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Sun Noise Measurement at Low Earth Orbiting Satellite Ground Station

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Abstract - *The project "MOST" (Microvariability and Oscillations of Stars) is a Canadian micro satellite space telescope mission. The micro satellite carries a Rumak-Maksutov telescope with an aperture of 15cm. The size of the satellite is 65cm x 65cm x 30cm and the mass is about 65kg. The goals of the mission are to analyze the inner structure of stars, set a lower limit to the age of the universe and to search for Exoplanets. The project MOST consists of a Low Earth Orbiting (LEO) Satellite and three Ground Stations, one of them in Vienna [1]. The Vienna ground station system was set up at the Institute for Astronomy of the University of Vienna in cooperation with the Institute of Communications and Radio-Frequency Engineering of the Vienna University of Technology. The downlink budget calculations are done for the worst propagation conditions. Among measurements related to the performance it is finally measured the Figure of Merit (G/T_s) of the receiving system based on the Sun flux density method.*

Keywords – *Sun noise, LEO, satellite*

1. INTRODUCTION

Receiving systems frequently must process very weak signals. The noise added to the signals by the system components tends to obscure such signals. In course of receiver evaluation, measurements of the noise contributions are necessary. Device sensitivity is characterized by *noise figure* or alternatively by *effective noise temperature*. Thus, these parameters have to be measured.

The idea of these papers is to explain a Sun noise experiment done with the receiving system at the Vienna's LEO satellite ground station. The measurements are based on the *Hot/Cold Method*, also known as the *Y-factor Method*. In the following we will discuss this method in general. The measurement set up is presented in Fig.1. Here, DUT means Device Under Test.

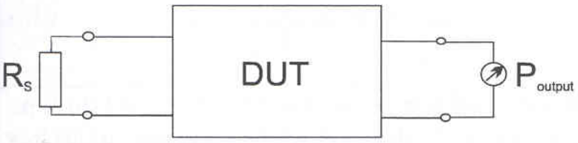

Fig. 1. Noise measurement with Y-factor method.

The "*Y-factor*" noise figure measurement technique uses two noise sources at two different temperatures to determine the noise temperature T_{dut} of the DUT. With each noise source Rs connected to the DUT (see Fig.1), the output powers corresponding to the different temperatures T_{hot} and T_{cold} are measured. The powers are termed P_{hot} and P_{cold}. The *Y*-factor is defined as the ratio of these powers:

$$Y = \frac{P_{hot}}{P_{cold}} \tag{1}$$

Also, it is known that the thermal noise power P_N within a bandwidth B is:

$$P_N = kTB \tag{2}$$

where $k = 1.38 \cdot 10^{-23}$ W/HzK is Boltzmann's constant.

If we let the DUT has gain $G = 1$ and bandwidth B, and further assume that there are no losses resulting from cables, and no mismatch losses, then P_{hot} and P_{cold} based on Eqn. (2) are:

$$P_{hot} = k(T_{hot} + T_{dut})B \tag{3}$$

and

$$P_{cold} = k(T_{cold} + T_{dut})B \tag{4}$$

Substituting Eqn. (3) and Eqn. (4) in Eqn. (1), the bandwidth B and Boltzmann's constant k will drop out. Then Y becomes:

$$Y = \frac{T_{hot} + T_{dut}}{T_{cold} + T_{dut}} \qquad (5)$$

Calculating T_{dut} from Eqn. (5) yields out:

$$T_{dut} = \frac{T_{hot} - YT_{cold}}{Y - 1} \qquad (6)$$

From Eqn. (6), for known temperatures and measured Y, the noise temperature T_{dut} can be obtained.

2. MEASUREMENT AT VIENNA SATELLITE GROUND STATION

For the satellite communication the performance of the receiving system is commonly defined through a *Receiving System Figure of Merit as G/Ts* where $T_s = T_A + T_{comp}$. Here T_A is antenna noise temperature and T_{comp} is composite noise temperature of the receiving system [2].

To obtain G/T_s one could determine G and T_s separately which needs elaborate measurements. It is much easier to obtain the ratio (G/T_s) by a single measurement based on the Sun Noise. As a *hot source* the *Sun* is considered and as a *cold source* the *cold sky*.

The principle behind determination of (G/T_s) is to measure the increase in noise power which occurs when the antenna is pointed first at a cold region of the sky (Temp. of around 6 K, [3]) and then moved to a strong source of known flux density - usually the Sun (Temp. of 13000 K, [4]). In this case, the Y-factor is:

$$Y = \frac{P_{sun}}{P_{coldsky}} \qquad (7)$$

The measured power consists of two components: the power generated by the receiving system itself (kT_sB) and the power coming from the external radio source. In case of the cold sky, because of the low temperature of around 6 K the Solar flux density can be considered as very low or zero. Then the measured power $P_{coldsky}$ can be expressed as:

$$P_{coldsky} = kT_sB \qquad (8)$$

because the contribution of the external source is negligible. The power P_{sun} when the antenna is pointed to the Sun is:

$$P_{sun} = kT_sB + F_{sun}A_eBL \qquad (9)$$

where $(F_{sun}A_eBL)$ is the noise power resulting from Solar radiation. In Eqn. (9) F_{sun} is the Solar flux density at the test frequency f and expressed in (W/m^2Hz), L is a beam size correction factor, B is the bandwidth of the system and A_e is the antenna's effective area as:

$$A_e = \lambda^2 G / 4\pi \qquad (10)$$

Since the Solar radiation is randomly polarized, half power is in each polarization state $(F_{sun.singlepol} = F_{sun}/2)$ [5]. Then for a single polarization state the measured power P_{sun} will be:

$$P_{sun} = kT_sB + \frac{F_{sun}}{2}A_eBL \qquad (11)$$

Substituing Eqn. (11) and Eqn. (8) into Eqn. (7) yields:

$$Y = \frac{P_{sun}}{P_{skycold}} = \frac{kT_sB + (F_{sun}/2)A_eBL}{kT_sB} \qquad (12)$$

and further:

$$Y = 1 + \frac{F_{sun}A_eBL}{2kT_sB} \qquad (13)$$

Substituting Eqn. (10) to Eqn. (13) gives:

$$Y = 1 + \frac{F_{sun}\lambda^2 GL}{8\pi kT_s} \qquad (14)$$

Solving Eqn. (14) by (G/T_s), finally, will get the *Figure of Merit of the Receiving System* as:

$$\frac{G}{T_s} = \frac{8\pi k}{F_{sun}L\lambda^2}(Y-1) \qquad (15)$$

For Eqn. (15) the value of Y will be obtained by measurement. Now, let us investigate L and F.
The beamsize correction factor L is expressed by:

$$L = 1 + 0.38(\frac{\theta_{sun}}{\theta})^2 \qquad (16)$$

and is dependent on antenna beamwidth [6]. In Eqn. (16) θ_{sun} is the diameter of the radio sun in degrees at frequency f and θ is the antenna 3 dB beamwidth at frequency f.

The diameter of the radio sun θ_{sun} is frequency dependent and for some frequencies is presented in the Table.1 [6].

Table 1. Radio Sun diameter table.

f	400 MHz	1420 MHz	≥3000 MHz
θ_{sun}	0.7^0	0.6^0	0.5^0

The beamwidth θ of a parabolic antenna is:

$$\theta = 70\frac{\lambda}{d} \qquad (17)$$

where λ is the wavelength corresponding to frequency f ($c = f\lambda$) and d is the diameter of the parabolic antenna. (In case of the Vienna ground station, the antenna has a diameter d = 3 m and the downlink frequency is f = 2232 MHz, then θ = 3.13^0). Based on this calculation and on the values from the Table. 1 it can be concluded that the component $0.38(\theta_{sun}/\theta)^2$ in Eqn. (16) is small and L can be considered $L = 1$. Then, the Eqn. (15) which expresses the Figure of Merit for the receiving system becomes:

$$\frac{G}{T_s} = \frac{8\pi k}{F_{sun}\lambda^2}(Y-1) \qquad (18)$$

The next term needed is *Solar flux density* (F_{sun}) at the test frequency. The USAF (United States Air Force) Space Command runs a worldwide Solar monitoring network and measures the Solar flux density at following eight "standard" frequencies [6]: 245 MHz, 410 MHz, 610 MHz, 1415 MHz, 2695 MHz, 4995 MHz, 8800 MHz and 15400 MHz. If the operating frequency does not fit with these standard frequencies the flux value is obtained by interpolation. Table. 2 presents data for Solar flux density recorded by Australian Space Weather Agency at Learmonth Observatory.

Table 2. Solar flux density.

f/Date	18/01 2004	19/01 2004	20/01 2004	21/01 2004	22/01 2004
245 MHz	15	15	14	14	12
410 MHz	30	29	39	28	29
610 MHz	47	51	48	46	44
1415 MHz	81	84	91	82	84
2695 MHz	105	108	124	114	113
4995 MHz	161	159	177	165	169
8800 MHz	263	250	246	257	248
15400 MHz	508	507	516	512	512

The data presented are for Quiet Solar, and the values are expressed in *sfu* units. The *sfu* is a unit for Solar flux density [7]. The Solar flux density is also expressed in *Jansky unit*, where:

$$1\,\text{Jansky} = 10^{-26}\ \text{W/m}^2\text{Hz} \qquad (19)$$

and

$$1\,sfu = 10^4\ \text{Jansky} = 10^{-22}\ \text{W/m}^2\text{Hz} \qquad (20)$$

Since the actual Solar flux density at any time is available, it may be used to make reasonably accurate measurements of receiving system performance. The accuracy of the determination of (G/T_s) is dependent on the accurate measurement of Y. The easiest measurement technique is to use a power meter connected to the receiver's IF. For this measurement the receiver must be operating in a linear region. Whatever technique is used, the Y-factor needs to be measured several times and an average must be taken. Solar flux density must be determined at the same time as the measurements of (G/T_s) are done.

At Vienna ground station this experiment was executed several times. In this work we use data taken on 24 January 04. As power meter we used a spectrum analyzer connected to the IF output. The result obtained is presented in Fig. 2.

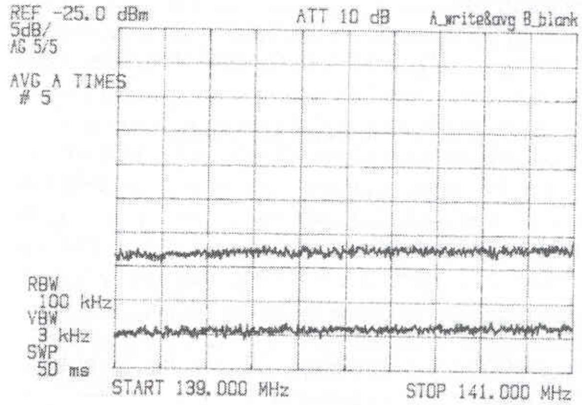

Fig. 2. Sun noise measurement result.

In the Fig. 2, *RBW* is the Resolution Bandwidth, *VBW* the Video Bandwidth, *SWP* the Sweep Time and SPAN is the span of frequency range observed. The chosen values of these parameters are used as criteria to have optimized picture on screen of the spectrum analyzer for the appropriate measurement task. In the Fig. 2, the signal at the bottom represents noise power density when antenna was pointed to the cold sky. This is proportional to $P_{coldsky}$. Then, we pointed antenna to the Sun. The result of the measurement is presented in Fig. 2. These two recorded traces will be considered for further calculations.

In order to have accurate result, I have measured the difference between the higher and the lower signal at eleven points, and found out an average difference of 11.5dB. Mathematically expressed based on Eqn. 7 is:

$$Y(\text{dB}) = \frac{P_{sun}}{P_{coldsky}} = 11.5 \text{ dB} \qquad (21)$$

or as a numerical value is:

$$Y = 14.125 \qquad (22)$$

Further, are needed data for Solar flux density. These data are provided from Learmonth Observatory in Australia and for the date of 24 January 2004, are presented in the Table 3.

Table 3. Solar flux density of 24 January 04.

f	245 MHz	410 MHz	610 MHz	1415 MHz	2695 MHz	4995 MHz
F_{sun}	12	26	42	74	100	150

Since the working frequency of the downlink at Vienna Ground Station is f=2232 MHz and this is not among standard frequencies for Sun flux measurement, the interpolation between fluxes at frequencies at 1415 MHz and 2695 MHz was done. The value for Solar flux density F_{sun} at frequency 2232 MHz is:

$$F_{sun} = 91 sfu = 91 \cdot 10^{-22} \text{ W/m}^2\text{Hz} \qquad (23)$$

Substituing $\lambda = c/f$ in Eqn. (15) yields:

$$\frac{G}{T_s} = \frac{8\pi k f^2}{F_{sun} c^2}(Y-1) \qquad (24)$$

With frequency $f = 2232 \cdot 10^6 \, Hz$, light's velocity $c = 3 \cdot 10^8 \, m/s$, Y from Eqn. (22) and F_{sun} from Eqn. (23) in Eqn. (24), we arrive at:

$$G/T_s = 14.4 \text{ dB} \qquad (25)$$

The value from link budget calculations ranges between 13.3 dB and 15.4 dB, where the first value is with atmospheric attenuation (A = 1 dB) and the second value represents the ideal case without medium attenuation. The result of measurement done on 24 January 04 is 14.4 dB and it is within the calculated range. This can be considered as an indication of proper receiving system performance.

3. CONCLUSION

At Vienna ground station the Sun noise measurement is executed several times. The results of the measurements agree with the calculated value of G/T_S within the uncertainty of the measurement. This confirms the proper implementation and functionality of the ground station.

Even this method requires a relative measurement the accuracy of the determination of Figure of Merit for receiving system depends on the accuracy of the used instrument. An accurate spectrum analyzer is a convenient tool. Method is very practical and easy to be executed.

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