Frequency Scaling from 19 to 39 GHz Using Alphasat Data from Prague

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***Abstract*—In this contribution we construct scatterplots 39 vs. 19 GHz of total attenuation (pairs) on satellite link. The results from the satellite link satellite Alphasat - two beacon receivers at the Institute of Atmospheric Physics (IAP) in Prague (Czech Republic) are used to investigate the frequency scaling. The usually used frequency scaling formulas are tested through our measured attenuation A pairs A_{39} -A_{19} GHz (one minute values on one hand and peak values on the other hand). The power law scaling method (power of frequency ratio n=1.4) seems to be most appropriate in our case. However, the ITU-R method could be also recommended as a general method which brings sufficient results.**

***Index Terms*—frequency scaling, satellite link, radiowave propagation.**

I. Introduction

"Frequency scaling" enables us to estimate atmospheric attenuation on frequency f_2 when the attenuation on frequency f_1 is known. Usually $f_2 > f_1$. This could be practical in many cases. For example, you measure atmospheric attenuation A_1 on frequency f_1 and you can estimate (hypothetical) attenuation A_2 on frequency f_2 without measurement or complicated computations.

Many frequency scaling models were published – see Chapter III. Usually they were derived from synchronous attenuation measurement on two frequencies (f_1 and f_2).

Involving within the "Aldo Paraboni Technology Demonstration Payload 5 (TDP #5)" or SCIEX (Scientific experiment) we measure the total atmospheric attenuation on satellite link on two frequencies (f_1 = 19 GHz and f_2= 39 GHz) at the receiving station situated at the Institute of Atmospheric Physics (IAP) in Prague. More details are described in Chapter II.

II. Attenuation Measurement - Site

Fig.1 Alphasat satellite receivers in Prague

Our satellite receiver (see Fig.1) is located at IAP in Prague, Czech Republic (50.04°N, 14.48°E, Azimuth 166.6°, Elevation 31.8°, h.a.s.l. = 0.274 km).

Both Alphasat satellite beacon receivers receive and process the transmitted signal at Alphasat TDP #5 frequencies of f_1=19.701 GHz (Ka band) and f_2 = 39.402 GHz (Q band). The reception is designed as two separate receiver units that are connected through the bus RS485 using protocol Modbus to Alphasat Monitoring Server. Using Monitoring Server the staff can control all functions of both receivers.

Both receivers are composed of offset parabolic Andrew antenna with electrical diameter 1.8 m. The antenna is heated in order to be protected from frost. The LNB is placed in focus and its temperature is regulated by thermostat being set at 40°C. A chain from IF_1 is also thermostatically controlled at a constant temperature of 40°C to ensure a constant gain during possible temperature variations.

The first downconversion is performed in LNB while the IF1 being 1451 MHz in case of 19.7 GHz receiver and 1702 MHz in case of 39.4 GHz receiver.

Antennas are automatically tracked in elevation. There is also a smaller satellite motion in azimuth. Therefore, the signal intensity variations caused by the satellite space motion have to be reduced also mathematically.

III. Frequency Scaling Methods

In the literature there were many "frequency scaling" formulas published. The simplest one is the power law formula:

$$\frac{A_2}{A_1} = \left(\frac{f_1}{f_2}\right)^n \qquad (1)$$

where A_1 (A_2) is the attenuation in (dB) on f_1 (f_2) frequency. The power "n" differs from author to author, see Table I:

TABLE I. Some values "n" of power law model

n in (1)	Derived from f [GHz]	Reference [1]
1.72	19/11	Drufuca
2.00	20/12, 30/12	Owolabi
1.80	30/20	Dintelmann
1.9	20/12,30/20,30/12	based on OLYMPUS data

Other method was published in [2], where

$$\frac{A_1}{A_2} = \frac{g(f_1)}{g(f_2)} \quad (2)$$

while

$$g(f) = \frac{f^{1.27}}{1+3\times10^{-7}f^{3.44}} \quad (3)$$

Dr. Barbalisca [3] and Prof. Fedi [4] based their frequency scaling formulas on assumption that the effective path length is 4 km:

$$A_2 = 4k_2\left(\frac{A_1}{4k_1}\right)^{\alpha_2/\alpha_1} \quad (4)$$

where k_i (α_i) are the parameters to estimate the specific rain attenuation $\alpha_{i,spec}$ [dB/km] according to the power law rule $\alpha_{i,spec} \sim k_i R^{\alpha}{}_i$ while R is the rain rate in [mm/h] and i=1, 2 [5].

More sophisticated model was recommended by ITU-R [6]. Here you are the formulas:

$$A_2 = A_1(\varphi_2/\varphi_1)^{1-H(\varphi_1,\varphi_2,A_1)} \quad (5)$$

$$\varphi(f) = \frac{f^2}{1+10^{-4}f^2} \quad (6)$$

$$H(\varphi_1,\varphi_2,A_1) = 1.12\times10^{-3}(\varphi_2/\varphi_1)^{0.5}(\varphi_1 A_1)^{0.55} \quad (7)$$

IV. Frequency Scaling – Test Criteria

To test the frequency scaling methods we used the standard RMSE and the ITU-R method testing the rain attenuation prediction methods [7]. From it next formulas are taken:

$$S_i = A_{p,i}/A_{m,i} \quad (8)$$

$$V_i = ln\, S_i(A_{m,i}/10)^{0.2} \quad \text{for } A_{m,i} < 10\, dB \quad (9)$$

$$V_i = ln\, S_i \quad \text{for } A_{m,i} \geq 10\, dB \quad (10)$$

$$\rho_V = (\mu_V{}^2 + \sigma_V{}^2)^{0.5} \quad (11)$$

where $A_{p,i}$ is the predicted attenuation [dB] (computed $A_{2,i}$ from $A_{1,i}$ using chosen frequency scaling method)

$A_{m,i}$ is the measured attenuation on f_2 frequency,

μ_V (σ_V) is mean value (standard deviation) of V_i value series,

ρ_V is a measure of the frequency scaling model accuracy (the lower ρ_V value the better frequency scaling method).

V. Frequency Scaling - Results

Selection of events – Two years of the one-minute atmospheric attenuation data were selected for the frequency scaling analysis. The minimum attenuation was set to be 2 dB on both frequencies. For the general scatterplot see Fig. 2 where are no values filtered. A saturation around 22 ~ 28 dB is obvious in the case of 39 GHz link.

In Fig. 3 one can see the scatterplot of data from Fig. 2 where the saturated attenuations were excluded. Also “frequency scaling” relations A_2 as a function of A_1 are plotted.

To see a scatterplot for the attenuation peak values look at the Fig. 4. A good fit between the ITU-R model (red curve) and measurement is acknowledged if we exclude the saturated values.

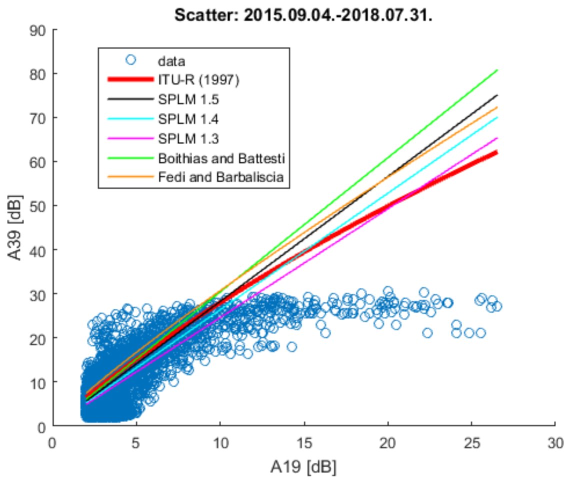

Fig. 2 General scatterplot of one minute attenuation 39 GHz vs attenuation 19 GHz. Frequency scaling models are added (SPLM means the power law formula (1) while the power is plotted alongside).

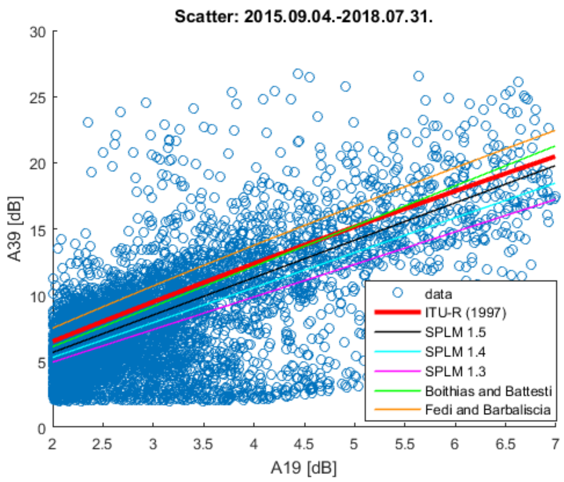

Fig.3 Filtered scatterplot of one-minute attenuation 39 GHz vs. attenuation 19 GHz. Frequency scaling models are added (SPLM means the power law formula (1) while the power is plotted alongside)

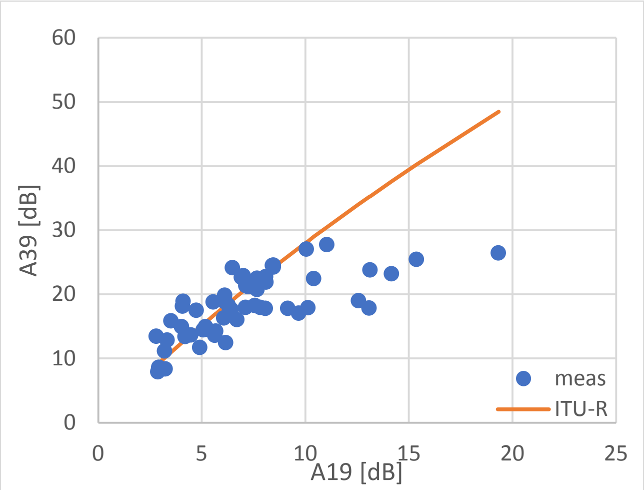

Fig. 4 Scatterplot of peak attenuation values (example)

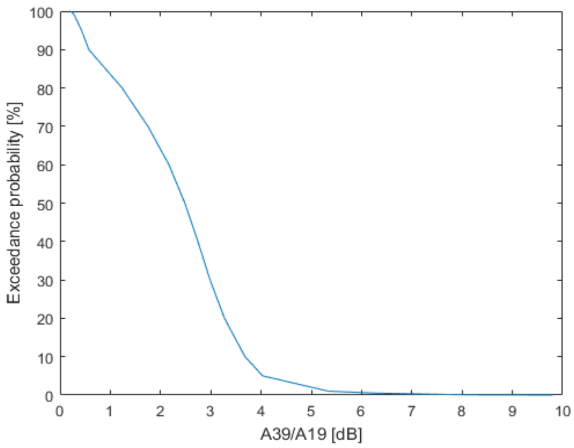

Fig. 5 Cumulative distribution of the 39 and 19 GHz atmospheric attenuation ratio (in dB) measured in Prague on the Alphasat satellite link (2 years measurement)

In Fig. 5 there is shown the CD of a ratio A_{39}(dB)/A_{19}(dB). 50% of such ratio values exceeds a value of 2.5.

Table II shows the comparison of frequency scaling formulas accuracy. For testing purposes 2 year Alphasat atmospheric attenuation data from Prague were used.

TABLE II. TEST RESULTS USING METHODS FROM CHAPTER IV

	ITU-R [7]	RMSE [dB]
ITU-R	0.3159	2.0628
SPLM 1.5	0.2447	**1.5065**
SPLM 1.4	0.2223	1.5466
SPLM 1.3	**0.2173**	1.7843
Bothias, Battesti	0.2821	1.7403
Fedi, Barbaliscia	0.4066	3.0179

VI. CONCLUSION

Having the Alphasat receivers working on frequencies 19 and 39 GHz we prepared scatterplots of measured total attenuation pairs on both frequencies. This is a “demo” of frequency scaling which is a useful method. The attenuation measurement on 39 GHz is limited by saturation so we can consider and process attenuation values up to 22 – 28 dB. It seems that the power law method (1) for power n = 1.4 fits the frequency scaling relatively effectively. The ITU-R method being more general can also be recommended.

As it can be seen from our figures, the relationship between 39 GHz and 19 GHz attenuation is ambiguous. Considering the peak attenuation values the situation is better. Therefore we recommend the frequency scaling method as an approximate method.

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