Satellite TVRO G/T calculations

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Introduction

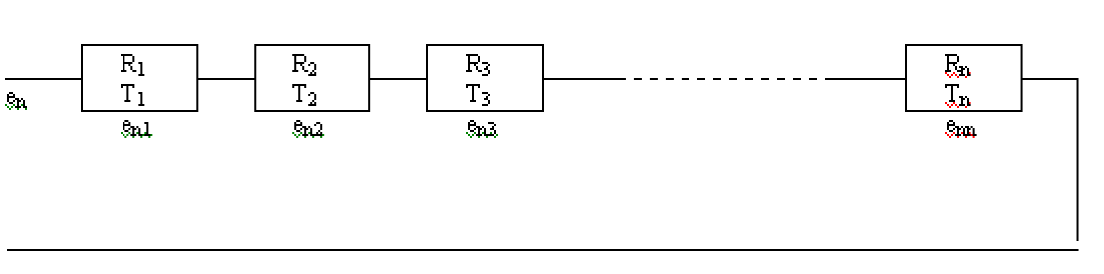
In order to understand the G/T calculations, we must start with some basics. A good starting point is the derivation of the total system noise temperature in terms of its composite temperatures that are found in a satellite system. After delving into the composition of these component temperatures, the final total system noise temperature equation with all of its components derived, will eventually be used to derive the Gain to Temperature ratio (G/T). The total system noise temperature T_{sys} (K), is given by:

$$T_{sys} = \sigma T_A + (1 - \sigma)T_c + T_{LNB} \quad \text{K} \qquad (1)$$

where, σ is the fractional transmissivity of the antenna feed and connectors, T_A is the effective antenna noise temperature either for clear sky or for a given percentage of the time (K), T_{LNB} is the equivalent noise temperature of the LNB (K) and T_C is the physical temperature of the coupling (waveguide) components (K).

Noise voltages

Consider the diagram below, in which resistors are connected in series, and a voltage e_n is applied to the end terminals. Each resistor has a noise voltage developed across it, that is e_{n1}, e_{n2}, …,e_{nn}, and each resistor can be considered to have a noise temperature, T_1,T_2, …, T_n.



As noise voltages add on a squared basis, the voltage squared at the end terminal can be expressed as:

$$e_n^2 = \sum_{i=1}^{n} e_{ni}^2 = 4k\sum_{i=1}^{n} T_i R_i \qquad (2)$$

From equation 2, the average noise power can be found, that is,

$$P_{av} = \frac{e_n^2}{4R_{total}} = \frac{4kB\sum_{i=1}^{n} T_i R_i}{4\sum_{i=1}^{n} R_i} = kB\sum_{i=1}^{n} T_i \frac{R_i}{\sum_{i=1}^{n} R_i} = kBT_{Total} \qquad (3)$$

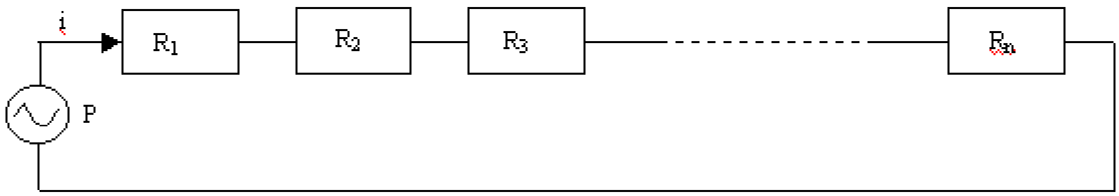
From equation 3, we find that the total noise temperature T_{Total} is given by,

$$T_{Total} = \sum_{i=1}^{n} T_i \frac{R_i}{\sum_{i=1}^{n} R_i} = \sum_{i=1}^{n} \alpha_i T_i \qquad (4)$$

where

$$\alpha_i = \frac{R_i}{\sum_{i=1}^{n} R_i} \qquad (5)$$

At first, α_i appears to be the ratio of one of the resistors in the chain to the total number of resistors in the chain, however, it has deeper implications. Consider applying a signal generator of available power P, to the same chain of series resistors, as shown in the diagram below,



Then, the total power which is dissipated in the chain of resistors must equal the total power that is available, that is,

$$P = i^2 \sum_{i=1}^{n} R_i \qquad (6)$$

The power which is dissipated in each resistor, say resistor R_i, is $i^2 R_i$, thus the

$$\frac{\text{Power dissipated in } R_i}{\text{Total power available}} = \frac{P_i}{P_{av}} = \frac{i^2 R_i}{i^2 \sum_{i=1}^{n} R_i} = \alpha_i \qquad (7)$$

Thus, the sum of all the separate powers dissipated in each resistor must equal the total power available, that is,

$$\sum_{i=1}^{n} P_i = P_{av} \quad (8)$$

which from equation 7, means

$$\sum_{i=1}^{n} P_i = P_{av} \sum_{i=1}^{n} \alpha_i = P_{av} \quad (9)$$

giving the important relationship,

$$\sum_{i=1}^{n} \alpha_i = 1 \quad (10)$$

Noise analysis of Antenna system

Fractional transmissitivy σ

The fractional tranmissivity σ , is defined as the fraction of incident energy between zero and 1 that passes through a medium and emerges from the other side. A value of zero indicates total absorption by the medium and a value of 1 indicates that the medium is not absorbent or transparent.

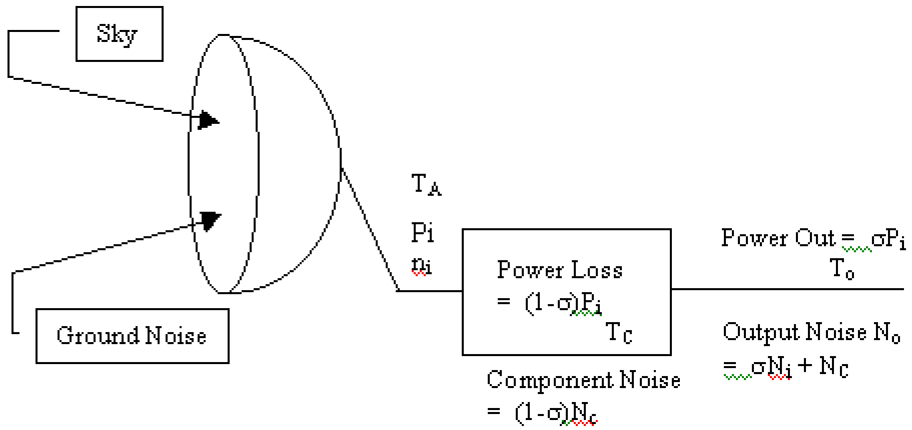
When an absorbing medium is in equilibrium with its surroundings, it will isotropically radiate as much energy as it absorbs. If say, in the diagram below, the absorbing medium is raised to a temperature T_m by, say, absorbing energy from the ground, the efficiency with which it is absorbing and re-radiating energy can be quantified by its fractional transmissivitiy σ . A signal, of power P, passing through the absorbing medium will emerge at the other side at a reduced power level of σ P. Since the radiated energy is isotropic, any receiver detecting this signal will also detect an increase in noise temperature of $(1-\sigma)T_m$. The principles are the same whether we are referring to a rain cell or an absorbing or lossy feed. It is more common to substitute more convenient attenuation values rather than to use the feed transmissivity parameter directly. The transmissivity of a medium σ , is related to the attenuation A, by the relationship,

$$A = 10\log\left(\frac{1}{\sigma}\right)\text{dB, which on rearrangem ent gives,} \quad \sigma = \frac{1}{10^{0.1A}} = 10^{-0.1A} \quad (11)$$

Two points can be seen from this discussion, first, an intervening rain cell in the earth space path will not only attenuate a signal by the receiver will also detect an increase in noise temperature. Secondly, the incident antenna noise as well as the signal are absorbed by the insertion of the waveguide components such as feedhorns, polarizers and orthomodal transducers (OMTs).

Quantifying the system noise temperature

Consider the following diagram,



Into the box, containing waveguide components, etc., is a power P_i. As these components have an insertion loss A, from equation 11, it means that these components also have a transmissivity. The amount of power emerging from the component box is σP_i . That means that the amount of power dissipated by the components is $P_i - P_{out} = P_i - \sigma P_i = (1-\sigma)P_i$.

Thus, from equation 7,

$$\alpha_C = \frac{P_i(1-\sigma)}{P_i} = (1-\sigma) \quad (12)$$

As there are two absorbing elements, the input to the antenna, as well as the components, from equation 10,

$\alpha_C + \alpha_A = 1$ (13)

giving,

$\alpha_A = 1 - \alpha_C = 1 - (1-\sigma) = \sigma$ (14)

From equation 4,

$T_o = \alpha_A T_A + \alpha_C T_C = \sigma T_A + (1-\sigma) T_C$ (15)

System Noise Temperature

The addition of a low noise block (LNB) downconverter adds its own noise temperature to the noise temperature from the sky and component block, already derived. Thus, the system noise temperature T_{sys} is given by equation 1, that is,

$$T_{sys} = T_{LNB} + (1-\sigma)T_c + \sigma T_A \quad \text{K} \quad (1)$$

or its equivalent in terms of the feed attenuation or insertion loss figure A_{feed}, using equation 11,

$$T_{sys} = T_{LNB} + (1 - 10^{-0.1A_{feed}})T_C + 10^{-0.1A_{feed}}T_A \quad \text{K} \qquad (16)$$

The following sections discuss each of the temperatures T_A, T_C and T_{LNB} in more detail and provide a worked example for each section.

The different noise temperatures

The equivalent LNB noise temperature T_{LNB}

T_{LNB} in equations 1 and 16 is the overall LNB noise factor expressed as an equivalent noise temperature and it is the major contributor to the overall system noise temperature. A noise *factor* when expressed as a power ratio in dB becomes a *noise figure*. The noise performance of a LNB can be expressed as an equivalent noise temperature in kelvin or, more commonly, as a noise figure (dB). In the latter case, the noise figure needs to be converted to an equivalent noise temperature in order to calculate the system noise. The conversion is,

$$T_{LNB} = 290\left(10^{\left(\frac{NF}{10}\right)} - 1\right) \quad \text{K} \qquad (17)$$

where T_{LNB} is the noise temperature (K) and NF is the noise figure of the LNB (dB).

Example: What is the equivalent noise temperature of a LNB whose noise figure is given as 1.5 dB?

$$T_{LNB} = 290\left(10^{\left(\frac{1.5}{10}\right)} - 1\right) = 290(0.4125375) = 119.636\,\text{K}$$

Note that the calculation involved at least six decimal places, in order to obtain an accuracy of three decimal places in the answer. It is advisable to always work to at least six decimal places in your calculations and express your answer to three decimal places. It is usually more difficult an expensive to achieve low noise figures the higher the frequency. For the Ku band, low-cost LNBs are in the range 1.2 to 1.5 dB. Lower noise figures can be achieved with the use of high electron mobility transistors (HEMT). Typical noise figures for the Ku band for these devices are 0.8 to 1 dB.

Coupling Noise re-radiated portion $(1-\sigma)T_C$

The $(1-\sigma)T_C$ term in equation 1 is the noise isotropically radiated by the feed components. These will absorb energy principally from the ground and thus have a fractional transmissivity value or inherent loss. This isotropically re-radiated portion $(1-\sigma)T_C$ will be detected by the LNB. Insertion losses or attenuation experienced by waveguide components are normally quoted by manufacturers in dB. Use, therefore, must be made of equation 11 or 16. The total feed attenuation figure is the sum of the attenuation contributions of waveguide components such as feed horns, OMTs and polarizers, etc. T_C is the physical temperature of the feed and is normally taken as 290 K. This applet has this figure of 290 K built into its calculations and does not ask you to provide it.

Example: Components with a total insertion loss of 0.3 are assembled in a satellite dish head unit. What is the additional noise temperature detected by the LNB?

$$(1-\sigma) = 290\left(1-10^{-0.1A_{feed}}\right) = 290\left(1-10^{-0.03}\right) = 290(1-0.9332543) = 19.356\ \mathrm{K}$$

Modified antenna noise temperature $\sigma\ T_A$

The last term $\sigma\ T_A$, in equation 1, is the modified antenna noise temperature which is the effective noise temperature of the antenna, T_A. This temperature comprises all the noise components incident on the antenna, and is reduced only by the feed transmissivity σ .

Example: Suppose (after much calculation) that the effective antenna temperature was determined to be 68 K and the feed has an insertion loss of 0.3 dB. What is the modified antenna temperature seen at the LNB input?

$$\sigma T_A = 10^{-0.1A_{feed}} T_A = \left(10^{-0.03}\right)68 = 68(0.9332543) = 63.461\ \mathrm{K}$$

Effective antenna temperature $T_A = T_{ANT} + T_{clearsky/rain}$

The effective antenna noise temperature T_A , is determined by many factors, such as antenna size, elevation angle, external noise sources and atmospheric propagation effects. During clear sky conditions, the principal noise component of the effective antenna noise temperature is ground noise pick-up. This is because, in this case, atmospheric propagation effects (rain, etc.) have been neglected and the only noise source left, apart from a relatively small contribution from galactic background noise, is that from the ground. This is the ‘antenna noise’ parameter that manufacturers often tabulate for a range of elevation angles. There are three main contributions to the overall antenna noise. These are; antenna noise temperature due to ground noise T_{ANT}, Cosmic or galactic noise and Atmospheric propagation components. Each will be separately discussed.

Antenna noise temperature T_{ANT}

The smaller the antenna the wider and more spread out are the side lobes intersecting the warm earth and, consequently, the more ground noise is picked up by the antenna. It can also be seen that these side lobes, principally the first side lobe, would intersect the ground at a higher elevation angle than that of a larger antenna and so would be a noisier device when set at a given elevation. Ground noise pick-up may be reduced, at the expense of gain, by under- illuminating the dish; thus, this factor essentially determines the efficiency of the dish. Size being equal, a prime focus antenna would detect increased ground noise over an offset design since the head unit, directly mounted in the signal path, would be ‘seen’ at the same temperature as the Earth. Since the antenna noise temperature has so many variable factors, it is apparent that in the absence of a manufacturer supplied figure, an estimate is perhaps the best that can be obtained. An approximate value of T_{ANT} is given by equation 18 below. This equation takes into account the elevation and the dish diameter and may be used to calculate to a reasonable approximation the antenna noise under clear-sky conditions.

$$T_{ANT} = 15 + \frac{30}{D} + \frac{180}{EL} \quad \mathrm{K} \qquad (18)$$

where D is the antenna diameter (m) and EL is the dish elevation angle (degrees), that is the angle from the horizontal.

Example: A dish of diameter 0.65 m is used in a satellite system. Estimate the worst-case antenna noise temperature at an elevation of 25°.

$$T_{ANT} = 15 + {}^{30}\!/_{0.65} + {}^{180}\!/_{25} = 68.354 \ \mathrm{K}$$

Before continuing with the second contribution – that is the cosmic or galactic noise component, we will digress to consider the changing of the antenna gain to a diameter. The applet asks for an antenna gain and then provides a screen print of the value of the antenna diameter. This value of diameter is then used in equation 18. To find the elevation, the applet permits you to click anywhere on the screen where a ball, representing the satellite appears. The angle that the ball makes with the satellite dish is printed on the screen. Clicking elsewhere changes the angle and also the values of the calculation that the applet makes. This is because the value of elevation chosen is used in equation 18.

Antenna Gain (G) and Diameter (d)

The antenna gain G (dBi), is related to its diameter d (m), by the following equation,

$$G = 10\log\left[\frac{\eta(\pi d)^2}{\lambda^2}\right] = 10\log\left[\frac{\eta(\pi d f)^2}{c^2}\right] = 20\log\left[\frac{\sqrt{\eta}(\pi d f)}{c}\right] \qquad (19)$$

where λ is the carrier wavelength (m), η is the antenna efficiency ($\eta \leq 1$), f is the frequency (Hz), c is the speed of light (2.99792458×10^8 m/s). Rearrangement of this equation permits the dish diameter d, to be found for a given antenna gain (dBi). An antenna efficiency of 0.67 is usually taken for antennas with a 30 to 40 dBi gain. The applet has built into its calculations an efficience η =0.67. Notice that a carrier frequency is required to determine the dish diameter given the gain, or the gain given the dish diameter. This frequency is asked for in the applet.

Example: A dish of diameter 0.65 m and having an efficiency of 67% (0.67) is used in a satellite system using a carrier frequency of 11.332 GHz. Determine the antenna gain (dBi).

$$G = 20\log\left[\frac{(0.65\,\pi)(11.332)\sqrt{0.67}}{0.299792458}\right] = 20\log(63.18099973) = 36.012\text{ dBi}$$

Cosmic or galactic noise temperature component T_g

This is background cosmic noise, principally the residual noise of 'the big-bang"? It has a small noise temperature of about 2.7 K. This component is relatively small in relation to the error in estimating the ground noise component and may be omitted from practical calculations. Depending on how 'antenna noise' is defined in manufacturers' specifications, this may be incorporated. The applet has used this component and it is built into its calculations.

Atmospheric propagation components

Water vapour and oxygen attenuation A_{atm}

There are two main propagation effects experienced on the downlink. Firstly, atmospheric gaseous absorption by water vapour and oxygen – this is basically a clear-sky effect. Its value depends on the absolute humidity or water vapour density, the antenna elevation and the carrier frequency used. It is a relatively minor contributor below about 7.5 GHz. Some approximate values of A_{atm} that can be used as a guide are; 8 GHz – 0. 06 dB, 10GHz – 0.1 dB, 15GHz - 0.19 dB, 20 GHz – 1.1 dB, 22GHz – 2.9 dB, 30 GHz – 1.1 dB, 40 GHz – 1.7 dB/km. Notice that at a frequency around 22 GHz, the absorption is very high. It is not usual to operate satellite or line-of-sight radio links at this frequency due to the high absorption by water vapour.

Precipitation attenuation A_{rain}

The second propagation effect is attenuation due to precipitation (raining). Consider the uplink situation, a receiver on board a satellite will 'see' a fairly constant but high noise temperature emitted from the warm Earth of around 290 K, so further thermal energy emission by rain will have a negligible effect. In the down link situation, the receiver is directed toward a relatively cool sky so the additional thermal noise contribution by rain is not a negligible component of the total system noise, especially if the receiver (LNB) is a low noise device operating in the Ku (10-15 GHz)or Ka band(17-22 GHz). The effects of rain and atmospheric absorption are negligible in the S band (2-3 GHz) and C band (3-8 GHz). Precipitation will not only directly attenuate the signal (known as a 'rain fade'), but the system noise temperature will also increase since the temperature of the intervening medium approaches that of the Earth. It is important that the increase in system noise is taken into account and not just the attenuation experience by a rain fade. The combination of the two is known as the *downlink degradation (DND)*. The effects of precipitation become significant above about 8 GHz. Rain, or to a lesser extent snow, fog, or cloud attenuate and scatter microwave signals,. The magnitude of the effects depends more on the size of the water droplets rather than the precipitation rate itself. Heavier rain tends to comprise larger droplets so the two are normally related. As a general rule, the physical medium temperature T_{mr}, for all forms of precipitation, is taken as 260 K. The applet takes this into account during its calculations. For clouds and clear sky T_m = 280 K is used. Again the applet takes this into consideration during its calculations. Some approximate values of A_{rain} that can be used as a guide are; 8 GHz – 0. 5 dB, 10GHz – 0.8 dB, 15GHz - 2 dB, 20 GHz – 3.1 dB, 22GHz – 3.8 dB. Above 1 GHz the curve of attenuation v frequency is approximately linear. For a tropical climate, it is expected that these figures would be slightly higher.

Noise increase due to precipitation and atmospheric absorption and $T_{clearsky}/T_{rain}$

During clear sky conditions the only attenuation experienced between the satellite and the ground station will be that due to atmospheric absorption A_{atm}, by oxygen and water vapour. During rain there will be a combined atmospheric gaseous absorption A_{atm} and attenuation due to the rain A_{rain} (dB). The overall consequence is to increase the effective antenna noise temperature T_A, above operation frequencies of about 8 GHz. For the S and C bands this calculation is not considered necessary since the contributions are negligible, but for the Ku and Ka bands it becomes increasingly significant, particularly at the low system noise temperatures achieved today. Even during clear-sky conditions an allowance for the temperature increase due to atmospheric absorption should be added to the effective antenna temperature, T_A. Equation 20 given below, may be used to calculate this increase. During rain an additional noise temperature increase can be calculated using equation 21 to allow for statistical rainfall effects.

$$T_{clearsky} = \left(1 - 10^{-0.1A_{atm}}\right)T_m + 10^{-0.1A_{atm}}T_g \quad \mathrm{K} \qquad (20)$$

$$T_{rain} = \left(1 - 10^{-0.1(A_{atm}+A_{rain})}\right)T_{mr} + 10^{-0.1(A_{atm}+A_{rain})}T_g \quad \mathrm{K} \qquad (21)$$

where T_m is the physical temperature of the medium for clear sky or cloud = 280 K, T_{mr} is the physical temperature of the medium for rain = 260 K, T_g is the cosmic or galactic noise temperature = 2.7 K (typical at frequencies > 4 GHz), A_{atm} is the gaseous attenuation due to atmospheric absorption (dB), A_{rain} is the rain attenuation for a given percentage of the time (dB).

Equations for T_A

Adding equations 20 or 21 to the antenna noise temperature due to ground noise T_{ANT}, given by equation 18 will yield the final equations for T_A. That is

$T_{Aclearsky} = T_{ANT} + T_{clearsky}$

Tarain = $T_{ANT} + T_{rain}$

That is,

$$T_{Aclearsky} = \left(15 + \frac{30}{D} + \frac{180}{EL}\right) + \left(1 - 10^{-0.1A_{atm}}\right)T_m + 10^{-0.1A_{atm}}T_g \quad \mathrm{K} \qquad (22)$$

$$T_{Arain} = \left(15 + \frac{30}{D} + \frac{180}{EL}\right) + \left(1 - 10^{-0.1(A_{atm} + A_{rain})}\right)T_{mr} + 10^{-0.1(A_{atm} + A_{rain})}T_g \quad \text{K} \qquad (23)$$

$T_{SYSclearsky}$ and $T_{SYSrain}$

Substitution of equation 22 and equation 23 into equation 1 or 16 gives the final system temperature equations used in the determination of G/T. That is, $T_{SYSclearsky}$ is the system noise temperature calculated during clear sky conditions including atmospheric gaseous absorption.

$$T_{sys_{clearsky}} = T_{LNB} + (1 - 10^{-0.1A_{feed}})T_C + 10^{-0.1A_{feed}} T_{Aclearsky} \qquad \text{K} \quad (24)$$

$$T_{sys_{clearsky}} = T_{LNB} + (1 - \sigma)T_c + \sigma T_{Aclearsky} \qquad \text{K} \quad (25)$$

$T_{SYSrain}$ is the system noise temperature calculated during rain for a specific percentage of the time of an average year.

$$T_{sys_{rain}} = T_{LNB} + (1 - 10^{-0.1A_{feed}})T_C + 10^{-0.1A_{feed}} T_{Arain} \qquad \text{K} \quad (26)$$

$$T_{sys_{rain}} = T_{LNB} + (1 - \sigma)T_c + \sigma T_{Arain} \qquad \text{K} \quad (27)$$

The increase in noise due to a given rain fade and the downlink degradation (DND)

The increase in noise due to a given rain fade expressed as a power ratio in dB is given by,

$$\text{Noise increase (rain)} = 10\log\left(\frac{T_{SYS_{rain}}}{T_{SYS_{clearsky}}}\right) \text{ dB} \qquad (28)$$

The downlink degradation (DND) experienced during a given rain fade is given by,

$$\text{DND} = \text{A}_{\text{rain}} + \text{Noise increase (rain)} = A_{rain} + 10\log\left(\frac{T_{SYS_{rain}}}{T_{SYS_{clearsky}}}\right) \text{ dB} \qquad (29)$$

<u>**Example:**</u> Using the quantities supplied in the other examples for the link budget, calculate the DND where the atmospheric gaseous absorption is 0.17 dB and the rain attenuation for 99.5% of an average year does not exceed 0.83 dB.

$$T_{clearsky} = \left(1 - 10^{-0.1(0.17)}\right)280 + \left(10^{-0.1(0.17)}\right)2.7 = 13.345\,\text{K}$$

$$T_{rain} = \left(1 - 10^{-0.1(0.17+0.83)}\right)260 + \left(10^{-0.1(0.17+0.83)}\right)2.7 = 55.619\text{ K}$$

$$T_{SYS_{clearsky}} = 119.636 + \left(1 - 10^{-0.1(0.3)}\right)290 + \left(10^{-0.1(0.3)}\right)\left(68.394 + 13.345\right) = 215.275\text{ K}$$

$$T_{SYS_{rain}} = 119.636 + \left(1 - 10^{-0.1(0.3)}\right)290 + \left(10^{-0.1(0.3)}\right)\left(68.394 + 55.619\right) = 254.728\text{ K}$$

$$DND = 0.83 + 10\log\left(\frac{254.728}{215.275}\right) = 1.561\text{ dB}$$

The noise increase due to the 0.83 rain fade is given by equation 21 and evaluates to 0.7308 dB. From this, it can be seen that although the rain fade is 0.83 dB, the corresponding degradation in the downlink is significantly higher (by a factor of 0.7308 dB) due to increased noise detection.

Nominal Figure of Merit $(G/T)_{nom}$

G/T is the ratio of the net antenna gain and total system noise temperature. The ‘nominal figure of merit’ $(G/T)_{nom}$ is the maximum obtainable figure for a given elevation angle and comprises the net antenna gain (Antenna gain – coupling loss) divided by a noise temperature factor made up from contributions of the equivalent receiver noise temperature (i.e. LNB), the coupling noise of inserted polarizers and waveguide components and the ‘clear sky’ modified antenna noise temperature. This is given by equation 30 below. No operational margins are included such as antenna, misalignment losses, ageing, or the increase in antenna noise for a given percentage of time due to rain. $(G/T)_{nom}$ is the highest value of the G/T ratio allowing qualitative comparison between different outdoor units. The higher the ratio the better the system will perform. G/T, in general, is the figure which has the greatest effect on the final carrier-to-noise ratio (C/N).

$$\left(\frac{G}{T}\right)_{nom} = 10\log\left[\frac{10^{0.1\left[G - A_{feed}\right)}}{T_{SYS_{clearsky}}}\right] \quad \text{dB/K} \qquad (30)$$

Where G is the antenna gain (dBi), A_{feed} is the coupling loss (dB) of the waveguide components and $T_{SYSclearsky}$ is the clear sky system noise temperature excluding propagation effects (K).

Example: Using the quantities supplied in the other examples for the link budget, calculate the $(G/T)_{nom}$.

$$\left(\frac{G}{T}\right)_{nom} = 10\log\left[\frac{10^{0.1(36-0.3)}}{215.275}\right] \quad \text{dB/K} = 12.370\text{ dB/K}$$

Usable Figure of Merit $(G/T)_{usable}$

The required G/T parameter needed in a detailed link budget is the 'usable (degraded or minimum) figure of merit $(G/T)_{usable}$. This parameter allows for further operational losses due to antenna pointing errors (discussed below), polarization effects, ageing and the increase in system noise due to precipitation for a given percentage of time. It comprises the net antenna gain (antenna gain – coupling loss – operational losses) divided by the total system noise temperature for rain. This G/T characterizes the 'in-service' performance and is the one used in detailed link budgets as shown in equation 31.

$$\left(\frac{G}{T}\right)_{usable} = 10\log\left[\frac{10^{0.1(G-A_{feed}-\beta)}}{T_{SYS_{rain}}}\right] \quad \text{dB/K} \qquad (31)$$

where G is the antenna gain (dBi), A_{feed} is the coupling loss (dB) of the waveguide components, β is the losses due to antenna pointing errors, polarization errors and ageing (dB) and $T_{SYSrain}$ is modified total system noise temperature which includes the increase in noise temperature due to precipitation for a given percentage of the time (K).

Example: Using the quantities supplied in the other examples for the link budget, calculate the $(G/T)_{usable}$. Assume a value of 0.646 dB for pointing errors, polarization errors and ageing.

$$\left(\frac{G}{T}\right)_{usable} = 10\log\left[\frac{10^{0.1(36-0.3-0.646)}}{254.728}\right] \quad \text{dB/K} = 10.993\ \text{dB/K}$$

To determine β , the contributions to the antenna pointing errors, polarization errors and ageing, which was assumed to be 0.646 dB in the above example, we must first consider the means by which we can obtain the antenna beamwidth.

Antenna Beamwidth θ_0

The half power beamwidth is taken as the width of the main lobe at a point –3dB down. The equations used to calculate the –3dB beamwidth θ_0, depending on the illumination adopted, that is, the aperture distribution used, are presented below,

$$\theta_{0(Uniform)} = 58.4\left(\frac{\lambda}{d}\right) = \frac{17.508}{df_{GHz}} \qquad (32)$$

$$\theta_{0(Co\,sine)} = 72.8\left(\frac{\lambda}{d}\right) = \frac{21.825}{df_{GHz}} \qquad (33)$$

$$\theta_{0(Co\,sine^2)} = 84.2\left(\frac{\lambda}{d}\right) = \frac{25.243}{df_{GHz}} \qquad (34)$$

$$\theta_{0(Pedestal)} = 66.5\left(\frac{\lambda}{d}\right) = \frac{19.936}{d f_{GHz}} \quad (35)$$

Where $\theta_{0,}$ is the 3dB beamwidth (degrees), λ is the carrier wavelength (m), d is the dish diameter (m) and f_{GHz} is the carrier frequency in GHz.
The cosine distribution is close to the average if the illumination method adopted is not known and may be used as a first approximation of the –3 dB beamwidth. This applet has used the cosine distribution (equation 33) in its calculations.

Example: Using the quantities supplied in the other examples for the link budget, calculate the antenna -3dB beamwidth for a cosine distribution.

$$\theta_{0(Cosine)} = \frac{21.825}{(0.649)(11.332)} = 2.968 \text{ degrees}$$

Antenna pointing loss P (dB)

The antenna pointing loss P, may be calculated as

$$P = 12\left[\frac{\theta_1^2 + \theta_2^2 + \theta_3^2}{\theta_{01}^2}\right] \text{ dB} \quad (36)$$

where θ_0 is the half-power beamwidth of the receiving antenna (degrees), θ_1 is the initial pointing accuracy of the fixed mount antenna to the satellite (degrees) – this is typically around 10-20% of the half power beamwidth of the antenna. The applet has taken 15% in its calculations. θ_2 is the pointing stability of the installation due to environmental factors such as wind and ageing (degrees). The applet uses a figure of 0.5 degrees in its calculations. θ_3 is the station keeping accuracy of the satellite (degrees). This figure is typically $\pm$ 0.16 degrees. The applet uses +0.16 degrees built into its calculations.

Example: Using the quantities supplied in the other examples for the link budget, calculate the

Antenna pointing loss if the initial pointing accuracy is 15% of the beamwidth, the pointing stability of the installation is 0.5 degrees and the station keeping accuracy is 0.16 degrees.

$$P = 12\left[\frac{[(0.15)(2.968)]^2 + (0.5)^2 + (0.16)^2}{(2.968)^2}\right] \text{ dB} = 0.645 \text{ dB}$$

The applet gives 0.646 dB due to the higher accuracy in the determination of θ_o. The larger the antenna diameter the greater is the pointing error due to the effects of wind pressure, so larger antennas greater than 1 m have a significant disadvantage in this respect. The pointing stability may be as high as 1° for solid large antennas in windy conditions. The use of mesh dishes can reduce this effect considerably.

See the bottom of the page at this URL for applet: http://aa.1asphost.com/tonyart/tonyt/Applets/Tvro/Tvro.html