# Antenna Noise Temperature for Low Earth Orbiting Satellite Ground Stations at L and S Band

Shkelzen Cakaj
Post and Telecommunication of Kosovo,
Faculty of Electrical and Computing Engineering,
Prishtina University, Kosovo
shkelzen.cakaj@ptkonline.com
shkelzen.cakaj@fulbrightmail.org

Bexhet Kamo, Indrit Enesi, Olimpjon Shurdi
Faculty of Information Technology
Polytechnic University of Tirana, Albania
bkamo@fti.edu.al; ienesi @fti.edu.al;
oshurdi@fti.edu.al

*Abstract* - **Low Earth Orbit (LEO) satellites are used for public communications and for scientific purposes. Most of the scientific satellites communicate with ground stations at S - band. Environmental satellites usually contain also equipment for search and rescue services communicating with ground terminals at L - band. The antenna noise temperature impacts satellite ground station performance. Antenna noise temperature is a measure of the effective noise integrated over the entire antenna pattern. On these bands the ionosphere effects are negligible. Heavy rain attenuation is considered as the most important atmospheric factor on determining antenna temperature on L and S bands. In this paper, the calculation and comparison of antenna noise temperature, caused under the worst propagation case, of the hypothetical satellite ground station implemented in different cities of Europe is given.**

***Keywords - LEO; Satellite; Antenna; Noise; Temperature***

## I. INTRODUCTION

Low Earth Orbit (LEO) satellites provide opportunities for investigations for which alternative techniques are either difficult or impossible to apply. Thus, it may be expected that such missions will be further developed in the near future especially in fields where similar experiments by purely Earth-based means are impracticable. Ground stations have to be established in order to communicate with such satellites, and the quality of communication depends on the performance of the satellite ground station, in addition to that of the satellite [1]. The downlink performance is commonly defined through a receiving system *Figure of Merit.* Figure of Merit depends on system noise temperature, consequently on antenna noise temperature [2]-[4]. The concern of this paper is the variation of antenna noise temperature at L and S band in Europe [5], [6].

At Section II, the concept of downlink budget expressed by range equation, the downlink margin and Figure of Merit are given. A general overview of system temperature, considering the best and the worst propagation case is presented at Section III. The paper aims to compare heavy rain attenuation impact on antenna noise temperature at different cities in Europe, as covered by Section IV.

## II. DOWNLINK BUDGET

In downlink budget calculations, of the greatest interest is receiving system signal to noise ratio [*(S/N)* or *(S/N₀)*] expressed by *range equation* [7], as:

$$\frac{S}{N_0} = \frac{EIRP(G/T_S)}{kL_S L_0} \tag{1}$$

where *EIRP* is Effectively Isotropic Radiated Power from the transmitter. Considering that $N=N_0B$, $N_0=kT$ where, $N_0$ is spectral noise density, $B$ receiver bandwidth, $k = 1.38\cdot 10^{-23}$ W/HzK is Boltzmann's constant, and expressing Eqn. 1 in decibels yields:

$$\frac{S}{N_0}(dB) = EIRP - L_S - L_0 + G/T_S + 228.6 \tag{2}$$

$L_S$ is free space loss and $L_0$ denotes other losses (polarization loss, misspointing etc). The downlink margin (*DM*) is defined as:

$$DM = (S/N)_r - (S/N)_{rdq} \tag{3}$$

where the *r* indicates expected signal to noise ratio to be *received* at receiver, and *rqd* means *required* signal to noise ratio by customer, based on defined performance. So, a positive value of *DM* is an indication of a good system performance. In efforts to maintain a positive link margin, we might trade among parameters of range equation. If all parameters of the link are rigorously treated (the worst case), high link margin is not needed to be designed. In satellite industry expressions *"link can be closed"* and *"link can not be closed"* are often used, meaning respectively that error performance satisfies or not satisfies [7].

The reception quality of the satellite receiving system is commonly defined through a *Receiving System Figure of Merit* as $G/T_S$ [7]:

$$T_S = T_A + T_{comp} \tag{4}$$

where $G$ is receiving antenna gain, $T_S$ is receiving system noise temperature, $T_A$ is antenna noise temperature and $T_{comp}$ is composite noise temperature of the receiving system, including lines and equipment. The Figure of Merit $G/T_S$ expresses the impact of external and internal noise factors.

## III. SYSTEM TEMPERATURE

Schematically the satellite ground station receiving system and environment concept is presented in Figure 1.

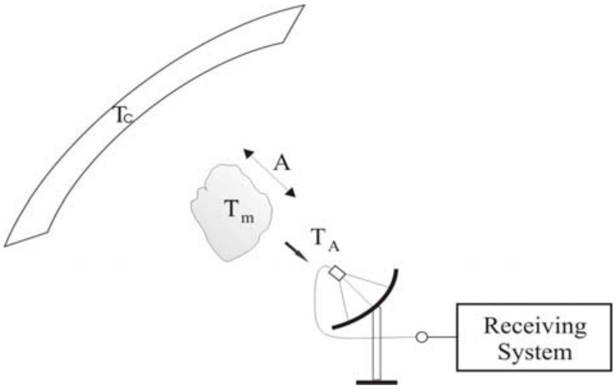

Figure 1. Satellite ground station and environment.

In Figure 1, $T_C$ represents the sky noise temperature, $T_m$ is medium temperature and $A$ is medium attenuation. It is clear that unwanted noise, is in part, *injected via antenna* $(kT_AB)$ and a part is *generated internally* $(kT_{comp}B)$ by line loss and equipment [7], [8].

### A. *Antenna temperature*

In front of receiving antenna different noise sources (natural, man-made or interferences) are present. The antenna temperature depends on where the antenna is looking at. From this surrounding environment (external sources) antenna will pick up a part of this noise power as:

$$N_A = kT_AB \tag{5}$$

where B is receiver's bandwidth.

Under assumptions, that solid angle subtended by the noise source is much larger than antenna solid angle, antenna sees the sky without medium attenuation and antenna itself is considered lossless, then antenna noise temperature $T_A$ is equal to the sky noise temperature $T_C$.

$$T_A = T_C \tag{6}$$

Referring to [6] at L and S band the sky noise temperature is $T_C$ = (3-10) K. This is *the best propagation* case, where $T_A = T_C$.

Due to an atmospheric process the absorption increases the antenna noise temperature. If it is considered the total cosmic temperature as $T_C$, the absorptive medium temperature as $T_m$ and the attenuation due the absorptive process as $A$, then antenna noise temperature $T_A$ is [8]:

$$T_A = T_m(1-10^{-A/10}) + T_C 10^{-A/10} \tag{7}$$

$T_C$ is 3K to 10K and $T_m$ from 275K to 290K for rain. [6]. LEO satellites move too fast over the ground station. Ground station's antenna has to track the satellite's movement. Thus, the antenna's elevation angle varies, also. Considering sky noise temperature as $T_C = 10$ K, antenna noise temperature as function of elevation angle is presented in Figure 2 [3].

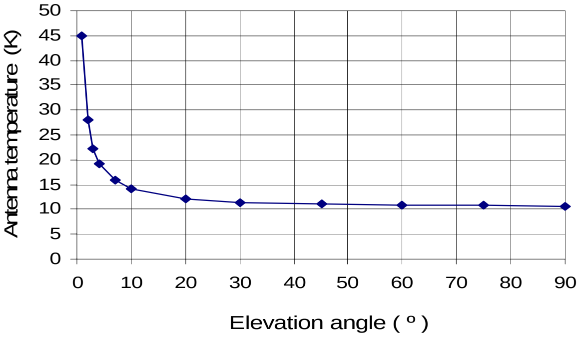

Figure 2. Antenna noise temperature

Figure 2, shows that under a perpendicular elevation angle it is the lowest antenna temperature.

### B. *Rain attenuation*

Atmospheric attenuation depends mainly on the liquid water content along the propagation path. For the link budget calculation, including all types of hydrometeors, it is sufficient as the worst propagation case in Europe to be considered a heavy rain.

The attenuation of a wave due to rain depends on the following: number of raindrops along the path, the size of drops and the length of the path through the rain. If $P_r(0)$ is the signal power before the rain region, $P_r(r)$ is the signal power after the rain region, and $r$ is the path length through the rain region, then the propagation loss $L$ (in decibels) because of rain attenuation is given by [8]:

$$L = 10\log\frac{P_r(0)}{P_r(r)} \tag{8}$$

ISBN: 978-1-61208-128-1

In practice, the propagation loss due to rain attenuation is usually expressed via the *specific attenuation* $\gamma$ in [dB/km] so, the propagation loss *L* is:

$$L = \gamma \cdot l_r \qquad (9)$$

where $\gamma$ is the specific rain attenuation expressed in [dB/km] and $l_r$ is rain path length in [km]. Specific attenuation depends on rain structure (including drops' radius $r_d$ , drop size distribution $n(r)$ , rain refractive index $m$) and frequency $f$ as:

$$\gamma = F[r_d, n(r), m, f] \qquad (10)$$

But, based on the specific attenuation model of ITU-R [8] it is found that $\gamma$ (*specific rain attenuation*) depends only on the rainfall rate *R*, measured on the ground in millimeters per hour. From this empirical model, the usual form of expressing $\gamma$ is:

$$\gamma = a \cdot R^b \left[\text{dB/km}\right] \qquad (11)$$

where $a$ and $b$ are constants which depend on frequency, polarization and average rain temperature [8]. Table I, shows values of $a$ and $b$ at various frequencies at 20 $^0$C for both polarizations [ITU 838, ITU-R P838-1].

TABLE I. PARAMETRS OF EMPIRICAL RAIN ATTENUTION MODEL

| Frequency (GHz) | $a_h$ | $b_h$ | $a_v$ | $b_v$ |
|---|---|---|---|---|
| 1.0 | 0.0000259 | 0.9691 | 0.0000308 | 0.8592 |
| 1.5 | 0.0000443 | 1.0185 | 0.0000574 | 0.8957 |
| 2.0 | 0.0000847 | 1.0664 | 0.0000998 | 0.9490 |
| 2.5 | 0.0001321 | 1.1209 | 0.0001464 | 1.0085 |
| 3.0 | 0.0001390 | 1.2322 | 0.0001942 | 1.0688 |
| 3.5 | 0.0001155 | 1.4189 | 0.0002346 | 1.1387 |
| 4.0 | 0.0001071 | 1.6009 | 0.0002461 | 1.2476 |

The specific rain attenuation depends on the geographical location of the ground station, respectively on rainfall rate at that location. A normal rain fall rate in Central Europe is 5 [mm/h]. For most of Europe a rainfall rate of 30 [mm/h] is suitable, except for some of Mediterranean regions where rainfall rates up to 50 [mm/h] have to be used [5], [6], [8]. Considering Eqn. 11 and Table I, it is calculated specific rain attenuation for different rainfall rates at different frequencies (L and S band) for horizontal and vertical polarization, presented in Table II and Table III.

TABLE II. SPECIFIC RAIN ATTENUATION FOR HORIZONTAL POLARIZATION AT 20 $^0$C.

| Rainfall rate (mm/h)<br>Frequency (GHz) | *R*=30 | *R*=40 | *R*=50 |
|---|---|---|---|
| 1.0 | 0.000699 | 0.000924 | 0.001147 |
| 1.5 | 0.001415 | 0.001897 | 0.002381 |
| 2.0 | 0.003184 | 0.004328 | 0.005491 |
| 2.5 | 0.005978 | 0.008253 | 0.010599 |
| 3.0 | 0.009185 | 0.013094 | 0.017237 |
| 3.5 | 0.014403 | 0.021664 | 0.029733 |
| 4.0 | 0.024803 | 0.039312 | 0.056191 |

TABLE III. SPECIFIC RAIN ATTENUATION FOR VERTICAL POLARIZATION AT 20 $^0$C.

| Rainfall rate (mm/h)<br>Frequency (GHz) | *R*=30 | *R*=40 | *R*=50 |
|---|---|---|---|
| 1.0 | 0.000572 | 0.000732 | 0.000887 |
| 1.5 | 0.001207 | 0.001562 | 0.001908 |
| 2.0 | 0.002517 | 0.003307 | 0.004087 |
| 2.5 | 0.004520 | 0.006042 | 0.007567 |
| 3.0 | 0.007362 | 0.010012 | 0.012708 |
| 3.5 | 0.011280 | 0.015652 | 0.020181 |
| 4.0 | 0.017138 | 0.024456 | 0.032415 |

Table II and Table III confirm that the specific rain attenuation increases with rainfall rate and frequency. For the same frequency and the same rainfall rate it is lower rain attenuation for vertical polarization, thus, vertical polarization is more convenient for communication under rain conditions. Passing through a rain medium, except the attenuation the polarization state of a wave can change also; such a vertical polarized wave can occur as a horizontal polarized wave. This is called *rain depolarization*. Depolarization depends on rain attenuation. Lower rain attenuation means less depolarization loss and vice versa. Problem of depolarization is avoided applying circular polarization, what is the most applicable polarization for satellite communication. Since, horizontal polarization is more sensitive on rain, representing the worst propagation case from the polarization point of view, further analyses relate on horizontal polarization. Specific rain attenuation for different frequencies and different rainfall rates for horizontal polarization as the worst case is presented in Figure 3.

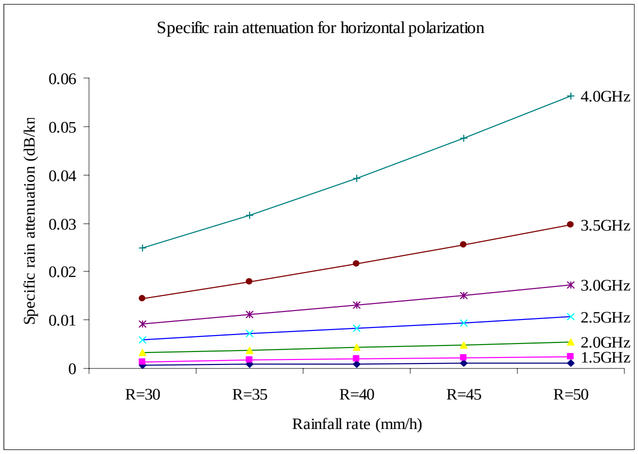

Figure 3. Specific rain attenuation for horizontal polarization.

Rain attenuation *A* [dB] depends on the specific rain attenuation $\gamma$ and the rain path length $l_r$ . The rain attenuation path length geometry is presented in Figure 4 [8].

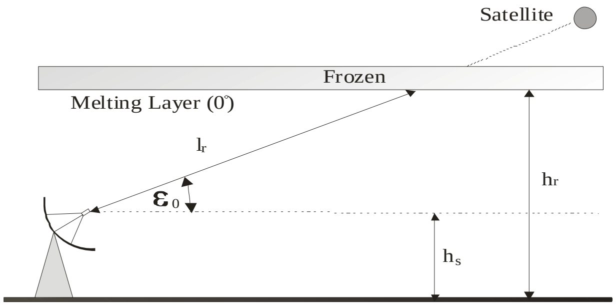

Figure 4. Rain attenuation path geometry.

All heights in Figure 4 are considered above mean sea level and $\varepsilon_0$ stands for the elevation angle. The effective rain height $h_r$ in Figure 4, is the same as the height of the melting layer, where the temperature is usually around 0 $^0$C. The representative values for effective rain height vary according to the latitude $\phi$ of the ground station. Since Europe belongs to the Northern Hemisphere, these values expressed in [km], are given by [8]:

$$\begin{aligned} h_r &= 5 - 0.075(\phi - 23) \text{ for } \phi > 23 \\ h_r &= 5 \text{ for } 0 \le \phi \le 23 \end{aligned} \tag{12}$$

The rain path length from the Figure 4 can be expressed as:

$$l_r = \frac{h_r - h_s}{\sin \varepsilon_0} \tag{13}$$

where the $h_s$ is altitude of the ground station. Thus, the rain attenuation *A* (dB) for rain path length $l_r$ is:

$$A = \gamma l_r = aR^b l_r = aR^b \frac{\Delta h}{\sin \varepsilon_0} \tag{14}$$

where is $\Delta h = h_r - h_s$ . For rain paths under too low elevation angle (ex. $\varepsilon_0 < 5^0$), it is necessary to take into the account the variation of rain in the horizontal direction [8].

LEO satellites move too fast over the Earth. Obviously, the satellite's path length over the ground station for different passes is not the same [1]; consequently the rain path length between the satellite and the ground station is not constant and varies for each orbit path. Considering the whole horizon in the azimuth range of 0° - 360°, in any direction of the horizon plane the natural barriers will differ [9]. The practical acquisition and loss elevation values ranges from 1°- 4°. In order to avoid the problem of natural barriers, designers predetermine the lowest elevation of the horizon plane which is applied during link budget calculations. The horizon plane with a predetermined minimal elevation is considered the *designed horizon plane*. Usually, for meteorological and search and rescue satellites operating on S and L band respectively, the ground station horizon plane is defined above 5° elevation [10] [11]. By this reason all further analyses as the worst case consider the communication under 5 ° elevations. For rain attenuation calculations, some cities of Europe are chosen where hypothetically is supposed to be implemented a satellite ground station dedicated for scientific or search and rescue services. The horizon plane of ground stations is supposed above 5° elevation. From the http://earth.google.com/ are provided latitude and altitude of these cities and presented in Table V. Rain path length is calculated based on Eqn. 13.

TABLE V. ALTITUDE, LATITUDE AND RIAN PATH LENGTH.

| Location | Altitude ($h_s$) [m] | Latitude [°] | $h_r$ [km] | $l_r = \frac{h_r - h_s}{\sin 5^0}$ [km] |
|---|---|---|---|---|
| Madrid | 588 | 40.4 | 3.695 | 35.7 |
| Tirana | 104 | 41.3 | 3.625 | 40.4 |
| Rome | 14 | 41.9 | 3.582 | 41.0 |
| Prishtina | 65 | 42.6 | 3.525 | 33.0 |
| Zagreb | 130 | 45.8 | 3.290 | 36.3 |
| Vienna | 190 | 48.2 | 3.110 | 33.5 |
| Paris | 34 | 48.8 | 3.060 | 34.8 |
| Brussels | 76 | 50.8 | 2.915 | 32.6 |
| London | 14 | 51.5 | 2.862 | 32.7 |
| Berlin | 34 | 52.5 | 2.786 | 31.6 |

Applying Eqn. 14 it is calculated rain attenuation in (dB) for heavy rain storm in Europe (*R*=50mm/h) under 5° elevation and horizontal polarization as the worst propagation case for the link budget and presented in Table VI.

TABLE VI. RAIN ATTENUATION (dB) IN EUROPE AT 5º EL.

| Location | 1GHz | 2GHz | 3GHz | 4GHz |
|---|---|---|---|---|
| Madrid | 0.041 | 0.196 | 0.615 | 2.000 |
| Tirana | 0.046 | 0.221 | 0.696 | 2.270 |
| Rome | 0.047 | 0.225 | 0.706 | 2.303 |
| Prishtina | 0.037 | 0.181 | 0.568 | 1.854 |
| Zagreb | 0.041 | 0.199 | 0.625 | 2.039 |
| Vienna | 0.038 | 0.184 | 0.577 | 1.882 |
| Paris | 0.039 | 0.191 | 0.599 | 1.955 |
| Brussels | 0.037 | 0.179 | 0.561 | 1.831 |
| London | 0.037 | 0.179 | 0.563 | 1.837 |
| Berlin | 0.036 | 0.173 | 0.544 | 1.775 |

Results from Table VI are graphically given in Figure 5. The variation in rain attenuation for the highest rainfall rate in Europe is presented in Figure 6.

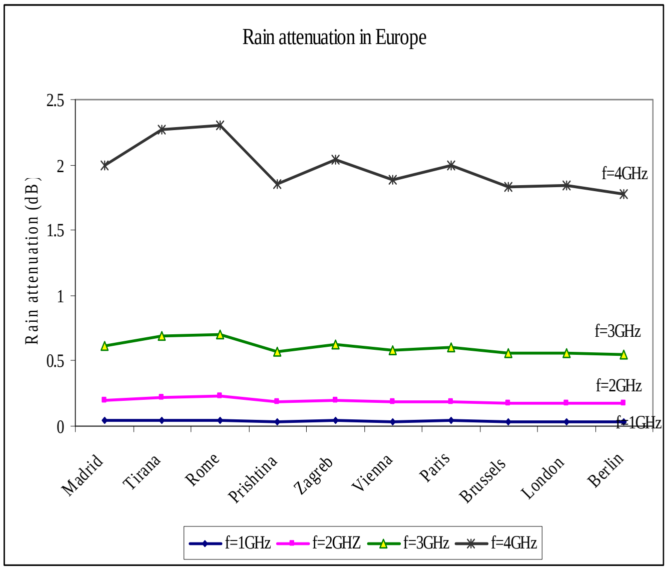

Figure 5. Rain attenuation in Europe.

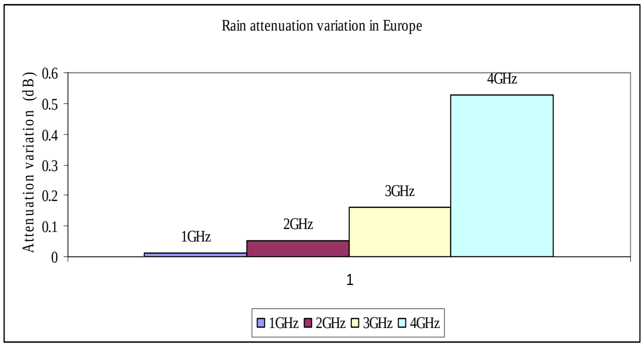

Figure 6. Rain attenuation variation in Europe.

Rain attenuation variation at 2GHz is less than 0.16dB and at 4GHz is less than 0.6dB. This is the first indication that the satellite ground station will perform approximately equally in different cities.

## IV. ANTENNA TEMPERATURE COMPARISON

Considering Eqn 7 about antenna temperature calculation and data from Table VI related to heavy rain attenuation in Europe (*R*=50mm/h) under 5º elevation as the worst propagation case, it is calculated antenna noise temperature and presented in Table VII. For these calculations it is considered $T_C = 10$ K and $T_m$=290K.

TABLE VII. ANTENNA TEMPERATURE (K) IN EUROPE AT 5º EL.

| Location | 1GHz | 2GHz | 3GHz | 4GHz |
|---|---|---|---|---|
| Madrid | 12.6 | 22.3 | 46.9 | 113.3 |
| Tirana | 12.9 | 23.8 | 51.4 | 123.9 |
| Rome | 13.0 | 24.1 | 52.0 | 125.2 |
| Prishtina | 12.3 | 21.7 | 44.3 | 107.0 |
| Zagreb | 12.6 | 22.4 | 47.4 | 114.8 |
| Vienna | 12.4 | 21.6 | 44.8 | 108.5 |
| Paris | 12.5 | 22.4 | 46.0 | 111.5 |
| Brussels | 12.3 | 21.3 | 43.8 | 106.3 |
| London | 12.3 | 21.3 | 43.8 | 106.3 |
| Berlin | 12.3 | 20.9 | 42.9 | 103.9 |

Data from Table VII in Figure 6 and Figure 7 are given.

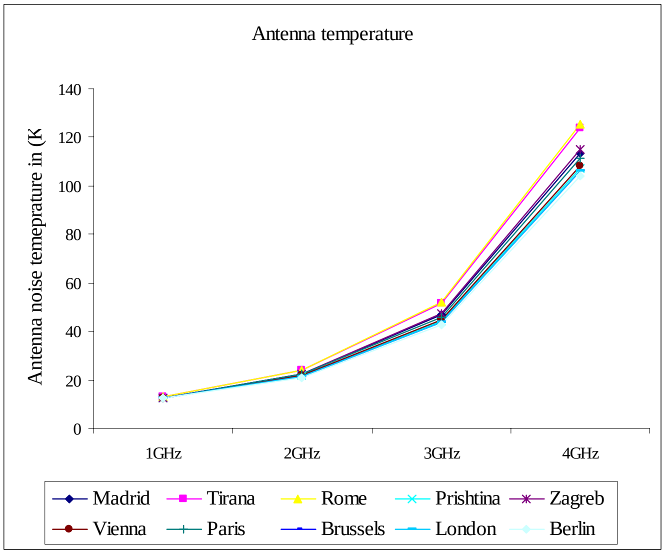

Figure 7. Antenna temperature in Europe.

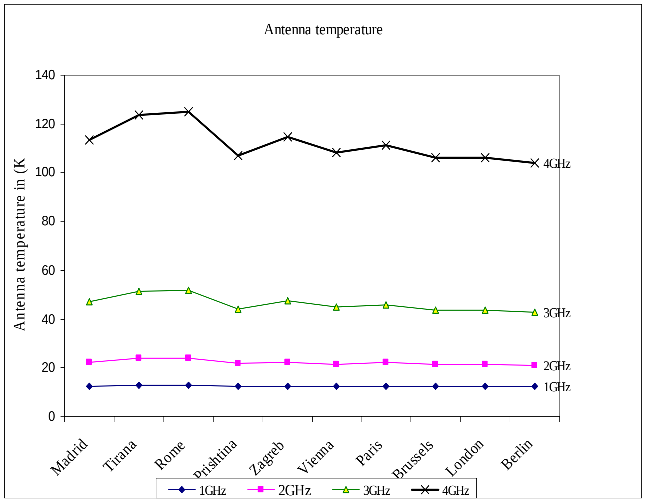

Figure 8. Antenna temperature in Europe.

Figure 6, confirms the fact that antenna noise temperature increases approximately exponentially with the raise on frequency. Figure 7 and Figure 8, show that the variation in antenna noise temperature among European cities increases with raise of frequency, also. The difference of the highest and the lowest antenna noise temperature for European cities is presented in Table VIII.

TABLE VIII. ANTENNA NOISE TEMPERATURE (K) DIFFERENCE

| Frequency | 1GHz | 2GHz | 3GHz | 4GHz |
|---|---|---|---|---|
| Ant. temp. $\Delta T_A$ (K) | 0.7 | 3.2 | 9.1 | 21.3 |

Obviously with raise on frequency this difference increases, and for 1GHz and 2GHz it is negligible. This means that communication between satellites and ground stations at L band, dedicated for search and rescues services, will have very similar performance in Europe. At S band, the upper edge at 4GHz is considered. For the case of communication on 4 GHz, it is considered a hypothetical ground station with composite temperature (including lines and equipment) of $T_{comp} = 70$ K [12] and receiving antenna with gain of $G = 35$ dBi. For the ground station implemented in Rome, where the antenna noise temperature is the highest, yields the Figure of Merit as:

$$\left(\frac{G}{T_S}\right)_{ROME} = 12.1dB \tag{15}$$

Further, considering the same equipment implemented in Berlin, where the antenna noise temperature is the lowest, yields the Figure of Merit as:

$$\left(\frac{G}{T_S}\right)_{BERLIN} = 12.6dB \tag{16}$$

The difference in Figure of Merit, between Rome and Berlin as cities with the highest and the lowest antenna temperature caused because of heavy rain under very low elevation angle of 5º, it is 0.5 dB. Considering that the most of communication among satellites and ground stations is above 5º, ground station will perform almost similarly at most of Europe in L and S band.

## V. CONCLUSION

The antenna noise temperature has an effect to the link performance expressed by range equation. Only rain attenuation on antenna temperature is considered. Other local influences are not subject of this paper. Considering horizontal polarization transmission, and heavy rain under too low elevations as the worst propagation case, it is confirmed that the reception quality of a ground station within central Europe at L and S bands does not highly depend on location. The difference in Figure of Merit, between Rome and Berlin as cities with the highest and the lowest antenna temperature under the worst propagation case, it is always less than 0.5 dB at L and S band. This low difference in Figure of Merit, become negligible at circular polarization applications.

## REFERENCES

[1] S. Cakaj and K. Malaric, “Rigorous analysis on performance of LEO satellite ground station in urban environment,” International Journal of Satellite Communications and Networking, Vol. 25, No. 6, pp. 619–643, UK, November/December 2007.

[2] D. Roddy, “Satellite communications”, McGraw Hill, New York 2006.

[3] M. Richharia, “Satellite communication systems”, McGraw Hill, New York 1999.

[4] G. Maral and M. Bousquet, “Satellite communication systems”, John Willey & Sons, Ltd, Chichester, England, 2002.

[5] S.Cakaj and K. Malaric , “Rain attenuation at Low Earth Orbiting satellite ground stations”, 48th International Symposium ELMAR 2006 focused on Multimedia Systems and Applications 7-09, IEEE June 2006, Zadar , Croatia, pp. 247-250.

[6] S. Cakaj and K. Malaric, “Rain Attenuation Modelling for Low Earth Orbiting Satellite Ground Station at S- band in Europe”, 18th IASTED International Conference on Modelling and Simulation, MS 2007, May 30 –June 1 2007, IASTED, Montreal , Canada, pp. 17-20.

[7] B. Sklar, “Digital Communication”, Prentice Hall PTR, New Jersey 2005.

[8] S.R. Saunders, “Antennas and propagation for wireless communication system”, John Willey & sons, Inc, 1993.

[9] S. Cakaj, “Practical Horizon Plane and Communication Duration for Low Earth Orbiting (LEO) Satellite Ground Stations”, WSEAS Journal: Transactions on Communications, Issue 4, Volume 8, April 2009, pp. 373-383.

[10] I. W. Taylor and M. O. Vigneault, “A neural network application to search and rescue satellite aided tracking (SARSAT), In Proceedings of the Symposium/ Workshop on Applications of Experts Systems in DND, pp. 189 -201, Royal Military Coll. of Canada, 1992.

[11] C. Bulloch, “Search and Rescue by satellite – Slow steps toward an operational system”, Interavia (ISSN 0020 -5168), vol.42, pp. 275 – 277, 1987.

[12] S. Cakaj and K. Malaric “Composite Noise Temperature at Low Earth Orbiting Satellite Ground Station”, International Conference on Software, Telecommunications and Computer Networks, SoftCOM 2006, IEEE Sep. 29 –Oct.1 2006, Split , Croatia, pp.214-217.