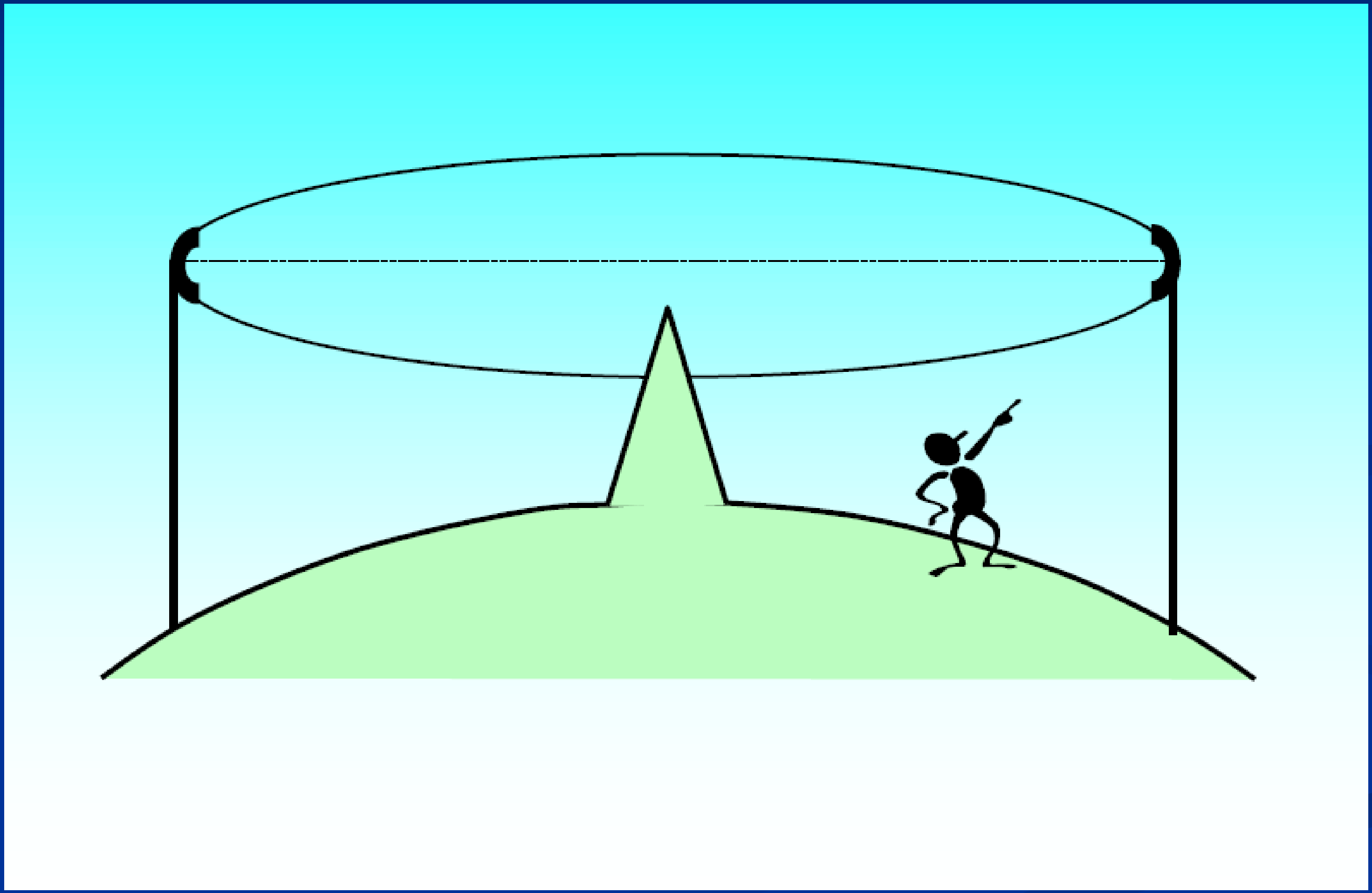
Obstacle Loss

Obstacle loss

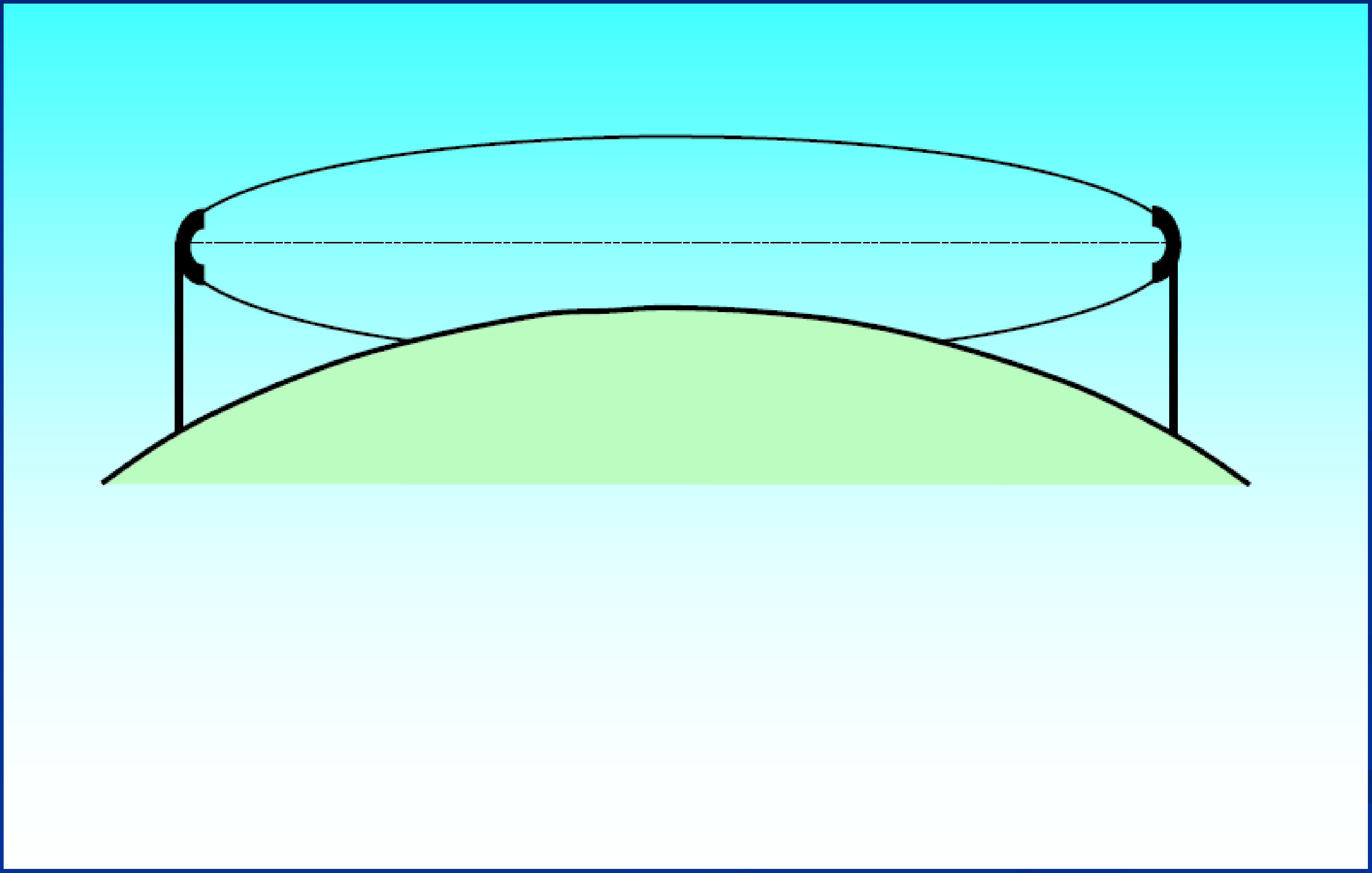
Knife edge obstacle loss

Smooth spherical earth obstacle loss

Knife Edge Obstacles



Smooth Spherical Earth Obstacles

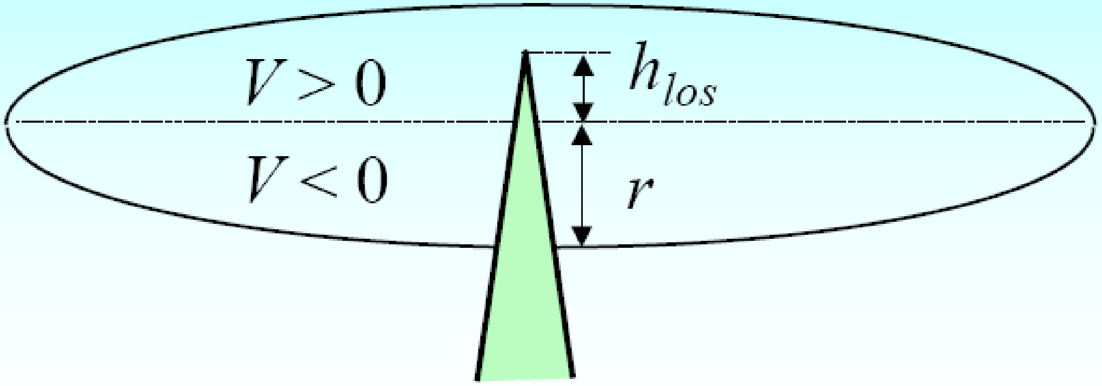


Knife Edge Loss

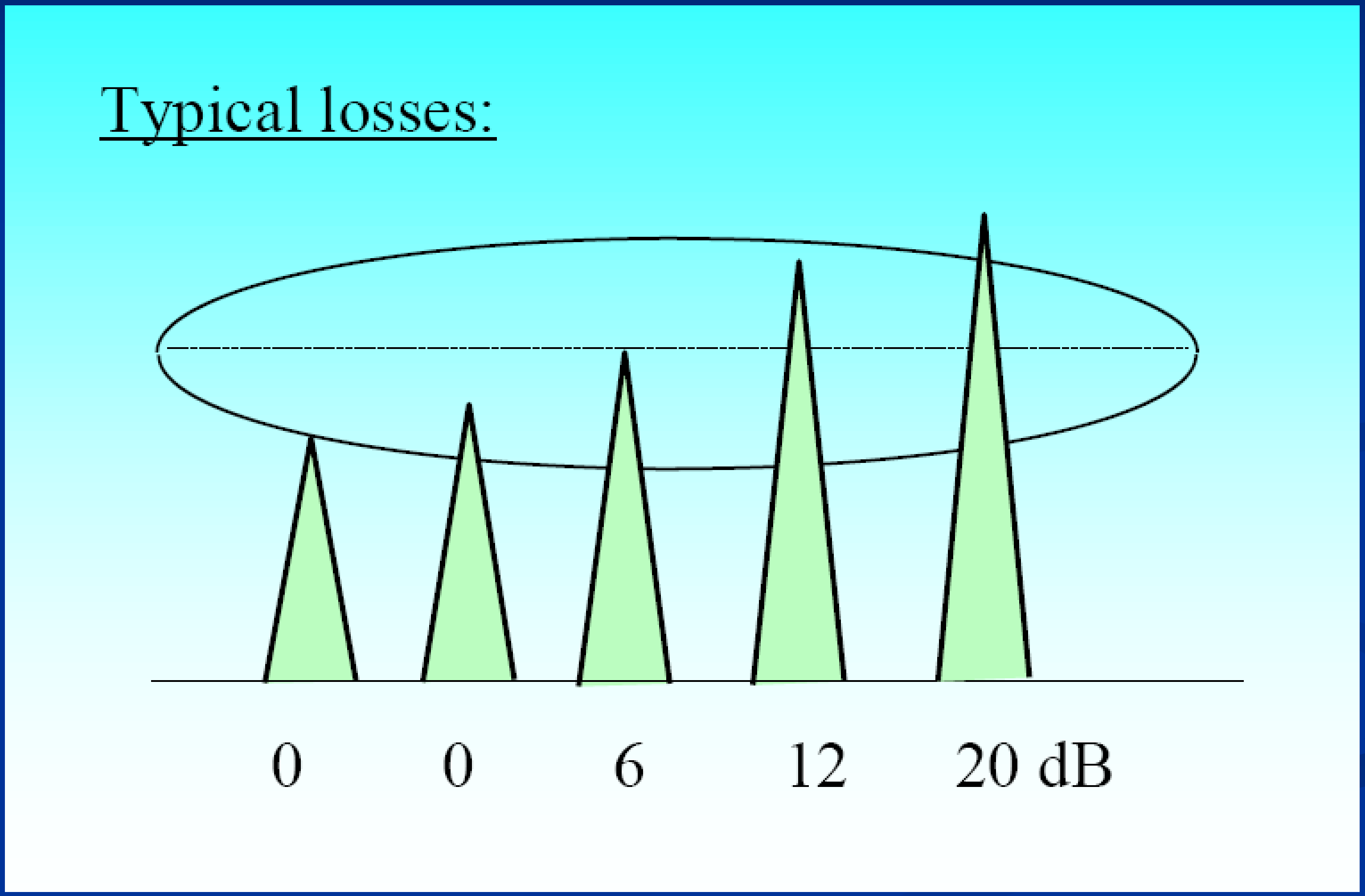
From curve or approximate formula:

$$A_{obst} \approx 6.4 - 20\log(v\sqrt{2} + \sqrt{1 + 2v^2})$$

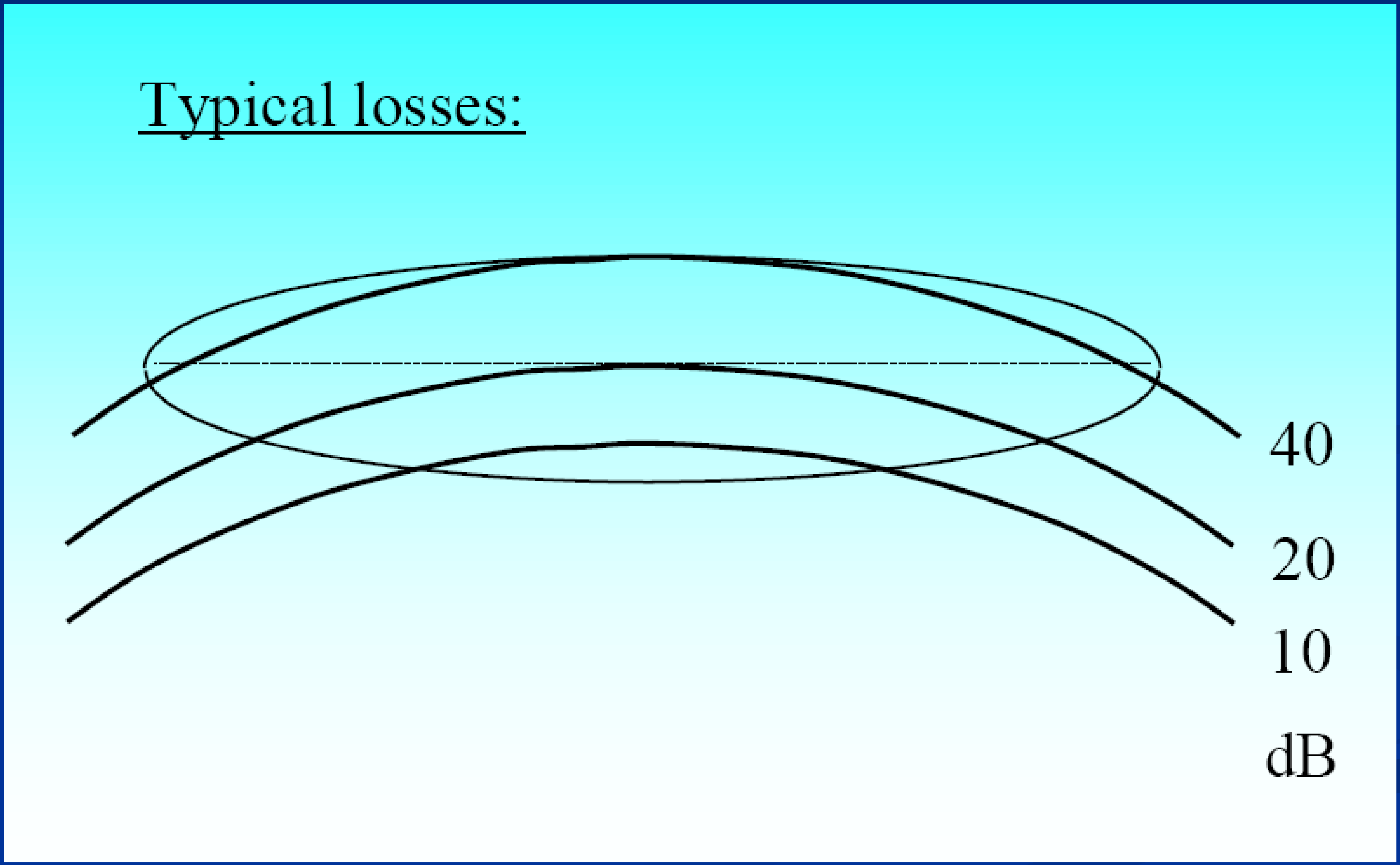
$$v = \frac{h_{los}}{r}$$



Knife Edge Loss

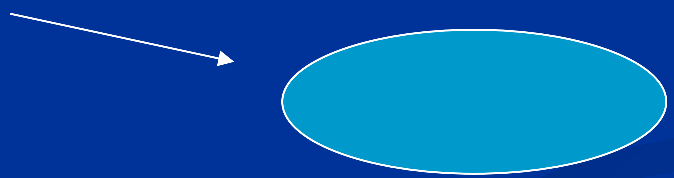


Smooth Spherical Earth Loss



Rain Attenuation

Two types of attenuating mechanisms:
absorption and scattering caused by the rain drops.



Horizontally polarized waves are attenuated more than vertically polarized waves.

Rain Attenuation, contd.

Rain intensity [mm/h].

- For the calculations the cumulative distribution of rain intensity, i.e. the percentage of time during which a given rain intensity is exceeded, is interesting.
- ITU-R presents the cumulative distribution of rain intensity for 15 different rain zones on earth
- The reference level is the rain intensity that is exceeded 0.01% of all time (R0.01).

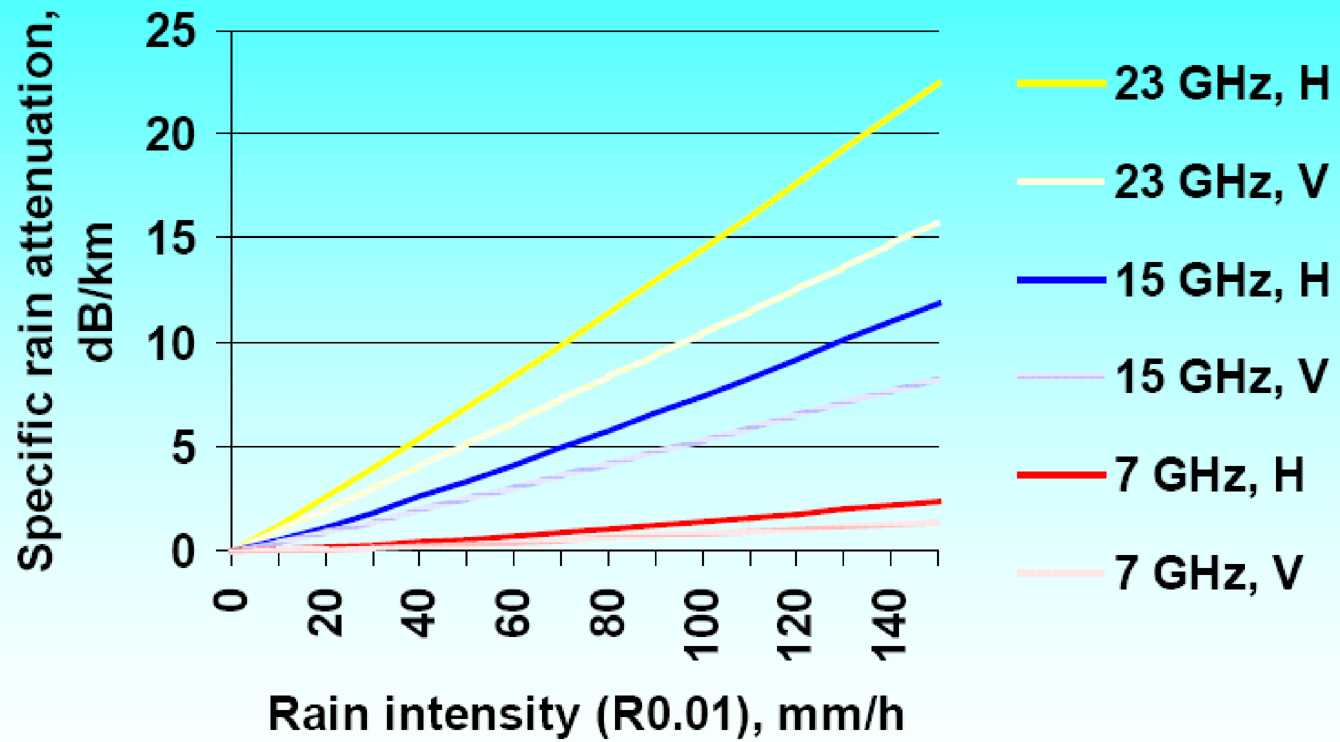
Rain Attenuation, contd.

$$A_R = \gamma_R \cdot d_{eff}$$

γ_R : Specific rain attenuation [dB/km]

d_{eff} : Effective path length, km

Rain Attenuation, contd.



H/V: Horizontal/Vertical polarisation

Rain Fading

The probability that a given fade margin is exceeded, on an annual basis:

$$P_{rain} = 10^{11.628\left[-0546+\sqrt{0.29812+0.172\cdot\log(0.122\cdot\frac{A_{R0.01}}{M})}\right]}$$

$A_{R0.01}$:The rain attenuation exceeded 0.01 % of the time

M: Fade Margin

Rain Fading, contd.

Conversion between yearly values and worst month values:

$$P_{month}=2.85\ .P_{year}^{0.87}$$

$$P_{year}=0.3\ .P_{month}^{1.15}$$

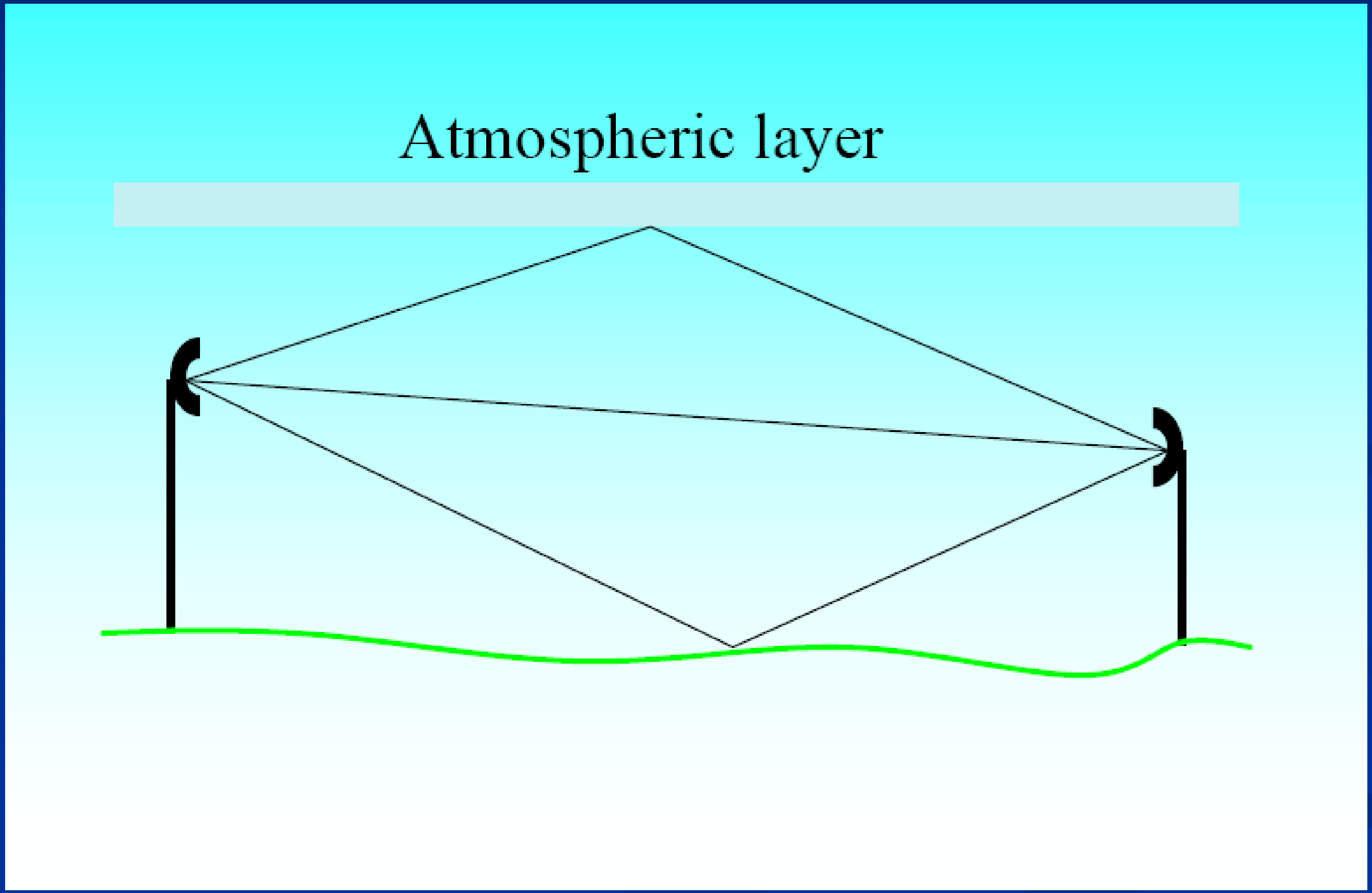
Formulas based on climatic constants.

Multipath Fading

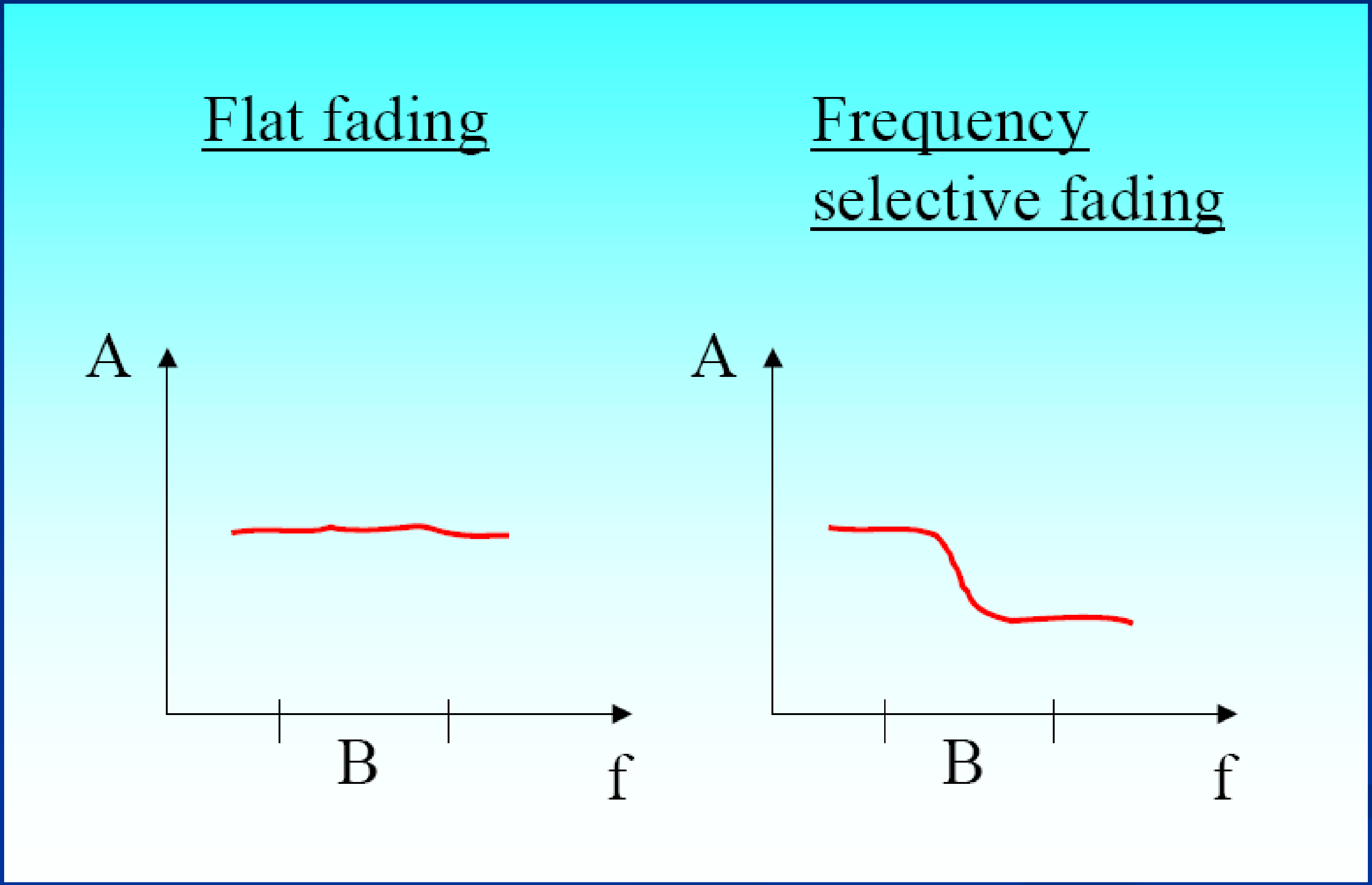
Multipath fading

- Flat fading
- Frequency selective fading

Multipath Fading, contd.



Multipath Fading, contd.



Flat Fading

The probability that a given fade margin is exceeded, on a worst month basis:

$$P_{flat} = K\, d^{3.6}\, f^{0.89}\, (1+\varepsilon)^{-1.4}\, 10^{(-M/10)}$$

d: Path length [km]

f: Frequency [GHz]

ε: Path slope [mrad]

M: Fade margin [dB]

K: Geoclimatic factor

Frequency Selective Fading

- The prediction of frequency selective fading is very difficult and there exists many different prediction models.

$$P_{sel} = \frac{4.3 \cdot \eta \cdot W \cdot 10^{\frac{B}{20}} \cdot \tau_m^2}{\tau_r}$$

Frequency Selective Fading, contd.

η :Probability of the occurrence of mp fading

W :Signature width [GHz] Equipment dependent

B :Signature depth [dB] Equipment dependent

τ_m : Mean value of the echo delay

τ_r :The time delay used during measurements

of the signature curves (reference delay)

[ns]. Normally 6.3 ns.

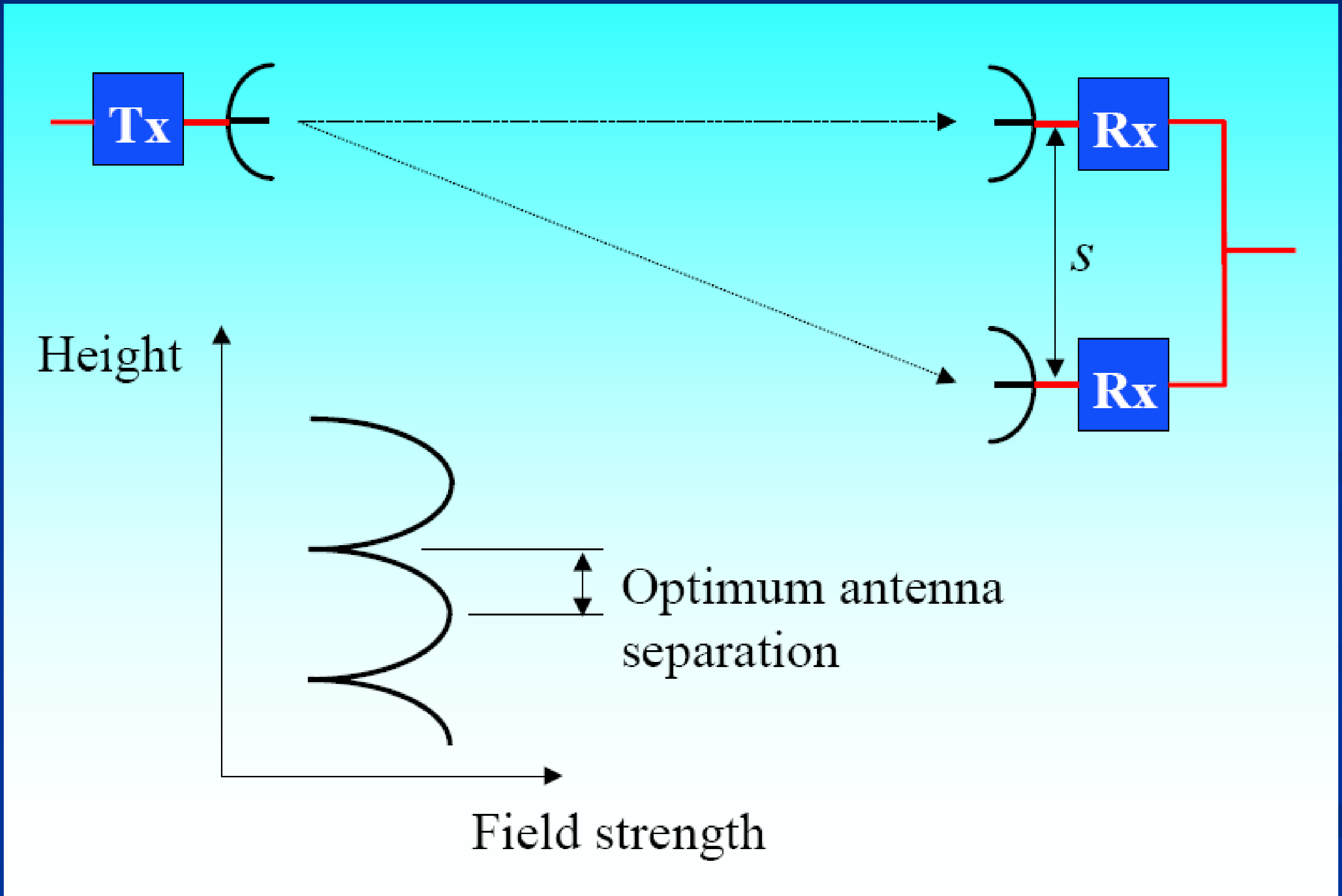
Diversity

Primarily used to reduce the effects of Multipath fading.

Diversity:

- Space Diversity
- Frequency Diversity (requires more bandwidth)

Space Diversity



Space Diversity Improvement

$$P_{mp_{div}} = \frac{P_{mp}}{I} = \frac{P_{flat} + P_{sel}}{I}$$

$$I = \left[1 - e^{\left(-3.34 \cdot 10^{-4} \cdot s^{0.87} \cdot f^{-0.12} \cdot d^{0.48} \cdot \frac{P_0}{100}^{-1.04}\right)}\right] \cdot 10^{\frac{M - |\Delta G|}{10}}$$

s	Vertical separation between antennas [m]
f	Frequency [GHz]
d	Path length [km]
M	Fade margin [dB]
ΔG	The difference in antenna gain between the two antennas [dB]

P_0 from the formula for flat fading

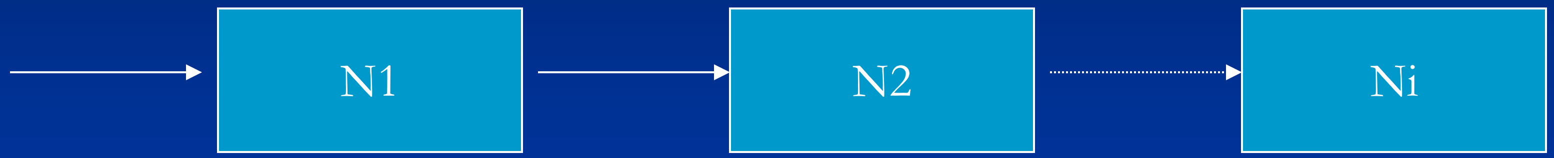
Hardware Unavailability

- Unavailability of one equipment module

$$N1 = MTTR/(MTBF + MTTR)$$

$$\approx MTTR/MTBF$$

Hardware Unavailability, contd.

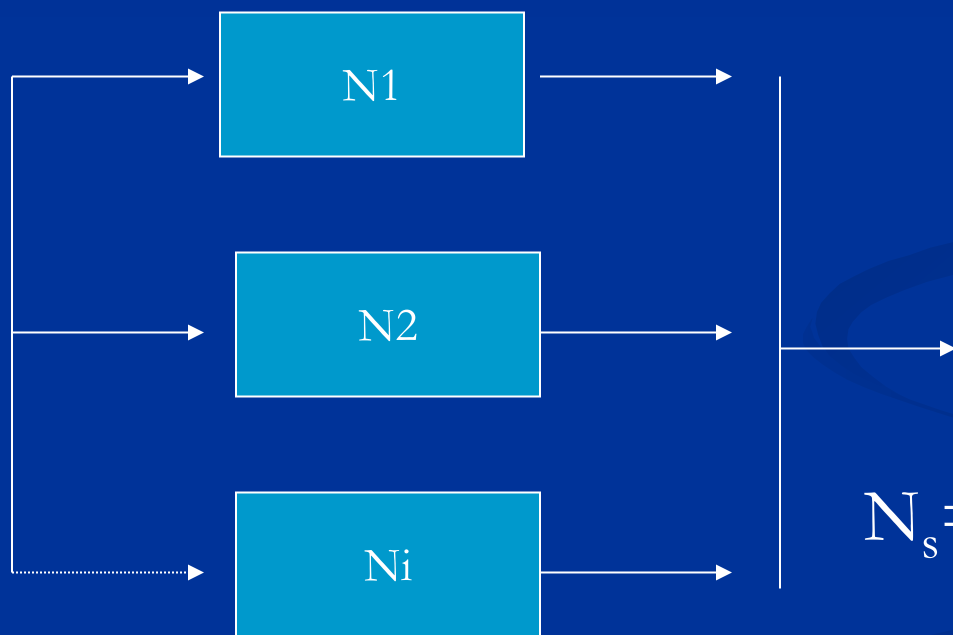


Unavailability of cascaded modules

$$N_s = N1 + N2 + .. + Ni$$

Unavailability, contd.

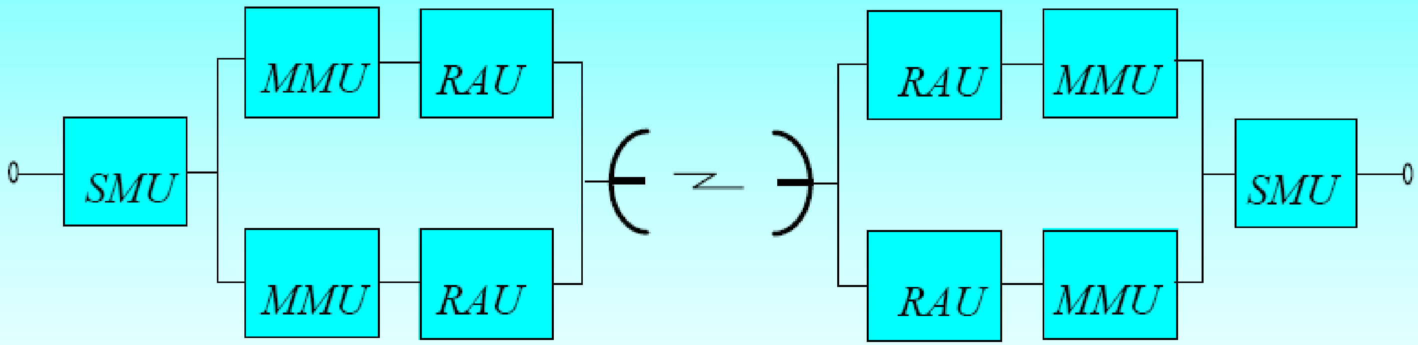
Unavailability of parallel modules



$N_s = N1 x N2 x..x Ni$

Hardware Unavailability

MINI-LINK 1+1 system:



$$N_s = 2 \cdot \left[N_{SMU} + (N_{MMU} + N_{RAU})^2 \right]$$

Quality and Availability Objectives

- **Unavailable time (UAT)**

A period of unavailable time begins when one or both of the following conditions occur for 10 consecutive seconds:

1. The digital signal is interrupted,

2. The bit error ratio in each second of the 10 consecutive seconds are worse than 1.10-3. These 10 seconds are considered to be unavailable time.

- **Available Time (AT)**

A period of available time begins with the first second of a period of 10 consecutive seconds of which each second has a bit error ratio (BER) better than 1.10-3.

Q & A Objectives, contd.

- **Errored Second (ES)**

Any second containing one or more errors.

- **Severely Errored Second (SES)**

An errored second with a bit error ratio (BER) worse than 1.10-3.

- **Degraded Minutes (DM)**

Obtained by subtracting severely errored seconds from the available time and collecting the remaining seconds into groups of 60 seconds. Any group with a bit error ratio worse than 1.10-6 is considered a degraded minute.