Microwave Attenuation Spectra of Forest Crowns

***Alexander A. Chukhlantsev*, Anatoly M. Shutko**

Institute of Radioengineering and Electronics, Russian Academy of Sciences, 1 Vvedensky sq., Friazino, Moscow region, 141190, Russia, Tel: +7-(496)-5652633, alchuk51@mail.ru

Abstract

Super wide band waveguide transition system has been designed for measuring microwave attenuation by trees fragments in the frequency range 0.8 – 8.5 GHz. Field active measurements has been conducted that has provided data on attenuation by single trees in the frequency range 0.47…2.1 GHz. The data obtained has been compared with several data sets on attenuation properties of forests reported earlier. A simple formula has been proposed for microwave intensity extinction rate: $\gamma = c\, f^{\beta} w$, were γ is the extinction rate in dB/m, f is the frequency in GHz, w is the crown unit volume water content in kg/m^3, c (in dB/kg/m^2) and β (dimensionless) are the model coefficients that has been found from regression analysis of experimental data.

1. Introduction

Forests are one of the most important objects of ecological monitoring. Knowledge of microwave attenuation properties of forests is needed in this respect since attenuation values and their dependence on frequency and biometrical features afford a basis for microwave remote sensing retrieving algorithms. The paper summarizes the results of authors' research on microwave attenuation properties of forest crowns. Wide band waveguide transition system has been created and measuring technique has been developed to obtain continuous attenuation spectra of vegetation fragments in the frequency range 0.8…8.5 GHz. Attenuation spectra of pine, aspen, birch, and maple tree parts has been obtained. Field active measurements has been conducted that has provided data on attenuation by single fir, chestnut, and apple trees in the frequency range 0.47…2.1 GHz. Microwave radiometric (passive) methods, as applied for measurements of attenuation, has been used to measure microwave attenuation by fir and pine branches. The paper gives a review of results mentioned above. Simple formulas for estimating microwave attenuation by forest canopies are proposed on the base of theoretical models and regression analysis of experimental data.

2. Attenuation Model

It was first reported in [1] that the optical thickness of a vegetation layer τ is connected to the vegetation water content per unit area W by the expression

$$\tau = bW\ , \tag{1}$$

where b is a coefficient that depends on the frequency and type of vegetation. This model was tested by numerous researchers and was found to be acceptable for interpretation and modeling microwave radiometric features of vegetated lands. The extinction rate (the attenuation per meter) is found from (1) as

$$\gamma(dB/m) = 4.34bw = b(dB/(kg/m^2))w(kg/m^3)\ , \tag{2}$$

where w is canopy water content in the unit volume. B-factor in Eq. 2 can be decomposed to separate its frequency dependence as [2]

$$b = cf^{\beta}\ , \tag{3}$$

where f in GHz, c in dB/(kg/m^2), and the coefficient β defines the slope of frequency dependence of attenuation. Coefficients c and β are to be found from the analysis of experimental data on microwave attenuation by different crowns.

3. Measuring Techniques and Results

3.1. Measurements with Waveguide Transition System

Description of the system and measuring technique is given in detail in [3]. Block diagram of transition system is presented in Fig.1. The following equipment is used in the system.

- Vector Network Analyzer.

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

- Two measuring wide band horn antennas with coaxial input. Horn aperture is 350×260 mm. Antennas operate in the frequency band of 800…10000 MHz.
- Measuring chamber in the form of rectangular waveguide section with a cross section of 350×260 mm and a length of 1500 mm.

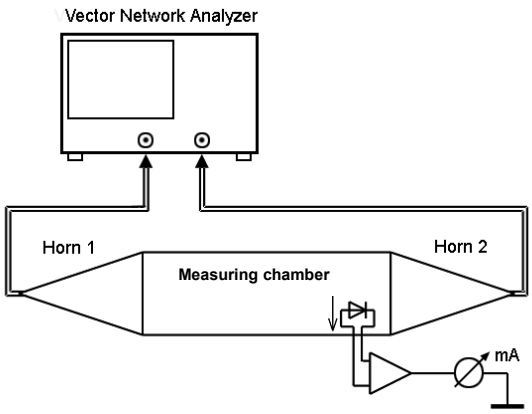

Fig.1. Block diagram of transition system.

The horn antenna transforms TEM-wave of coaxial cable into H_{10}-wave of rectangular waveguide. Since the divergence angle of antenna is not large, an excitation level of high-order waves is small. When H_{10}-wave passes through the chamber it is attenuated by investigated object. The second horn antenna, in turn, transforms coming wave into TEM-wave of coaxial cable. Therefore, the antennas serve as filters of spatial harmonics providing the single-mode propagation regime in the waveguide and the correct interpretation of attenuation measurements. Direct measurements of the electric field distribution in the waveguide confirm the realization of the single-mode propagation regime. These measurements were performed with the use of a diode probe. Measurements of attenuation were also performed with a plate of absorbing material that was placed vertically along the waveguide at different distance from the narrow wall of the waveguide. Results of measurements prove the realization of the single-mode regime of propagation. Electric properties of the system are described in detail in [3].

The following measuring procedure was applied. A big branch of a tree (or young tree) was cut. The branch was cut into smaller parts to put into the waveguide and to obtain attenuation spectrum of the branch as a whole. Attenuation measurements were accompanied by measuring the weight and gravimetric moisture of samples. Finally, attenuation values were recalculated to find spectral dependences of specific attenuation (*b*-factor) for each branch, i.e., attenuation per kg/m^2 of the water content of the branch.

To check on the model (1), measurements were made for samples of different weight but belonging to one of the species. It was found that the dependence of attenuation on the weight (water content) of the sample is close to the linear dependence. So it was interesting to find the spectral dependence of the coefficient *b*. These dependences were obtained for aspen, maple, and pine branches.

3.2. Field Measurements

Field measuring complex was used to measure attenuation spectra of trees [4]. Measurements were conducted in the frequency range 0.47…2.1 GHz. Attenuation on the path between transmitting and receiving antennas was measured. Wide band noise generator was used as a transmitter and tunable radiometers were used as receivers. To obtain reliable data and to avoid the influence of antennas diagram effects on the measurements the following procedure of measurements was applied. Antennas were placed at a height of 3 meters above the ground and at a distance of 6…10 meters from each other. First, nothing was positioned between the antennas. That provided the reference free space propagation. Secondly, trees were located between antennas and attenuation at different frequencies was recorded. The main goal of measurements was obtaining the slope of frequency dependence of attenuation (that is a relative level of attenuation at different frequencies) and studying the spread of experimental data due to the different position of trees on the propagation path. Frequency dependences of attenuation were obtained for single trees of spruce, apple, and chestnut at the vertical and horizontal polarizations.

3.3. Other Available Measurements

The radiometric method of measuring attenuation is described, particularly, in [5]. Fresh cut branches were placed on a metal plate and attenuation values were found from measurements of the normalized brightness temperature (the emissivity) of plate-branches system. Results of measurements for crown branches are summarized in [6]. The mentioned measurements give for the slope of frequency dependence of attenuation β the value 0.47-0.58.

Several data sets are summarized in [2]. It was found that in the frequency range 0.1-1 GHz the attenuation by forests increases with frequency as $\gamma(dB/m) = 0.2 f^{0.8}$, where f in GHz.

3.4. General Frequency Dependence of B-factor.

Coefficients β and c were derived from the results of the field measurements and laboratory measurements. It was found that at the frequencies up to C-band the slope of the frequency dependence of attenuation by trees crowns β is close to 0.8. For higher frequencies this slope decreases ($\beta \sim 0.5$). For P-, L-, and S-band the extinction rate can be estimated by the equation

$$\gamma(dB/m) = c f^{0.8} w \tag{4}$$

where f is in GHz, $c = 0.3 \pm 0.1$, and w is in kg/m^3. For natural forests crowns, the value of w is usually less or of the order of 1 kg/m^3.

4. Conclusion

Measurements of microwave attenuation by trees fragments and trees have been conducted in the wide frequency range 0.5-10 GHz. It has been shown that the extinction rate of microwave radiation for forest crowns can be expressed as

$$\gamma = cwf^{\beta} \tag{9}$$

where the coefficient β has been found from the waveguide, radiometric, and field measurements. For not-polarized radiation $\beta = 0.8$ (in the frequency range 0.1-1 GHz) and decreases to 0.45-0.5 (in the frequency range 1-10 GHz). For natural forest stands, there is the difference between the values of β for vertical and horizontal polarization. Laboratory measurements under the close control of vegetation parameters have allowed obtaining the values of the coefficient c. For mixed forest, $c = 0.30 \pm 0.10$ dB/(kg/m^2).

4. References

1. A.M Shutko and A.A. Chukhlantsev, “Microwave Radiation Peculiarities of Vegetative Covers”, *IEEE Trans. Geosci. Remote Sensing*, **20**, 1982, pp. 27-29.

2. A.A. Chukhlantsev, A.M. Shutko, and S.P. Golovachev, “Attenuation of Electromagnetic Waves by Vegetation Canopies in the 100-10000 MHz Frequency Band”, *Journal of Radio Electronics*, February 2003, (www. journal) available at http://jre.cplire.ru/jre/feb03/4/text.html.

3. A.A. Chukhlantsev and S.V. Marechek, “A Superwideband Waveguide System for Measuring the Attenuation of Electromagnetic Waves by Fragments of Vegetation”, *Instruments and Experimental Techniques*, 47, 2004, pp. 678-682.

4. A.G. Grankov, A.A. Mil’shin, and A.A. Chukhlantsev, “Experimental estimates of attenuation by trees crowns in mm-, cm- and dm-bands”, *Issledovanie Zemli is Kosmosa*, No. 1, 2005, pp. 1-7 (in Russian).

5. C. Matzler and U. Wegmuller, “Progress in multi-frequency radiometry of natural objectsr” *ESA/NASA International Workshop*. VSP, 1994, Eds.: B.J. Choudhury, J.H. Kerr, E.G. Njoku and P. Pampaloni, pp. 345-355.

6. A.G. Grankov, A.A. Mil'shin, and A.A. Chukhlantsev, “Modeling of Thermal Emission from a Rain-Wetted Forest Canopy in the Millimetric, Centimetric, and Decimetric Wave Bands”, *Journal of Communications Technology and Electronics,* **50**, No. 12, December 2005, pp. 1340-1342.