Antenna Noise Temperature Calculator

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Abstract: *Designers of antennas and their associated components presently enjoy the convenience of performing fast, accurate, automated, design-related calculations due to the availability of a multitude of software "design tools" for modeling electromagnetic fields. Computations involved with specific problems such as antenna noise temperature, however, require supplementary software tools to augment the capability of these general purpose state-of- the-art professional programs. To address this need, we have developed the "Antenna Noise Temperature Calculator" software program that utilizes either modeled or measured radiation patterns to calculate antenna noise performance parameters.*

1. Introduction

Design objectives for Cosmic-to-Earth radio communication systems mandate a very low receiver noise budget to permit reception of extremely weak signals. In this respect, antenna-temperature interaction plays a critical role in the receiving chain's noise performance. The antenna temperature performance calculation is conceptually described as multiplying the spatial function of antenna gain by the temperature distribution of the space surrounding the antenna, integrated over all space.

The antenna noise temperature calculation in spherical coordinates is given by the formula:

$$Ta = \frac{\int_0^{2\pi}\int_0^{\pi} G(\theta,\phi)Tb(\theta,\phi)\sin\theta\, d\theta\, d\phi}{\int_0^{2\pi}\int_0^{\pi} G(\theta,\phi)\sin\theta\, d\theta\, d\phi} \tag{1}$$

Where

Ta is the antenna noise temperature in a given direction
Tb is the environmental noise temperature
G is antenna gain

Our Antenna Noise Temperature Calculator program (also referred to as ANTC) computes antenna noise using antenna radiation patterns input from CST Microwave Studio Software [1], FEKO Software [2] or from an actual antenna measurement. Antenna noise temperature is calculated for elevation angles from 0 to 90 degrees in single degree increments. ANTC also enables the calculation of system noise and average noise temperatures.

2. Axes and Angles Defined

Orientation of axes and angles used with spherical coordinates are shown in Fig.1. The antenna elevation angle, Alpha, also shown in Fig. 1, ranges from 0 to 90 degrees, from horizon to zenith respectively. The angles and axes convention for measured data is shown in Fig. 2. The incremental angle for radiation pattern data calculated by CST and FEKO software is 1 degree for both Theta and Phi or 1 degree Theta increments for a maximum of four angles of measured Phi data. The angles and axes convention [3] for environmental noise temperature is the same as for computed radiation patterns.

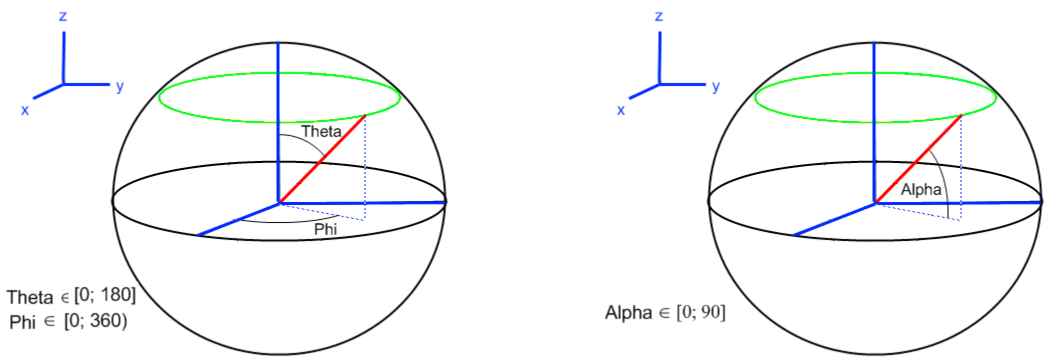

Fig. 1 Definition of spherical coordinates (left) and elevation angle Alpha (right)

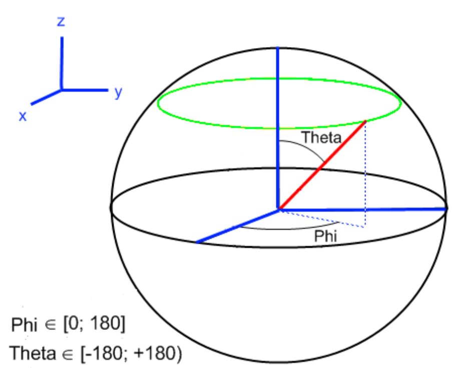

Fig. 2 Definition of spherical coordinates for measured data

3. Main Computation

ANTC software, written in C++ programming language, was developed in parallel with a corresponding MATLAB program to verify the basic claculations. wxWidgets and pplot libraries were used for the graphical interface and for plotting curves in our C++ program. The program is based on formula (1) and uses the following sequential steps:

a. Read and (if necessary) convert the scale of the radiation pattern and environmental noise temperature
b. Multiply the radiation pattern by the function sin(Theta)

c. Calculate radiated power for antenna radiation pattern normalization
d. Rotate the environmental noise temperature by angle Alpha around the X-axis, using precalculated rotation matrices
e. Multiply the rotated environmental noise temperature by the radiation pattern
f. Integrate results from the previous step over angles Phi and Theta
g. Divide the result of this integration by radiated power. This result is the antenna noise temperature for the appropriate angle alpha

Some of the more important attributes of the C++ version of ANTC are described in the following sections.

3.1. Reading the Radiation Pattern and Environmental Noise Temperature

Radiation Pattern

Input radiation patterns may be obtained from antenna simulation software or from direct measurements. The user selects the source of the input radiation pattern (CST, FEKO or Measured) and the scale type (Linear or Logarithmic) using the input selector switch shown in Fig. 3. Input files must have the specified data format associated with the selected file type. This is checked during file reading and an error message appears if an incorrect format is detected. Since data files from CST MW Studio and FEKO software contain more data than ANTC needs, the program loads only the necessary data.

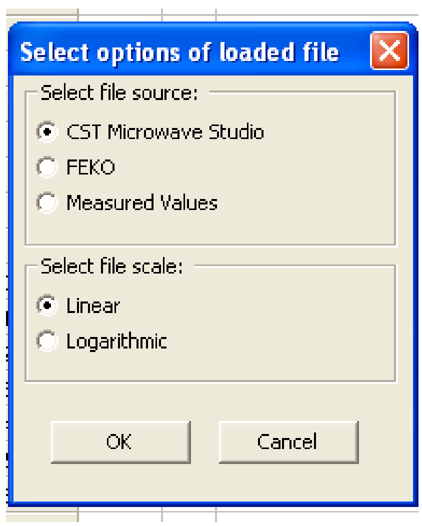

Fig. 3 Input data selector

If the "Measured Values" button is selected, the "Select Measured Files" dialog window is opened. See Fig. 4. Here the user loads and may, optionally, modify the measured data, which are displayed in four tables. At least one and a maximum of four tables must be populated. For measured data, ANTC calculates a mean value from the number of loaded radiation patterns. An axially symetric radiation pattern around the Z axis is created in this manner. The software then tranforms the coordinates according to the definition shown in Fig. 1 left.

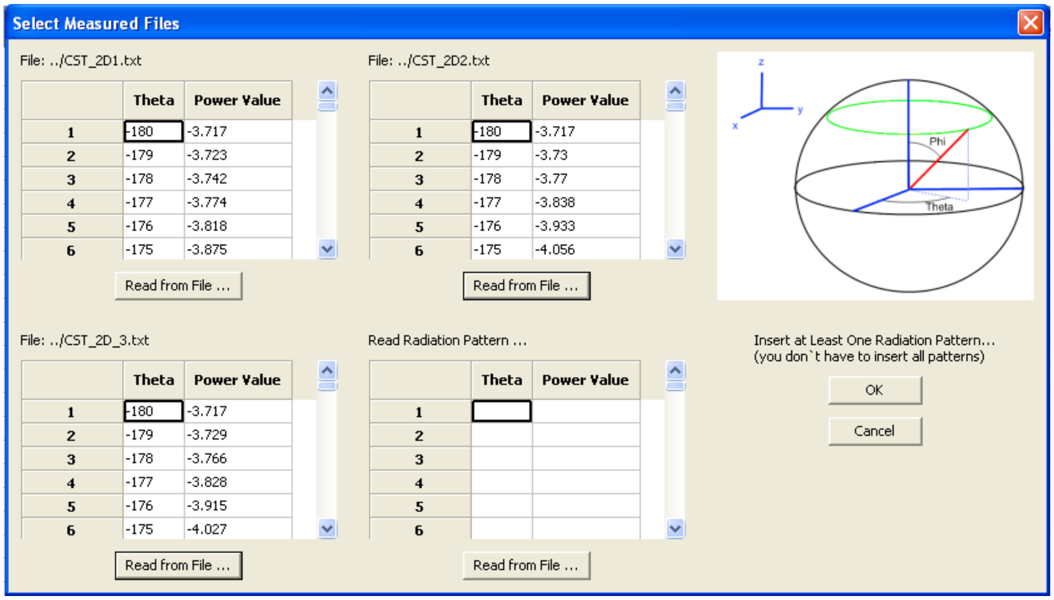

Fig. 4 The measured data dialog window

Environmental Noise Temperature

Environmental noise temperature depends on frequency. Tables of environmental noise temperature for some important frequencies are included in ANTC. These temperature tables were created based on ITU documents CCIR rep. 720-2 [4]. The user may select a frequency-implicit noise temperature table in the noise temperature dialog box (see Fig. 5) or define one's own environmental noise temperatures and input them. The data format of an input noise temperature file must be the same as the format of tables of implicit noise temperatures. Environmental noise temperatures for frequencies below 1 GHz are very much affected by cosmic and man-made noise. Consequently, implicit values for 0.15 GHz and 0.5 GHz are provided as convenient approximations. For better results, actual measured or defined values should be used.

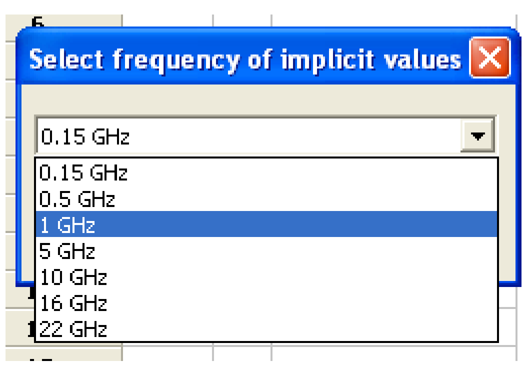

Fig. 5 Environmental noise temperature dialog box

3.2. Enviromental Noise Temperature Matrix Rotation

To calculate antenna noise temperature for a desired angle alpha, we must rotate the enviromental noise temperature matrix or antenna radiation pattern through the angle Alpha. In ANTC, we choose to rotate noise temperature due to its lower range of values, in what is from a mathematical point of view an equivalent operation. The first versions of the C++ program (to version 3.0) employed a direct rotation of the noise temperature matrix. Since rotation in spherical coordinates is very complicated, the data format was converted to Cartesian coordinates prior to performing a Cartesian rotation using the following formulae:

$$\begin{aligned} x &= r * \cos(Phi) * \sin(Theta) \\ y &= r * \sin(Phi) * \sin(Theta) \\ z &= r * \cos(Theta) \end{aligned} \qquad (2)$$

We then multiplied the converted matrix by the Euler rotational matrix around the X axis with parameter Alpha. For our definition of angle Alpha (See Fig. 1 right), the Euler matrix for rotation around the X axis is:

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) \\ 0 & -\cos(\alpha) & \sin(\alpha) \end{pmatrix} \qquad (3)$$

A 3-D graphical illustration of noise temperature matrix rotation is shown in Fig. 6.

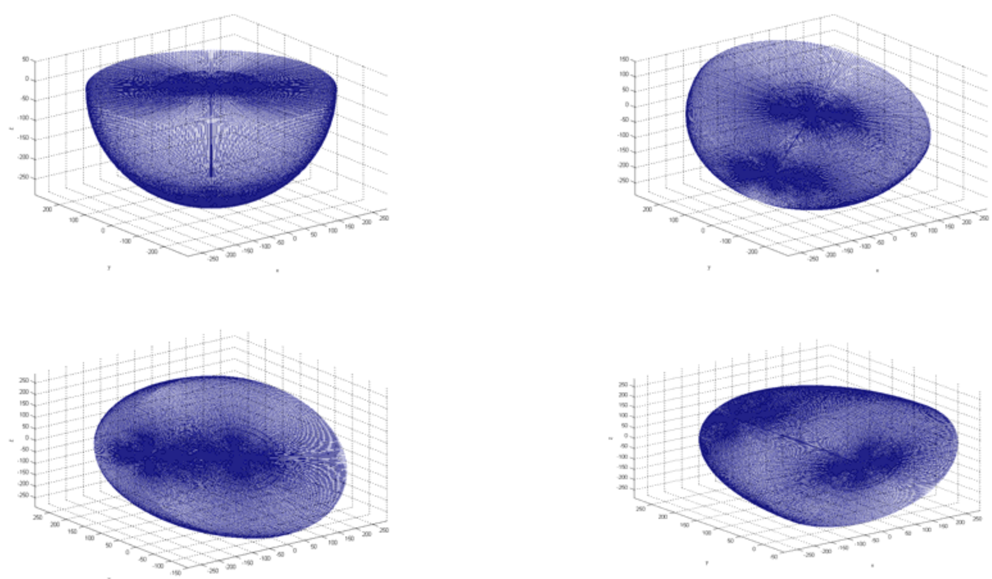

Fig. 6 Rotation of noise matrix around axis X. 0° deg.-top left, 30° deg.-top right, 60° deg.-bottom left, 90°-bottom right

Next, the rotated noise temperature matrix was converted back to spherical coordinates. The formulae used for converting to spherical coordinates are:

$$\begin{aligned} r &= \mathrm{sqrt}(x^2+y^2+z^2) \\ Phi &= \mathrm{atan2}(x, y) \qquad (4) \\ Theta &= \mathrm{acos}(z / r) \end{aligned}$$

Since transformation of the noise matrix according to formula (2) and reverse transformation of the rotated noise matrix according to formula (4) are based on circular functions, the resulting rotated noise matrix in spherical coordinates has non-linear scales for angles Theta and Phi. For subsequent calculations it was necessary to find the nearest value of noise temperature for the appropriate angles Theta and Phi of the radiation pattern. The most accurate calculation is based on finding the great circle minimum deviation by the formula:

$$\Delta\sigma = 2r\,arcos\sqrt{\sin^2([\theta 1-\theta 2]/2)+\sin\theta 1*\sin\theta 2*\sin^2([\phi 1-\phi 2]/2)} \qquad (5)$$

where

$\Delta\sigma$ is the minimum distance deviation
r is the great circle radius
θ_1, $\theta 2$, φ_1, φ_2 are angles the of radiation pattern and noise temperature expressed in spherical coordinates

Using equation (5) for sorting is very time consuming. To increase computation speed, ANTC sorts based on the following formula:

$$\Delta\sigma_\varphi = |\ \varphi_1 - \varphi_2\ | \qquad (6)$$

After sorting data for angles φ in accordance with formula 6, the following, similar, formula for angles θ is applied:

$$\Delta\sigma_\theta = |\ \theta_1 - \theta_2\ | \qquad (7)$$

Taking into account user feedback, we revised our method of noise matrix rotation. Our goals were to increase the program speed and enhance performance, reliability and precision. The most critical modification to the original ANTC software was streamlining the bi-directional spherical-Cartesian coordinate conversions. Also, improvements were made in sorting the rotated matrix values, which previously slowed calculations.

Our new matrix rotation method is based on angular transformation of a unit sphere in spherical coordinates. Equations (2), (3) and (4) are applied to a unit sphere for alpha angles between 0 and 90 degrees. Each element of the basic matrix (not the rotated unit sphere) has its own associated index. After applying equations (2), (3) and (4), we find the appropriate element with appropriate index in the basic matrix for each rotated element of the unit sphere. This is accomplished using formulae similar to (6) and (7). Thus we create 90 matrix files with a pair of indices in txt format using MATLAB software. During the calculation, ANTC software selects the corresponding rotation matrix and assorts actual noise matrix elements according to rotation matrix indices. In this manner, the noise matrix rotation is transformed into processes of sorting elements.

3.3. Integration of results from previous step over angles Phi and Theta

"Trapezoidal integration," a numerical integration method, is employed to integrate results from the previous step over angles Phi and Theta using the following formula:

$$\begin{aligned} A_T &= \sum_{i=0}^{n} \frac{\Delta x}{2} \left(f(x_i) + f(x_{i+1}) \right) \\ &= \frac{\Delta x}{2} \left(f(x_0) + 2f(x_1) + 2f(x_2) + \cdots + 2f(x_{n-1}) + f(x_n) \right) \end{aligned} \quad (7)$$

Since double integration over all space must be performed, all values of items with the same angle Phi are added together (the first and the last item with the same Phi angle are added after multiplying these values by ½) thereby performing integration over angle Theta. Then an integration is performed over angle Phi (the first and the last item are added after these values are multiplied by ½).

4. Additional Features

4.1. Plotting

When antenna noise temperature is calculated, a plot with calculated values appears in a pop-up window. Calculated noise temperature is displayed as a function of an elevation angle. The user may also display the plot by choosing "Tools->Draw Graph of Noise Temperature." The displayed plot may be saved as a ".bmp file" by pressing "Save Plot" in the displayed dialog window.

4.2. System Noise Temperature

When antenna noise temperature is calculated, system noise temperature may be calculated as well. System noise temperature Ts and system G/Ts ratio are calculated from antenna noise temperature for a given elevation angle and receiver noise figure. See Fig. 7.

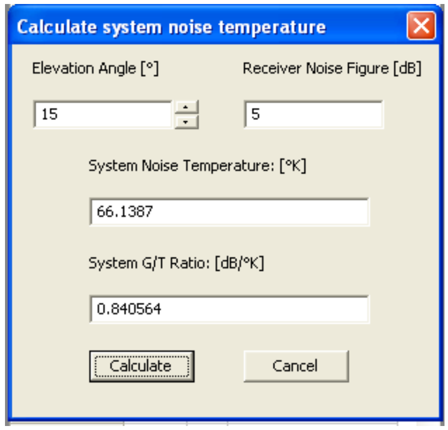

Fig. 7 System noise temperature dialog

4.3. Average Noise Temperature Calculation

The average noise temperature for a given range of elevation angles is a useful parameter for design and optimization of antennas with variable elevation angle. Prime applications are antennas intended for receiveing signals from satellites or for EME (Earth-Moon-Earth communication) use. The elevation angle is determinated by low and high limits for these applications. Calculated antenna noise temperature is an arithmetic mean value that corresponds with the angles of this interval.

4.4. Storing Calculated Data

Calculated antenna noise temperature may be saved in text file format. The user selects "File->SaveOutput" in the main menu.

4.5. Log

ANTC records all operations in a log. The file name of the log is "log.txt", which is stored in the sotware`s working directory. All operations, whether or not successful, and calculated data, including intermediate data, are recorded in the log.

5. Practical Application of ANTC

Courtesy of Sergei Zhutyaev –RW3BP, we had the opportunity to check the ANTC software`s accuracy using real-world measured data. Sergei`s EME antenna consists of a 2.4/3.4 m diameter offset dish for the 23 cm band with an extended mesh reflector on half of the perimeter. The dish was equipped with a dual-mode horn designed by Dmitry Dmitriev. See Fig. 8. With this antenna system Sergei achieved excellent EME reception. The best measured G/T ratio based on sun noise vs. cold sky noise measurement was 19 dB for elevation angles of approximately 30 degrees.

The first step in making the calculated vs. measured data comparison was to model Sergei`s antenna with CST MW studio software to calculate its radiation pattern applying the MLFMM method (I-solver). The calculated 3D radiation pattern is shown in Fig. 9. From this pattern it is apparent that the major portion of the side lobe points toward the sky, insuring a low antenna noise temperature. The calculated antenna noise temperature dependence on antenna elevation angle is plotted in Fig.10. Calculated results for the G/T ratio are shown by the dotted line in Fig. 12.

Since Sergei’s intent was to optimize his antenna system for the highest G/T ratio, Dmitry designed a new feed having a narrower radiation pattern for this purpose. See Fig.11. The designed system achieved a maximum G/T ratio of about 20dB. Calculated values for this configuration are shown by the solid line in Fig. 12.

Fig. 8 RW3BP offset dish antenna system

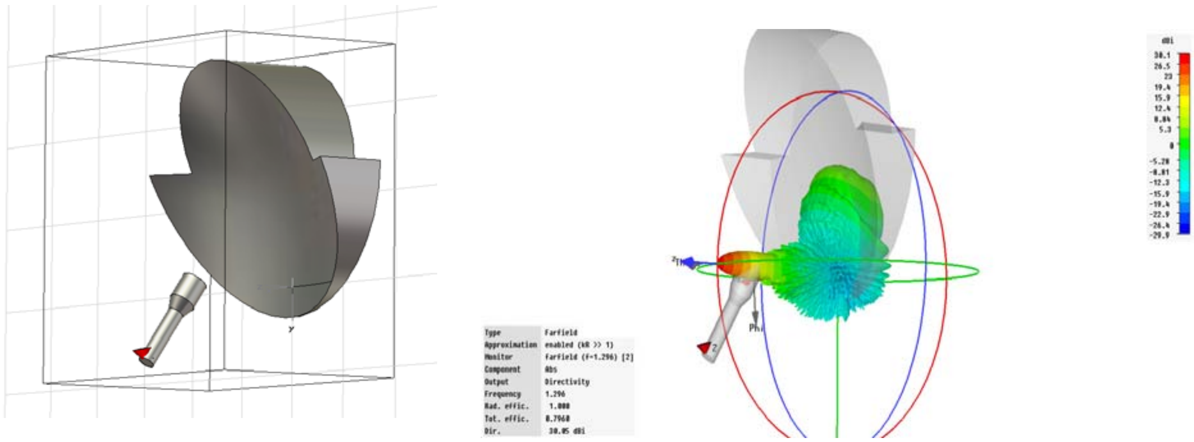

Fig. 9 **A**ntenna model and its calculated 3D radiation pattern from CST MW Studio software

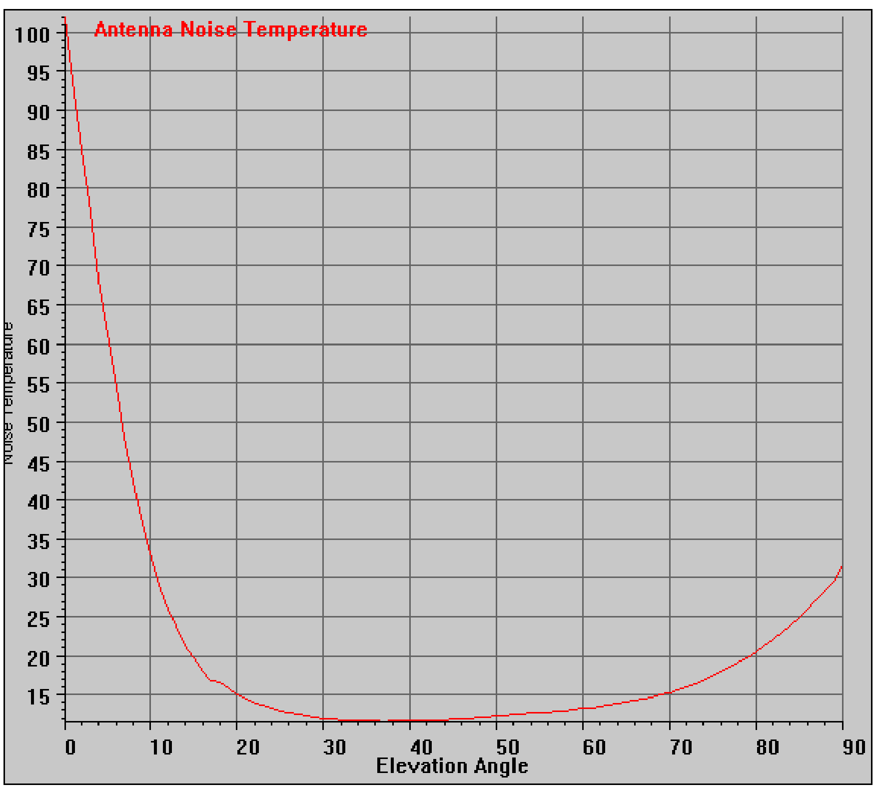

Fig. 10 Calculated antenna noise temperature of the antenna shown in Fig.8

Fig. 11 Enhanced Antenna Configuration

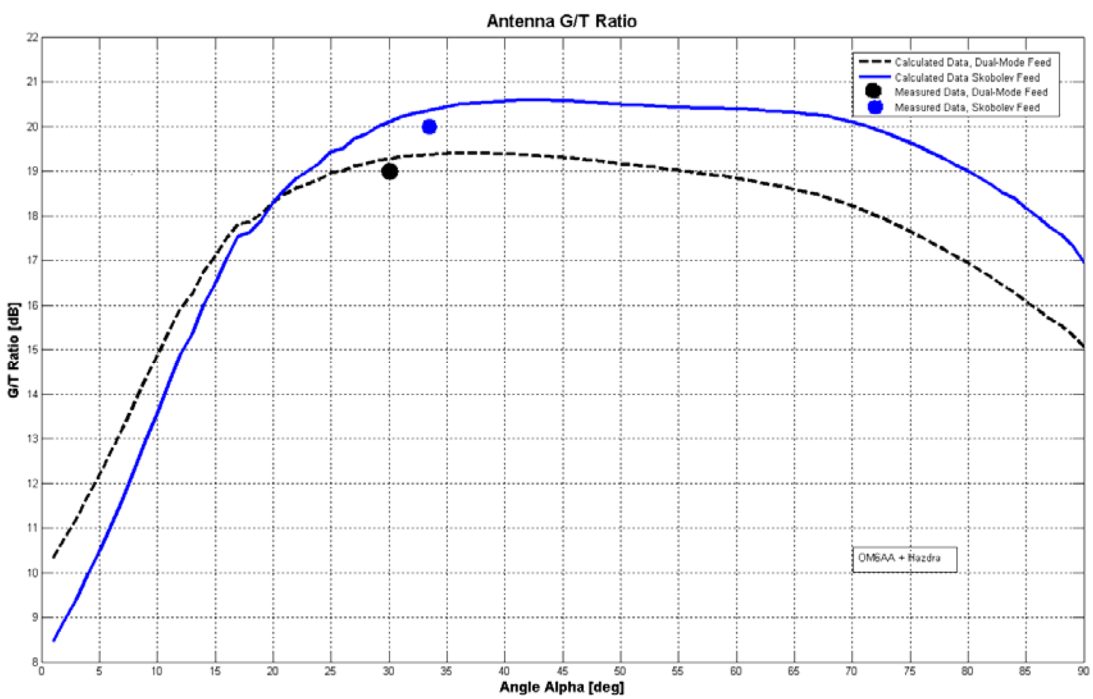

Fig. 12 Calculated Antenna G/T Ratio Dependence on Elevation Angle

6. Summary and Conclusion

ANTC software was developed for parabolic dish antenna optimization. Verified with a real antenna, ANTC used in conjunction with the CST MW Studio program achieves very good accurancy (similar results are expected, though not yet verified, using FEKO software). With the current one degree radiation pattern digitization, the program is able to calculate noise temperature for antennas with gains up to 34 dB. To deal with very fine digitization and immense data volume requirements associated with higher gain antennas, the noise analysis should be modified by dividing it into two tasks: an analysis of the antenna main beam only with very fine digitization followed by an analysis of the remaining radiation pattern with the current 1 degree digitization. This proposed future modification of ANTC software would be necessary for calculation of absolute noise parameters. If a noise relationship study between the feed and parabolic reflector shapes is required, a scale model should be used for this purpose.

Copies of ANTC software for MATLAB and also the stand-alone C++ version are available for free download at: http://www. om6aa.eu

Acknowledgements

The authors would like to express their thanks to Robert Valenta for his valuable technical and language assistance in creating this article. We would also like to thank Sergei Zhutyaev - RW3BP for providing antenna-measured data and his technical remarks.

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