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M. Can

Sergey Kharkovsky
Missouri University of Science and Technology

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DEVELOPMENT OF A PROGRAM FOR NUMERICAL ANALYSIS OF MICROWAVE RADIO LINKS UNDER DIFFERENT CONDITIONS

*M.Can, S.Kharkovsky
Dept. of Electrical&Electronics Eng., Cukurova University, 01330 Balcali, Adana, TURKEY
Tel. 90 322 325 02 36, Fax 90 322 325 02 40, E-mail: memduhcan@ttnet.net.tr

I. INTRODUCTION: In this work, numerical analysis of system power budget is performed for radio link design and transmission planning purposes in cellular networks. The behavior of three different frequencies; 10,5 GHz, 23 GHz and 38 GHz are examined under the influence of such parameters like transmitter power output level, rain rate, fog density, distance, polarization type, antenna radius, temperature, foliage depth and etc. Received power levels are measured, calculated and reported for different radio link types and environmental conditions. A new program is developed in order to make system power budget analysis and design better microwave radio links. Measured and calculated values are compared, and the reasons of possible differences between them are investigated and interrogated.

II. FORMULATION OF SYSTEM POWER BUDGET: The formulas used in the program to calculate the behavior of parameters causing the variations in system power budget (Figure 1) will be given and explained here. System loss is the most important concept to deal with and it is defined as the combination of all the losses in the transmitter power of a radio link including propagation loss, connector, cable and feeder losses minus the total of parabolic antenna gains used. For the proper functioning of a radio link, the ellipsoid covered by the First Fresnel zone should contain no obstacle disturbing the power delivered to the receiver end [3].

$G = \frac{4\pi(\pi r^2) f^2}{2c^2} = \left(\frac{D\pi f}{\sqrt{2}c}\right)^2$ **(1)** is the final form of microwave parabolic antenna gain in terms of watts where $A_e = \eta_a A$, $n\eta_a = 1/2$, $\lambda = \frac{c}{f}$ and $D = 2r$. After converting to units of frequency and putting in dB form: $g = 17.39027 + 20\log D + 20\log f$ **(2)** in dB.

It is well known that, in microwave communication systems, transmission loss is accounted for principally by the free space loss. The frequency and distance dependence of the loss between two isotropic antennas is expressed as: $A_0 = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2$ **(3)** in watts. Equation **(3)** is also put in dB form as: $a_0 = 92.44178 + 20\log d + 20\log f$ **(4)** in dB [4].

Gaseous losses occur when molecules of Oxygen (O_2), water vapor (H_2O) and other gaseous atmospheric constituents absorb waves traveling through the atmosphere. These losses are greater at certain frequencies coinciding with the mechanical resonant frequencies of the gas molecules. For current technology, important absorption peaks occur at 24 GHz and 60 GHz. Gaseous loss is calculated by using the formulas offered by ITU-R P.676-3 which gives approximate estimation of gaseous attenuation for a limited range of meteorological conditions and a limited variety of geometrical configurations [1, 6].

Microwave propagation is also affected by rain. Raindrops are roughly the same size as the signal wavelengths, and cause attenuation of the radio signal. In the program, rain attenuation γ_R, for the frequency, polarization and rain rate of interest is obtained from the power-law relationship given as: $\gamma_{Rain} = k \times R_p^{\alpha}$ **(5)** where R is the rain rate in mm/h, p [%] is the percentage of time the rate R is exceeded, k and α are the regression coefficients.

The regression coefficients in equation **(5)** are calculated by:

$k = \left[k_H + k_V + (k_H - k_V)\cos^2\theta\cos 2\tau\right]/2$ **(6)**

$\alpha = \left[k_H\alpha_H + k_V\alpha_V + (k_H\alpha_H - k_V\alpha_V)\cos^2\theta\cos 2\tau\right]/2k$ **(7)** where θ is the path

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elevation angle and τ is the polarization tilt angle relative to the horizontal. For linear vertical or horizontal polarizations used for transmission with the radio links, the polarization tilt angle τ, $\left(0^0 \le \tau < 180^0\right)$ describes the orientation of the electric field vector with respect to the local horizontal at the BTS, and $\tau = 90^0$ for vertical polarization and $\tau = 0^0$ for horizontal polarization. Path elevation angle; $\theta = 0^0$, as it is assumed that the angle of either arrival or launch with the ground is 0^0 [1, 5].

An estimate of the rain loss exceeded for %0. 01 of the time is: $a_{Rain} = \gamma_{Rain} d_{eff}$ **(8)** in dB where $d_{eff} = \dfrac{1}{1 + d/d_0}$ and $d_0 = 35e^{-0.015R_{0.01}}$.

In order to make an estimation of attenuation due to fog: $\gamma_{Fog} = K_l M$ **(9)** is used where K_l is the specific attenuation coefficient for fog, M is the liquid water density in the fog and are calculated by the formulas given by ITU-R P.840-2. The liquid water density in fog is typically about 0.05 g/m^3 for medium fog (visibility of the order of 300 m) and 0.5 g/m^3 for thick fog (visibility of the order of 50m) [1, 2].

Foliage loss is calculated by the empirical relationship that has been developed for the case where the foliage depth is less than 400 meters given by: $a_{foliage} = 0.2 f^{0.3} d_f^{\ 0.6}$ **(10)** in dB where f is the frequency in MHz, d_f is the depth of foliage transversed in meters and applies for $d_f < 400$ m [2].

Cable loss is another factor that should be considered especially for radio link systems having antennas mounted over the top of tall towers and the length of cable used is very long. The cable loss also depends on the quality of the cable used. In our digital radio link design program, cable loss will be assumed to be 3 dB for 100 meters. Feeder, connector and any other loss factors are considered as the additional losses and are assumed to be any value considered by the transmission planner.

III. PROGRAM AND MEASUREMENT METHOD: The program has two windows used to enter the information concerning the radio link hop: "radios" and "basics" windows. In "radios" window, it is possible to select the radio link type out of three available. When a radio link type is selected, the maximum transmitter and receiver threshold power for BER 10^{-3} are automatically selected. However, in order to observe the characteristics of a radio link type more specifically, it is possible to increase or decrease these values by the program. "Basics" window gives specific information regarding the radio link. It is possible to give a name to the radio link hop, enter the names and altitudes of near and far ends of the link. Unavailability percentage for rain loss calculation, hop length, rain rate, fog density, foliage depth, temperature of the location and additional losses are entered by using the textboxes of each one. Land type, mode of diversity, protection method and polarization type are also chosen in this window. Antenna diameters of parabolic antennas and RF cable lengths at each end of the link should also be entered.

When "calculate" button is clicked, "system power budget analysis" window appears. In this window, one may observe free space, gaseous, rain, fog, foliage, cable, additional losses, and antenna gains in terms of dB. System loss, power at the receiver end and fade margin are also calculated.

In order to measure the receiver power levels, two methods are used (Figure 6). First one is to connect a wattmeter to the outdoor unit, which is connected to the back of the parabolic antenna. The power measured here is in watts, which can be converted into dB form [7]. But here, the influence of cable loss is not included since the measurement is made at the outdoor unit. The second method is to connect locally with a computer to the indoor unit of the radio link through RS232 port available. By using special software, all of the information regarding the radio link can be taken including the received power level in dBm. The receiver power levels are usually different at each side of the link since the cable lengths, antenna diameters or the other parameters may differ at each end.

IV. NUMERICAL RESULTS: Some numerical results are taken from the program in order to show the influence of such parameters to the behavior of the links. As free space loss depends on frequency and distance directly, that is higher for 38 GHz than 23 GHz, and higher for 23 GHz than 10,5 GHz as shown in Figure 2.

Figure 5 shows the total gaseous loss for three different radio links under 1013 hPa, 15^0C and H_2O density of 7,5 g/m^3. The total gaseous loss is the highest for 23 GHz and the lowest for 10,5 GHz. In fact, O_2 loss is higher for 38 GHz than 23 GHz, but for water vapor the reverse is true and the total amount of loss is more for 23 GHz. Figure 4 shows variation of rain loss with frequency and polarization type for rain rate of 51,4 mm/h. Rain loss is the highest for 38 GHz horizontal polarization and the lowest for 10,5 GHz vertical polarization. Polarization type only affects the rain loss out of all the losses in the radio link power and the amount of loss increases if horizontal polarization is used.

The variation of fog loss is shown with Figure 3 for 1013 hPa of air pressure and 0,5 g/m^3 of fog density. Fog loss increases with frequency and decreases with the increase in temperature.

In order to compare the numerical data taken from the program with the measured values, eight different radio link hops were examined for three different conditions; 33^0C without rain, 17^0C with 22,4 mm/h of rain rate and 21^0C with 78,5 mm/h of rain rate, all with vertical polarization and the maximum transmitter powers available (16 dBm for 38 GHz, 18 dBm for 23 GHz and 25 dBm for 10,5 GHz). Table I gives the measured and calculated values for 3 different links. The maximum range of a 38 GHz radio link is found to be 4,8 Km if vertical polarization is used and 3,8 Km if horizontal polarization is preferred for Adana Region. In 23 GHz band, 12,3 Km is the maximum for vertical and 9,7 Km is the maximum for horizontal polarization. These values are found for average annual rain rate, temperature and fog density of Adana Region, those are 51,8 mm/h, 20^0C, and 0,5 g/m^3. The calculated and measured values at the receiver ends are not equal to each other, however the variation between each other is less than the defined limits. The maximum percentage of variation is %8,22 for the RL hops examined and %10 is the upper limit of tolerance. The reasons are the length of cables, the variations of path elevation and polarization tilt angles, possible foliages between the antennas for 10,5 GHz, reflections from the ground and etc.

RL Freq. (GHz)	Dist. (Km)	Ant. Diam. (meter)	Rain Rate (mm/h)	Temp. (^{0}C)	Rx Calc. (dBm)	Rx Meas. (dBm)	Diffr. (%)
38	1,45	0,3	0	33	-37,07	-38,4	3,464
38	1,45	0,3	22,4	17	-44,12	-45,23	2,454
38	1,45	0,3	78,5	21	-58,59	-60,01	2,37
23	10,23	0,6	0	33	-46,61	-47,48	1,83
23	10,23	0,6	22,4	17	-63,79	-64,78	1,53
23	10,23	0,6	78,5	21	-92,79	-93,70	0,97
10,5	28,27	1,2	0	33	-41,71	-43,87	4,92
10,5	28,27	1,2	22,4	17	-47,71	-49,74	4,08
10,5	28,27	1,2	78,5	21	-58,91	-61,45	4,13

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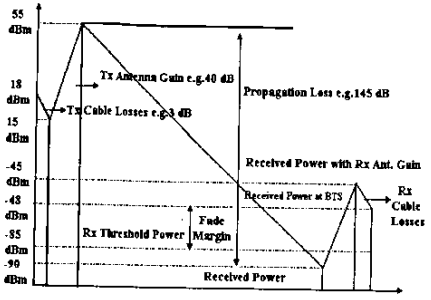

Figure 1: A Typical System Power Budget Diagram

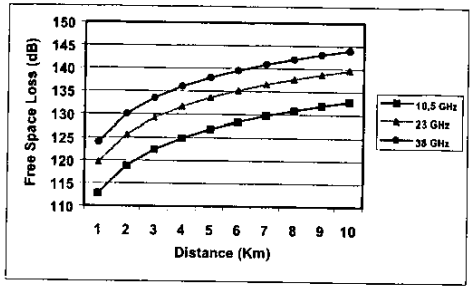

Figure 2: Free Space Loss for Three Different Frequencies

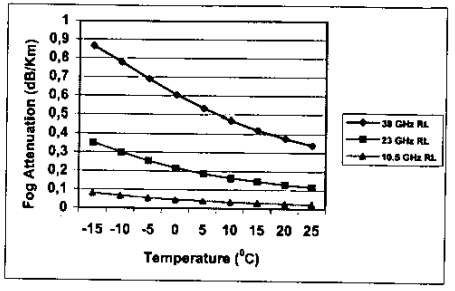

Figure 3: Variation of Fog Attenuation with Temperature

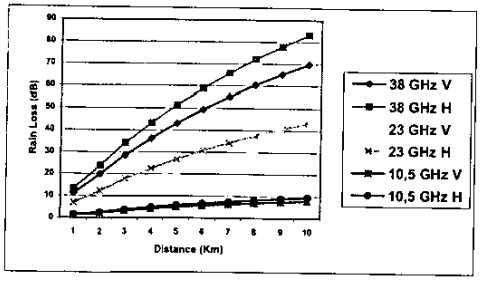

Figure 4: Rain Loss for Different Frequency and Polarizations (51,4 mm/h)

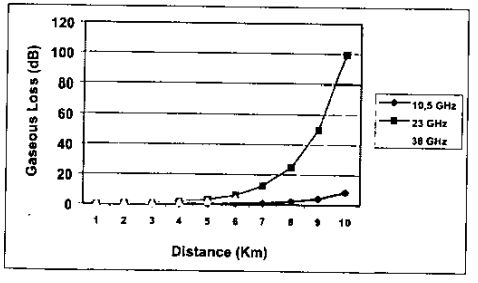

Figure 5: Total Gaseous Loss with Distance for the Frequencies Examined

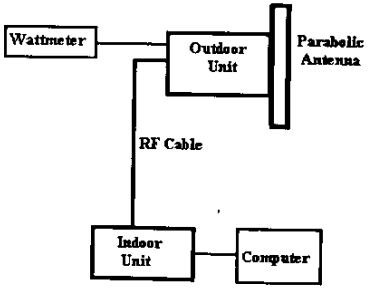

Figure 6: Radio Link Power Measurement Scheme