- **ITU-R Rec. P618-8 gives the following expression for the atmospheric noise temperature as seen by the receiving antenna:**

$$T_{atm} = T_m \left(1 - 10^{-L_{atm}/10}\right)$$

T_m is the effective temperature (K) of the atmosphere, a common value is 275 K

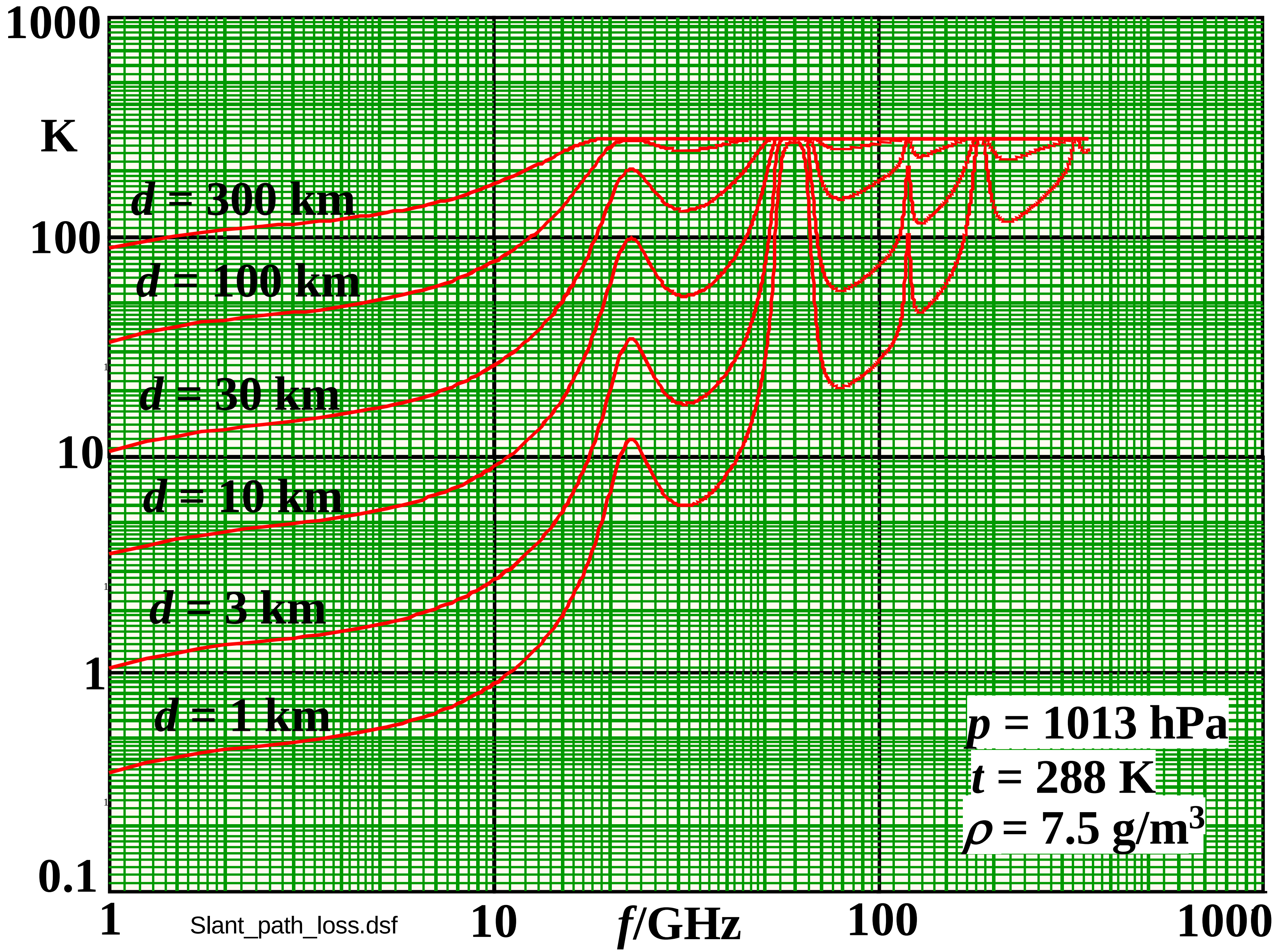
Based on the atmospheric loss calculated with the algorithms in ITU-R Rec. P676, the above noise temperature equation gives results for:

- **Atmospheric noise temperature as function of frequency of terrestrial paths of different lengths**
- **Atmospheric noise temperature as function of frequency of slant paths with different elevation angles**

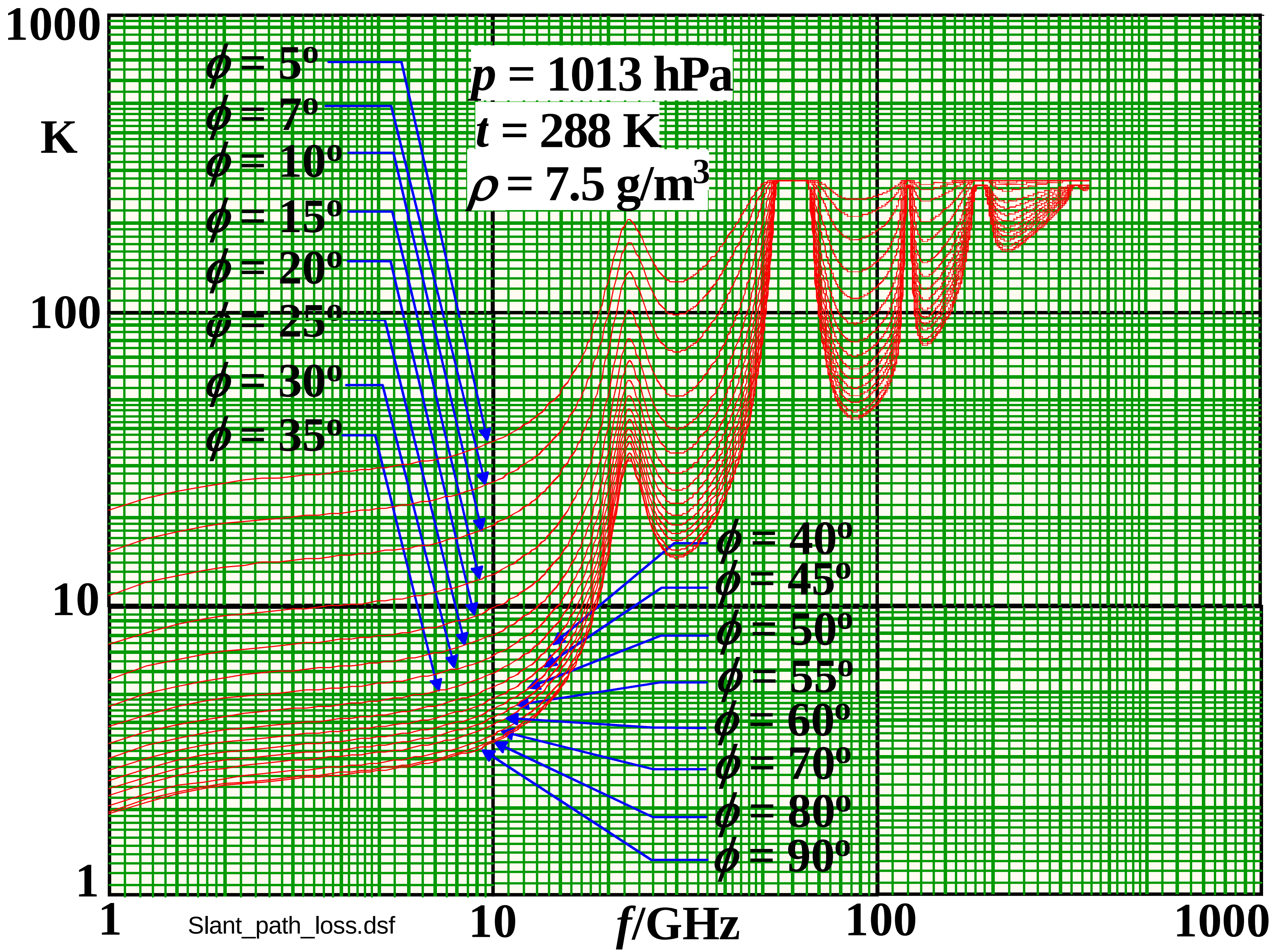
Observations:

- **The figures show that for terrestrial path up to 30 km length the noise temperature is quite low (< 10 K) for frequencies less than 10 GHz.**
- **The same is true for slant paths with elevation angles less than 10 degrees-**
- **At the absorption peaks at 60, 119.75, 183.3, and 325.2 GHz the noise temperature approaches the effective physical temperature.**

Atmospheric noise temperature on terrestrial paths

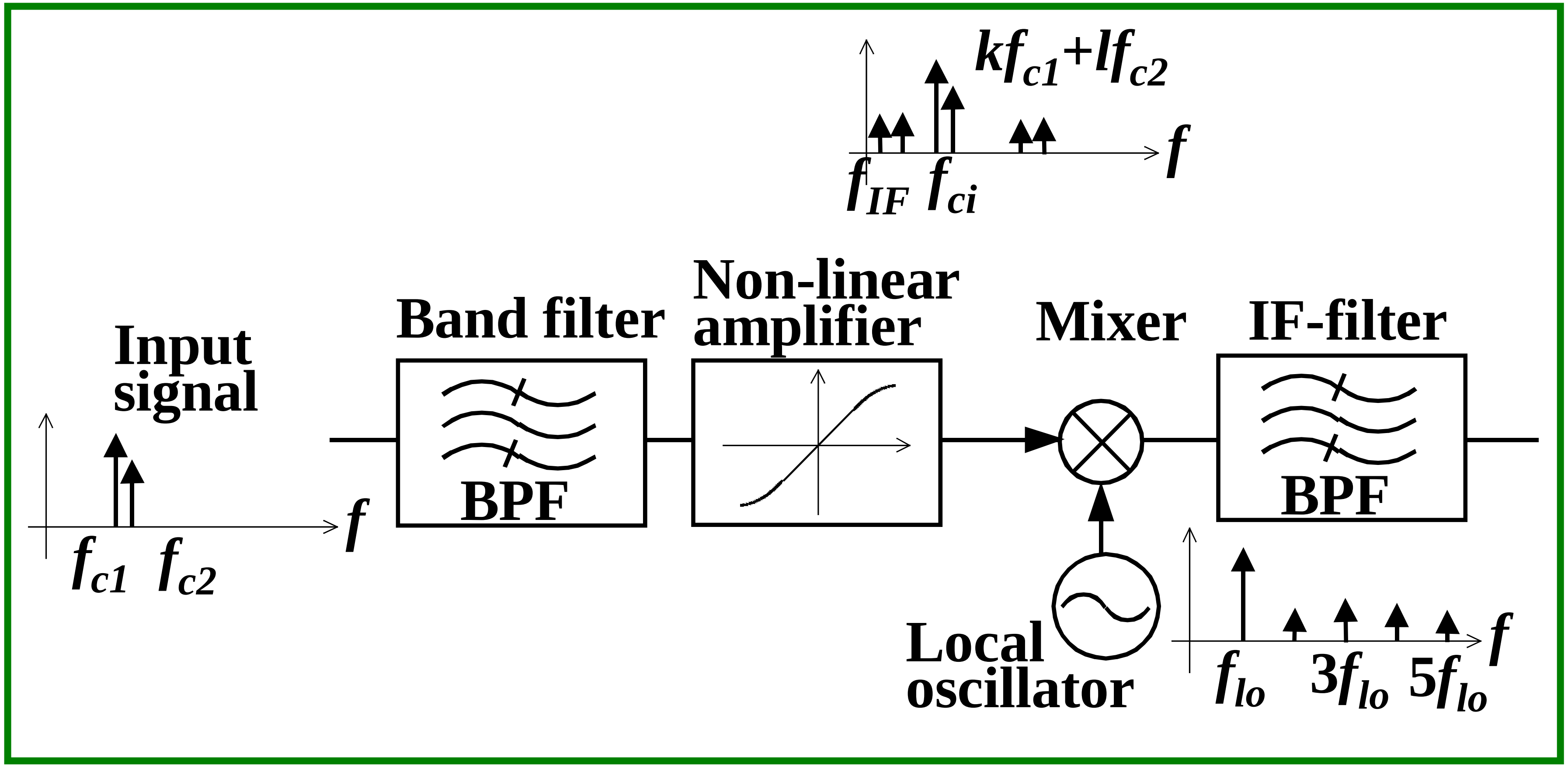


Atmospheric noise temperature on slant paths



Example (replaces slide 43)

- Wanted signal carrier in an FM-audio receiver at 100 MHz
- Signals in the band 87.5 – 108 MHz will pass the receiver input band filter
- The IF is 10 MHz
- The local oscillator frequency is 90 MHz
- Which carrier frequencies are potentially harmful due to receiver non-linearity and local oscillator harmonic components?



Derivation of the expression of critical carrier frequencies

(Insert after slide 44)

$$\left|kf_c \pm i \cdot f_{lo}\right| \in \left(f_{if} - \frac{B_{if}}{2}, f_{if} + \frac{B_{if}}{2} \right) \rightarrow \left|kf_c \pm i \cdot f_{lo}\right| \approx f_{if}$$

$$\rightarrow \pm\left(kf_c \pm i \cdot f_{lo}\right) = f_{if}$$

This can be written as four separate equations:

$$kf_c \pm i \cdot f_{lo} = f_{if} \rightarrow f_c = \frac{f_{if} \mp i \cdot f_{lo}}{k} = \mp \frac{i \cdot f_{lo} \mp f_{if}}{k}$$

$$-kf_c \mp i \cdot f_{lo} = f_{if} \rightarrow f_c = \frac{-f_{if} \mp i \cdot f_{lo}}{k} = \pm \frac{i \cdot f_{lo} \mp f_{if}}{k}$$

$$\rightarrow f_c = \left|\frac{i \cdot f_{lo} \pm f_{if}}{k}\right|$$

Example: (replaces page 111)

$b_o = 0.95\exp(j146°)$

$c_o = 0.45\exp(j250°)$

$\tau_2 - \tau_1 = 1/2f_c = 1/(2\cdot 6.8GHz) = 73.5ps$

$\tau_3 - \tau_1 = 5ns$

channel bandwidth 40 MHz

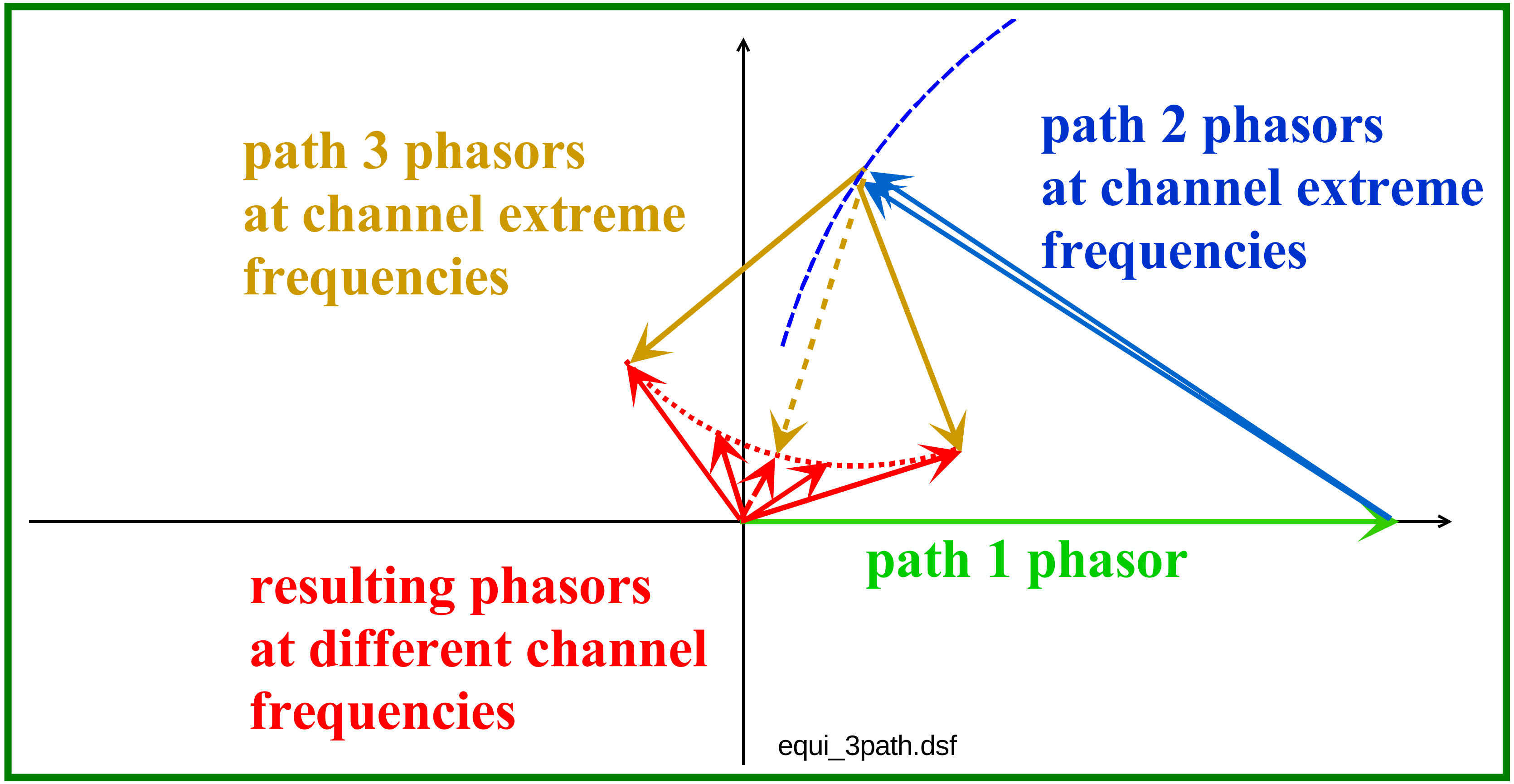
→ phasor phase shift over channel bandwidth

Path 2:

$40\cdot 73.5\cdot 10^{-6}\cdot 360° = 1.06°$

Path 3:

$40\cdot 5\cdot 10^{-3}\cdot 360° = 72.0°$



Outage improvement of vertical space diversity with maximum ratio combining (replaces p. 135)

For flat fade outage ITU-R Recommendation P.530-11 gives

$$P_{out,FF,div} = \frac{P_{out,FF}}{I_{sd,FF}}$$

where the flat fade diversity *improvement* is

$$I_{sd,FF} = \left[1 - \exp\left(-0.04 \cdot S^{0.87} f^{-0.12} d^{0.48} p_o{}^{-1.04}\right)\right] 10^{0.1(FFM-V)}$$

- S is centre to centre spacing (m), $S \in [3m, 23m]$
- f is the carrier frequency (GHz)
- d is the hop length (km) $d \in [43km, 240km]\left([25km, 240km]\right)$
- p_o is the multipath occurrence factor (%)
- FFM is the flat fade margin
- $V = |G_1 - G_2|$ (dBi)

The example continues (replaces p. 138)

Predict the total outage in a radio link with space diversity in Southern Finland having the following parameters:

▪ d = 40 km ▪ f_c = 6.8 GHz ▪ h_{rx} = 100 m ▪ h_{tx} = 100 m ▪ FFM = 35 dB ▪ dN_1 = –400 NU/km ▪ $B_{MP} = B_{NMP}$ = 18 dB ▪ $W_{MP} = W_{NMP}$ = 40 MHz Signature parameters are determined with τ = 6.3 ns	S = 10 m $G_1 = G_2 \rightarrow V$ = 0 dB
	Calculated before: p_o = 77.75 $P_{out,FF}$ = 0.0246% η = 0.153 $P_{out,SF}$ = 0.0142% P_{out} = 0.0484% $I_{sd,FF}$ = 77.0

The flat fade outage probability is (replaces p. 139)

$$P_{out,FF,div} = \frac{P_{out,FF}}{I_{sd,FF}} = \frac{0.0246}{77.0}\% = 3.19 \cdot 10^{-4}\%$$

The non-selective correlation coefficient is (using the absolute value of the FF outage probability)

$$k_{ns}^2 = 1 - \frac{I_{sd,FF} \cdot P_{out,FF}}{\eta} = 1 - \frac{77.0 \cdot 0.000246}{0.153} = 0.8752$$

which gives

$$r_w = \begin{cases} 1 - 0.9746\left(1 - k_{ns}^2\right)^{2.170}, & k_{ns}^2 \leq 0.26 \\ 1 - 0.6921\left(1 - k_{ns}^2\right)^{1.034}, & k_{ns}^2 > 0.26 \end{cases}$$

$$\rightarrow r_w = 1 - 0.6921\left(1 - 0.8752\right)^{1.034} = 0.9195$$

Outage improvement with frequency diversity

(replaces p. 143)

For flat fade outage ITU-R Recommendation P.530-11 gives

$$P_{out,FF,div} = \frac{P_{out,FF}}{I_{fd,FF}}$$

where the flat fade diversity *improvement* is given by

$$I_{fd,FF} = \frac{80}{fd} \cdot \frac{\Delta f}{f} \cdot 10^{0.1FFM}$$

- Δf is the diversity frequency spacing in GHz, if Δf >0.5GHz, this value is used
- f is the carrier frequency in GHz, $2 < f < 11$ GHz
- d is the path length in km, $30 < d < 70$ km
- $\Delta f/f < 0.05$

Otherwise the procedure is the same as for space diversity

The example continues (replaces p. 144)

Predict the total outage in a radio link with space diversity in Southern Finland having the following parameters:

▪ d = 40 km ▪ f_c = 6.8 GHz ▪ h_{rx} = 100 m ▪ h_{tx} = 100 m ▪ FFM = 35 dB ▪ dN_1 = –400 NU/km ▪ $B_{MP} = B_{NMP}$ = 18 dB ▪ $W_{MP} = W_{NMP}$ = 40 MHz Signature parameters are determined with τ = 6.3 ns	Δf = 0.16 GHz **Calculated before:** p_o = 77.75 $P_{out,FF}$ = 0.0246% η = 0.153 $P_{out,SF}$ = 0.0142% P_{out} = 0.0484% $I_{fd,FF}$ = 21.9

The flat fade outage probability is (**replaces p. 145**)

$$P_{out,FF,div} = \frac{P_{out,FF}}{I_{fd,FF}} = \frac{0.0246}{21.9}\% = 1.12 \cdot 10^{-3}\%$$

The non-selective correlation coefficient is

$$k_{ns}^2 = 1 - \frac{I_{fd,FF} \cdot P_{out,FF}}{\eta} = 1 - \frac{21.9 \cdot 0.000246}{0.153} = 0.965$$

which gives

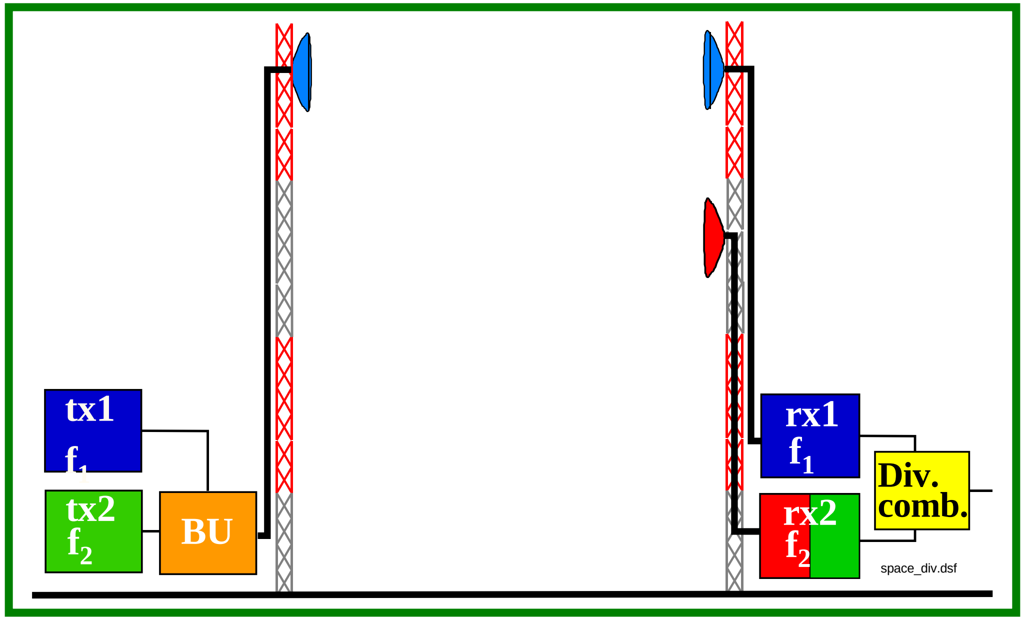
$$r_w = \begin{cases} 1 - 0.9746\left(1 - k_{ns}^2\right)^{2.170}, & k_{ns}^2 \le 0.26 \\ 1 - 0.6921\left(1 - k_{ns}^2\right)^{1.034}, & k_{ns}^2 > 0.26 \end{cases}$$

$$\rightarrow r_w = 1 - 0.6921(1 - 0.965)^{1.034} = 0.978$$

Outage improvement with combined space and frequency diversity with two receivers (replaces p. 149)

Step 1.
The non-selective correlation coefficients are calculated as above for both diversity types:

$$k_{ns,sd}^2 = 1 - \frac{I_{sd,FF} \cdot P_{out,FF}}{\eta}$$



$$k_{ns,fd}^2 = 1 - \frac{I_{fd,FF} \cdot P_{out,FF}}{\eta}$$

where

$$I_{sd,FF} = \frac{P_{out,FF}}{P_{out,FF,sd}}$$

$$I_{fd,FF} = \frac{P_{out,FF}}{P_{out,FF,fd}}$$

The example continues (replaces p. 152)

Predict the total outage in a radio link with space diversity in Southern Finland having the following parameters:

▪ d = 40 km ▪ f_c = 6.8 GHz ▪ h_{rx} = 100 m ▪ h_{tx} = 100 m ▪ FFM = 35 dB ▪ dN_1 = –400 NU/km ▪ $B_{MP} = B_{NMP}$ =18 dB ▪ $W_{MP} = W_{NMP}$ = 40 MHz Signature parameters are determined with τ = 6.3 ns	S = 10 m Δf = 0.16 GHz
	Calculated before: p_o = 77.75 $P_{out,FF}$ = 0.0246% η = 0.153 $P_{out,SF}$ = 0.0142% P_{out} = 0.0484% $I_{sd,FF}$ = 77.0 $I_{fd,FF}$ = 30.3 $k_{ns,sd}$ = 0.9355 $k_{ns,fd}$ = 0.9823

Outage improvement with combined space and frequency diversity with four receivers (replaces p. 157)

Step 1.
The non-selective correlation coefficients are calculated as above for both diversity types:

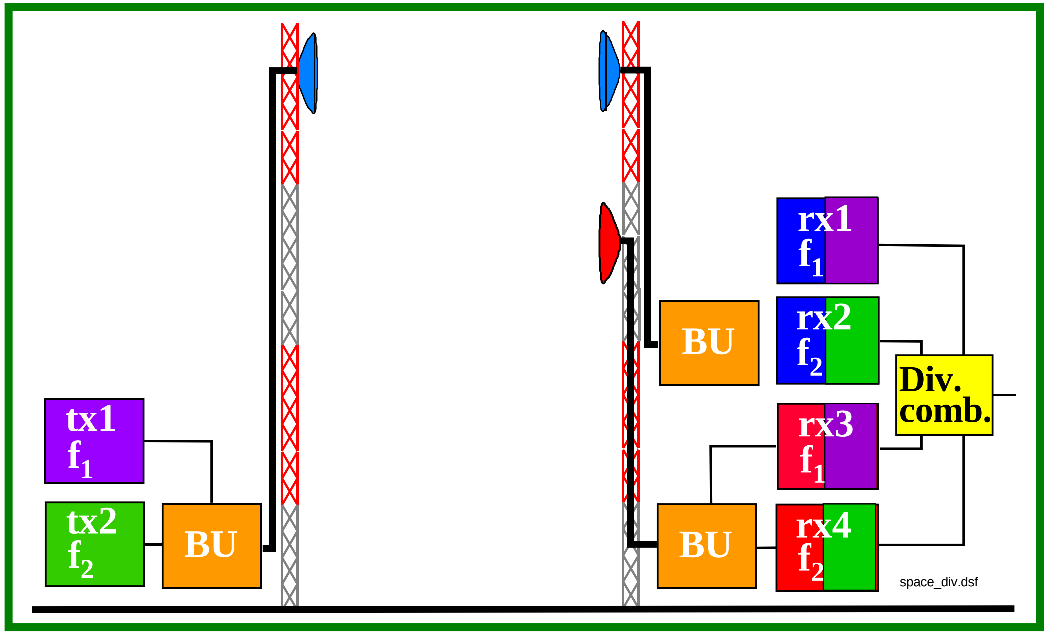
$$k_{ns,sd}^2 = 1 - \frac{I_{sd,FF} \cdot P_{out,FF}}{\eta}$$

$$k_{ns,fd}^2 = 1 - \frac{I_{fd,FF} \cdot P_{out,FF}}{\eta}$$

where

$$I_{sd,FF} = \frac{P_{out,FF}}{P_{out,FF,sd}}$$

$$I_{fd,FF} = \frac{P_{out,FF}}{P_{out,FF,fd}}$$



The example continues **(replaces p. 160)**

Predict the total outage in a radio link with space diversity in Southern Finland having the following parameters:

▪ d = 40 km ▪ f_c = 6.8 GHz ▪ h_{rx} = 100 m ▪ h_{tx} = 100 m ▪ FFM = 35 dB ▪ dN_1 = –400 NU/km ▪ $B_{MP} = B_{NMP}$ = 18 dB ▪ $W_{MP} = W_{NMP}$ = 40 MHz **Signature parameters are determined with τ = 6.3 ns**	S = 10 m Δf = 0.16 GHz
	Calculated before: p_o = 77.75 $P_{out,FF}$ = 0.0246% η = 0.153 $P_{out,SF}$ = 0.0142% P_{out} = 0.0484% $I_{sd,FF}$ = 77.0 $I_{fd,FF}$ = 30.3 $k_{ns,sd}$ = 0.9355 $k_{ns,fd}$ = 0.9823

The example continues **(replaces p. 169)**

Predict the total outage in a radio link with angle diversity in Southern Finland having the following parameters:

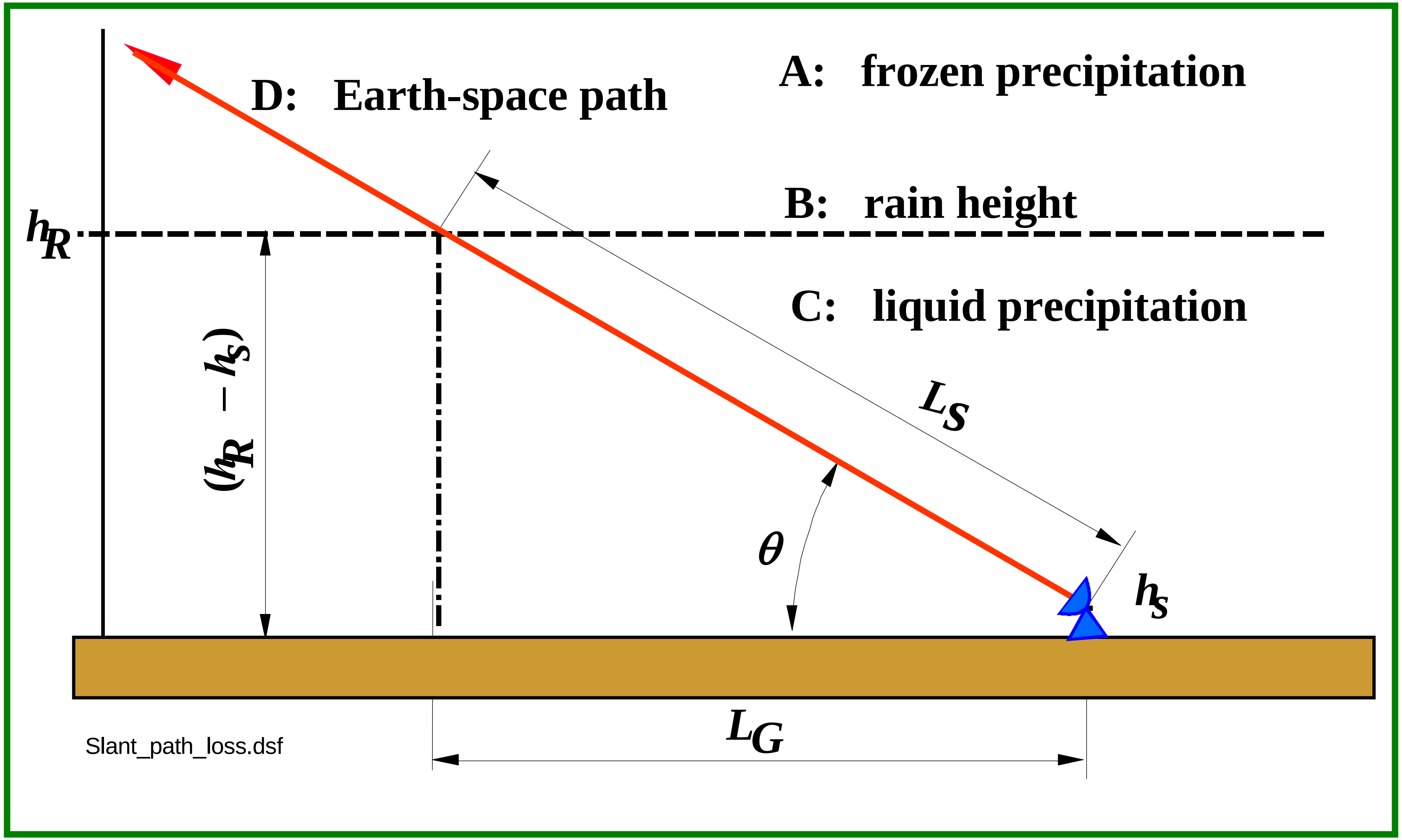
▪ d = 40 km ▪ f_c = 6.8 GHz ▪ h_{rx} = 100 m ▪ h_{tx} = 100 m ▪ FFM = 35 dB ▪ dN_1 = –400 NU/km ▪ $B_{MP} = B_{NMP}$ = 18 dB ▪ $W_{MP} = W_{NMP}$ = 40 MHz Signature parameters are determined with τ = 6.3 ns	δ = 0.5° ε = –0.5° Ω = 1.0° G_m = –40 NU/km
	Calculated before: p_o = 77.75 $P_{out,FF}$ = 0.0246% η = 0.153 $P_{out,SF}$ = 0.0142% P_{out} = 0.0484%

The average angle of arrival is

$$\mu_\theta = 2.89 \cdot 10^{-5} \cdot G_m d = 2.89 \cdot 10^{-5} \cdot (-40) \cdot 40 = -0.0462°$$

Rain attenuation estimation procedure

(Add these 6 pages after page 230)



Step 1: Determine the rain height, h_R, as given in Recommendation ITU-R P.839.

Step 2: For $\theta \geq 5°$ compute the slant-path length, L_s, below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \quad \text{km}$$

For $\theta < 5°$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \dfrac{2(h_R - h_s)}{R_e}\right)^{1/2} + \sin\theta} \quad \text{km}$$

If $h_R - h_s$ is less than or equal to zero, the predicted rain attenuation for any time percentage is zero and the following steps are not required.

Step 3: The horizontal projection, L_G, of the slant-path length is:

$$L_G = L_s \cos\theta \qquad \text{km}$$

Step 4: Determine the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year

Step 5: Obtain the specific attenuation, γ_R, using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma_R = k\,(R_{0.01})^{\alpha} \qquad \text{dB/km}$$

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\dfrac{L_G \cdot \gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)}$$

Step 7: Calculate the vertical adjustment factor, $\nu_{0.01}$, for 0.01% of the time:

$$\zeta = \tan^{-1}\left(\frac{h_R - h_s}{L_G \cdot r_{0.01}}\right) \quad \text{degrees}$$

For $\zeta > \theta, L_R = \dfrac{L_G \cdot r_{0.01}}{\cos\theta}$ km else, $L_R = \dfrac{(h_R - h_s)}{\sin\theta}$ km

If $|\varphi| < 36°$, $\chi = 36 - |\varphi|$ degrees

else, $\chi = 0$ degrees

$$\nu_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right) \cdot \dfrac{\sqrt{L_R \cdot \gamma_R}}{f^2} - 0.45\right)}$$

Step 8: The effective path length is:

$$L_E = L_R\, \nu_{0.01} \quad \text{km}$$

Step 9: The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_R L_E \qquad \text{dB}$$

Step 10: The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 5%, is determined from the attenuation to be exceeded for 0.01% for an average year:

If $p \geq 1\%$ or $|\varphi| \geq 36°$: $\beta = 0$

If $p < 1\%$ and $|\varphi| < 36°$ and $\theta \geq 25°$: $\beta = -0.005(|\varphi| - 36)$

otherwise: $\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25 \sin\theta$

$$A_p = A_{0.01} \left(\frac{p}{0.01} \right)^{-(0.655 + 0.033 \ln(p) - 0.045 \ln(A_{0.01}) - \beta(1-p)\sin\theta)} \qquad \text{dB}$$

Example

$R_{0.01}$ = 50 mm/h

h_s = 0 km

θ = 0 - 90°

φ = 0°

f = 30 GHz $\rightarrow$ k = 0.2291, α = 0.9129

R_e = 8500 km

h_R = 4 km

P5. A radio receiver has a noise figure of 6 dB and includes a modem that requires a 12 dB signal to noise ratio for proper performance in a 10 kHz bandwidth. Determine the equivalent noise temperature and the sensitivity in dBm of the receiver when the antenna sees a 270 K noise temperature. $\left(kT_o = 4\cdot 10^{-21}\ \text{W/Hz}\right)$

SOLUTION

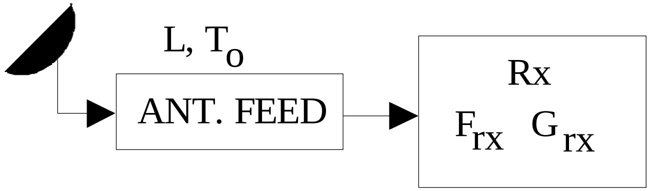
$$T_{rx} = (F-1)T_o = \left(10^{0.1\cdot 6}-1\right)290 = 864.5\ \text{K}$$

$$S = \gamma k\left(T_{rx}+T_{ant}\right)B = \gamma k T_o \frac{\left(T_{rx}+T_{ant}\right)}{T_o}B$$

$$= 10^{0.1\cdot 12}\cdot 4\cdot 10^{-21}\cdot\frac{(864.5+270)}{290}\cdot 10^4$$

$$= 2.480\cdot 10^{-15}\ \text{W} = 2.480\cdot 10^{-12}\ \text{mW} \leftrightarrow -116.1\ \text{dBm}$$

P7 c) Now the configuration in the figure below is investigated



The expression of the total noise temperature is now simplified to:

$$T_{totIII} = T_a + (L-1)T_o + L \cdot T_{rx} = 50 + \left(10^{2/10} - 1\right)290 + 10^{2/10} \cdot 70$$

$$= 50 + 170 + 111 = 321 \text{ K}$$

A comparison of alternatives II and III shows that the performance of alternative III is

$$\Delta SNR = 10\lg\frac{T_{totIII}}{T_{totII}} = 10\lg\frac{321}{163} = 2.9 \text{ dB} \quad \text{worse.}$$

Here it is important that the total noise temperatures are compared in a point where the signal power is independent of the receiver configuration, i.e. in the receiver antenna output.

P43 **The downlink characteristics of a GEO-satellite at longitude 10° W are:**

Transmitter parameters:
- **frequency 12 GHz, vertical polarization**
- **transmitter power 100 W**
- **antenna feeder loss 1.5 dB**
- **antenna diameter 2.4 m, efficiency η = 0.55.**

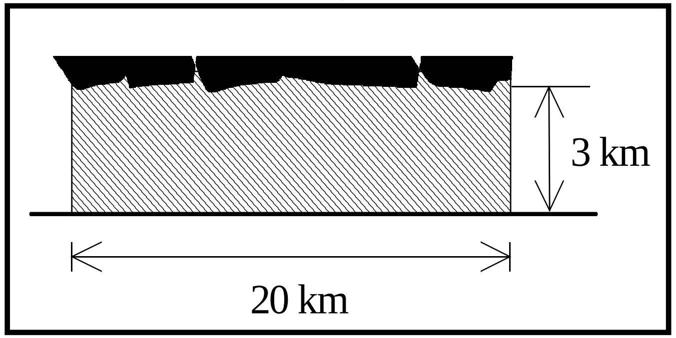
Receiver parameters:
- **location: (1) Hanko; 59°50' N, 23°00' E**
  (2) Utsjoki; 69°50' N, 27°00' E
- **antenna feeder 10 m, α = 30 dB/km**
- **other receiver losses 0.5 dB**

a) **Determine the receiver $G/T = 10\lg(g_{rx}/T_{tot})$ required for a *SNR*-value 20 dB, when the channel bandwidth is 30 MHz. (Clear air is assumed, and the atmospheric loss is obtained from the attached figure. The sky temperature seen by the receiver antenna is assumed to be 10 K).**

b) **Determine the required receiver antenna diameter (η=0.55), when the receiver noise temperature is 200 K.**

c) **Calculate the rain attenuation with the rain shower in the figure, when the rain rate is R = 20 mm/h.**

d) **Determine the *G*/*T*-degradation caused by the rain shower assuming the rain temperature to be 290 K. How large receiver antenna diameter is needed to cancel the rain loss?**



SOLUTION

a) The signal to noise ratio is

$$\gamma = 10^{0.1SNR} = \frac{p_{rx}}{p_n} = \frac{p_{tx} g_{tx} g_{rx}}{l_{tx} l_{rx} l_{ch}} \cdot \frac{1}{kT_{tot}B} = \frac{p_{tx} g_{tx} g_{rx}}{l_{tx} l_{rx} l_o l_{atm}} \cdot \frac{1}{kT_{tot}B}$$

$$\Rightarrow \frac{g_{rx}}{T_{tot}} = \frac{l_{tx} l_{rx} l_o l_{atm}}{p_{tx} g_{tx}} kB\gamma$$

$$\Rightarrow \frac{G}{T} = 10\lg \frac{g_{rx}}{T_{tot}} = SNR + L_{tx} + L_{rx} + L_o + L_{atm} - G_{tx} - P_{tx} + 10\lg kB$$

With the given parameters

- SNR = 20 dB
- L_{tx} = 1.5 dB
- $L_{rx} = \alpha l_{feed} + L_{other} = 30\ \mathrm{dB/km} \cdot 0.01\ \mathrm{km} + 0.5 = 0.8\ \mathrm{dB}$
- $L_o = 92.5 + 20\lg f/GHz + 20\lg d/km$

In the previous problem the distance between the GEO-satellite and the Earth station was derived:

$$d = \sqrt{R^2 + 2RR_o \cos\psi \cos\alpha + R_o^2}$$

where

- R is the distance of the GEO-satellite to Earth centre = 42300 km
- R_O is the Earth radius = 6370 km
- ψ is the longitude difference between the satellite and Earth station
- α = the latitude of the Earth station

in Hanko ψ = 23.0°+10.0°=33.0°, α = 59.8°

$$\Rightarrow d = \sqrt{42300^2 + 2 \cdot 42300 \cdot 6370 \cos 33° \cos 59.8° + 6370^2} = 40032 km$$

$$\Rightarrow L_O = 92.5 + 20 \lg 12 + 20 \lg 40032 = 206.1 \text{ dB}$$

in Utsjoki ψ = 27.0°+10.0°=37.0°, α = 69.8°

$$\Rightarrow d = \sqrt{42300^2 + 2 \cdot 42300 \cdot 6370 \cos 37° \cos 69.8° + 6370^2} = 41003 \text{ km}$$

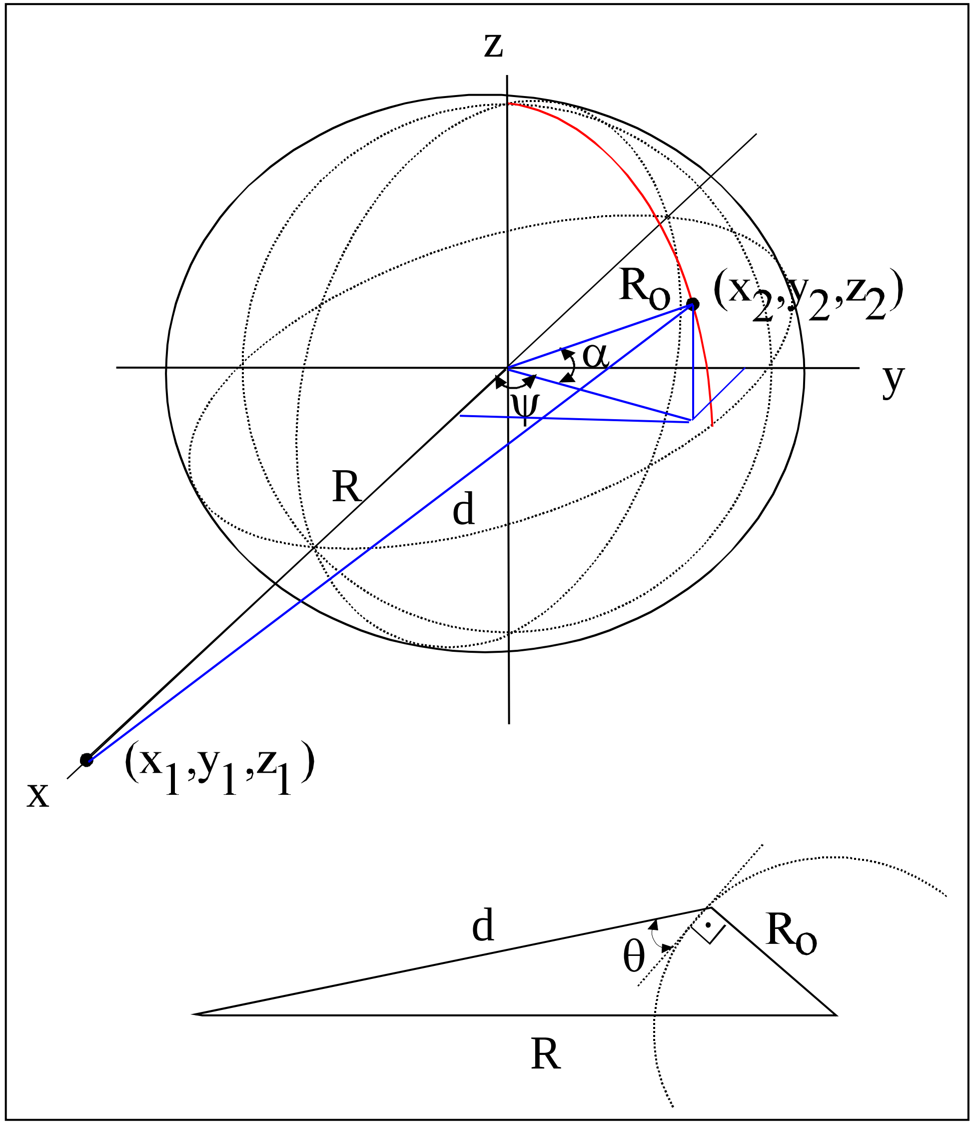
$$\Rightarrow L_O = 92.5 + 20 \lg 12 + 20 \lg 41003 = 206.3 \text{ dB}$$

The elevation angle of the Earth station antenna is obtained applying the law of cosines to the plane triangle defined by the Earth station, the satellite, and the centre of Earth.

$$R^2 = d^2 + R_o^2 - 2dR_o\cos(90° + \theta)$$
$$= d^2 + R_o^2 + 2dR_o\sin\theta$$

$$\rightarrow \theta = -\arcsin\frac{d^2 + R_o^2 - R^2}{2dR_o}$$

The atmospheric loss is estimated from the attached figure, where θ is needed.



In Hanko:

$$\theta = -\arcsin \frac{40032^2 + 6370^2 - 42300^2}{2 \cdot 40032 \cdot 6370} = 16.6° \rightarrow L_{atm} \approx 0.3 \text{ dB}$$

In Utsjoki:

$$\theta = -\arcsin \frac{41003^2 + 6370^2 - 42300^2}{2 \cdot 41003 \cdot 6370} = 7.4° \rightarrow L_{atm} \approx 0.5 \text{ dB}$$

- **the satellite transmitter antenna gain is**

$$G_{tx} = 10\lg\left(0.55\left(\frac{\pi D f}{c}\right)^2\right) = 10\lg\left(0.55\left(\frac{\pi \cdot 2.4 \cdot 12}{0.3}\right)^2\right) = 47.0 \text{ dB}$$

$$-10\lg(kB) = 10\lg\left(\frac{4 \cdot 10^{-21}}{290} \cdot 30 \cdot 10^6\right) = -153.8 \text{ dB}$$

Now the G/T-values in the two reception locations can be calculated.

Hanko:

$$\frac{G}{T} = SNR + L_{tx} + L_{rx} + L_o + L_{atm} - G_{tx} - P_{tx} + 10\lg kB$$

$$= 20 + 1.5 + 0.8 + 206.1 + 0.3 - 47.0 - 20 - 153.8 = 7.9\,\mathrm{dB/K}$$

Utsjoki:

$$\frac{G}{T} = SNR + L_{tx} + L_{rx} + L_o + L_{atm} - G_{tx} - P_{tx} + 10\lg kB$$

$$= 20 + 1.5 + 0.8 + 206.3 + 0.5 - 47.0 - 20 - 153.8 = 8.3\,\mathrm{dB/K}$$

b) To get the required receiver antenna gain the total receiver noise temperature at the antenna must be estimated. According to ITU-R Rec. P618-8

$$T_{atm} = T_m\left(1 - 10^{-0.1 L_{atm}}\right), \quad T_m = 260...280\,\mathrm{K}$$

In Hanko $T_{atm} = 270\left(1 - 10^{-0.1\cdot 0.21}\right) = 12.7\,\mathrm{K}$

In Utsjoki $T_{atm} = 270\left(1 - 10^{-0.1\cdot 0.46}\right) = 27.1\,\mathrm{K}$

Calculation of total noise temperature and receiver antenna diameter

Hanko:

$$T_{tot} = T_{rx} + \frac{l_{rx} - 1}{l_{rx}} T_o + \frac{T_{atm}}{l_{rx}} + \frac{T_{sky}}{l_{rx}}$$

$$= 200 + \frac{10^{0.08} - 1}{10^{0.08}} 290 + \frac{12.7}{10^{0.08}} + \frac{10}{10^{0.08}}$$

$$= 200 + 48.8 + 10.6 + 8.3 = 267.7 \text{ K}$$

$$\Rightarrow G_{rx} = \frac{G}{T} + 10 \lg T_{tot} = 7.9 + 10 \lg 267.7 = 32.2 \text{ dB}$$

$$g_{rx} = \eta \left(\frac{\pi D}{c/f} \right)^2 \Rightarrow D = \frac{c}{\pi f} \sqrt{\frac{g_{rx}}{\eta}} = \frac{0.3}{\pi \cdot 12} \sqrt{\frac{10^{3.22}}{0.55}} = 0.437 \text{ m}$$

Utsjoki:

$$T_{tot} = T_{rx} + \frac{l_{rx} - 1}{l_{rx}} T_o + \frac{T_{atm}}{l_{rx}} + \frac{T_{sky}}{l_{rx}}$$

$$= 200 + \frac{10^{0.08} - 1}{10^{0.08}} 290 + \frac{27.1}{10^{0.08}} + \frac{10}{10^{0.08}}$$

$$= 200 + 48.8 + 22.5 + 8.3 = 503.4 \text{ K}$$

$$\Rightarrow G_{rx} = \frac{G}{T} + 10 \lg T_{tot} = 8.3 + 10 \lg 503.4 = 35.3 \text{ dB}$$

$$g_{rx} = \eta \left(\frac{\pi D}{c/f} \right)^2 \Rightarrow D = \frac{c}{\pi f} \sqrt{\frac{g_{rx}}{\eta}} = \frac{0.3}{\pi \cdot 12} \sqrt{\frac{10^{3.53}}{0.55}} = 0.625 \text{ m}$$

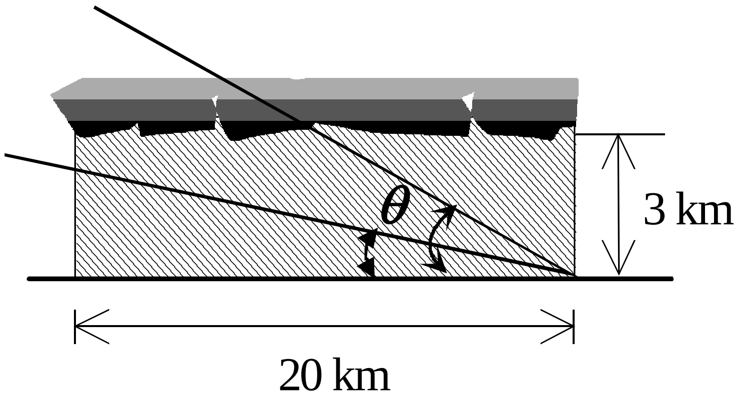
In clear weather conditions the difference in antenna diameters is not very large.

c) When the rain intensity is 20 mm/h, the characteristic loss at 12 GHz

$$\gamma_{rain} = kR^{\alpha} = 0.02455 \cdot 20^{1.216} = 0.938 \text{ dB/km}$$

The worst case occurs when the right border of the rain shower is just at the receiving station.

The distance travelled through the rain



$$s = \begin{cases} \dfrac{h}{\sin\theta}, & \theta > \arctan\left(\dfrac{h}{l}\right) \\ \dfrac{l}{\cos\theta}, & \theta < \arctan\left(\dfrac{h}{l}\right) \end{cases}$$

With the given dimensions of the rain shower the elevation angle corresponding to the discontinuity of the expression is 8.5°.

The rain attenuation is

In Hanko: $L_{rain} = 0.938 \cdot \dfrac{3}{\sin 16.6°} = 9.8 \text{ dB}$

In Utsjoki: $L_{rain} = 0.938 \cdot \dfrac{20}{\cos 7.4°} = 18.9 \text{ dB}$

d) Now the atmospheric loss is increased with the rain attenuation, which will have impact on both the G/T-requirement and the noise power.

Hanko:

$$\frac{G}{T} = SNR + L_{tx} + L_{rx} + L_o + L_{atm} + L_{rain} - G_{tx} - P_{tx} + 10\lg(kB)$$
$$= 20 + 1.5 + 0.8 + 206.1 + 0.3 + 9.8 - 47.0 - 20 - 153.8 = 17.7 \text{ dB/K}$$

$$T_{tot} = T_{rx} + \frac{l_{rx} - 1}{l_{rx}} T_o + \frac{T_{atm}}{l_{rx}} + \frac{(l_{rain} - 1)T_{rain}}{l_{rain} l_{rx}} + \frac{T_{sky}}{l_{rain} l_{rx}}$$
$$= 200 + \frac{10^{0.08} - 1}{10^{0.08}} 290 + \frac{12.7}{10^{0.08}} + \frac{\left(10^{0.98} - 1\right) 290}{10^{0.98} 10^{0.08}} + \frac{10}{10^{0.98+0.08}}$$
$$= 200 + 48.8 + 10.6 + 216.0 + 0.9 = 476.3 \text{ K}$$

$$\Rightarrow G_{rx} = \frac{G}{T} + 10\lg T_{tot} = 17.7 + 10\lg 476.3 = 44.5 \text{ dB}$$

$$g_{rx} = \eta \left(\frac{\pi D}{c/f} \right)^2 \Rightarrow D = \frac{c}{\pi f} \sqrt{\frac{g_{rx}}{\eta}} = \frac{0.3}{\pi \cdot 12} \sqrt{\frac{10^{4.45}}{0.55}} = 1.80 \text{ m}$$

Utsjoki:

$$\frac{G}{T} = SNR + L_{tx} + L_{rx} + L_o + L_{atm} + L_{rain} - G_{tx} - P_{tx} + 10\lg\left(kB\right)$$

$$= 20 + 1.5 + 0.8 + 206.3 + 0.5 + 18.9 - 47.0 - 20 - 153.8 = 27.2 \text{ dB/K}$$

$$T_{tot} = T_{rx} + \frac{l_{rx} - 1}{l_{rx}} T_o + \frac{T_{atm}}{l_{rx}} + \frac{(l_{rain} - 1)T_{rain}}{l_{rain} l_{rx}} + \frac{T_{sky}}{l_{rain} l_{rx}}$$

$$= 200 + \frac{10^{0.08} - 1}{10^{0.08}} 290 + \frac{27.1}{10^{0.08}} + \frac{\left(10^{1.89} - 1\right) 290}{10^{1.89+0.08}} + \frac{10}{10^{1.89+0.08}}$$

$$= 200 + 48.8 + 22.5 + 238.1 + 0.2 = 509.6 \text{ K}$$

$$\Rightarrow G_{rx} = \frac{G}{T} + 10\lg T_{tot} = 27.2 + 10\lg 509.6 = 54.3 \text{ dB}$$

$$g_{rx} = \eta \left(\frac{\pi D}{c/f} \right)^2 \Rightarrow D = \frac{c}{\pi f} \sqrt{\frac{g_{rx}}{\eta}} = \frac{0.3}{\pi \cdot 12} \sqrt{\frac{10^{5.43}}{0.55}} = 5.57 \text{ m}$$

In the investigated rain situation the antenna diameter in Hanko should be increased 4.12 times but in Utsjoki 8.91 times. However, this is a very rare rain situation and unfavourable for Utsjoki. Why? With a rain rate of 20 mm/h a 20 km large shower is very unlikely to occur. The rain rates for a given occurrence probability is moreover clearly lower in Utsjoki than in Hanko.

Compare the result to the results with a 5 km wide rain shower, even if the rain intensity would be 40 mm/h.

Earth - space slant path loss