Link Budget Analysis For Non-Line-Of-Sight Microwave Communication Link With Single Knife Edge Diffraction Obstruction

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***Abstract*— In this paper, link budget analysis for non-line-of-sight microwave communication link with single knife edge diffraction obstruction is presented. In the link budget computation, the path loss included the free space path loss and the single knife edge diffraction loss caused by the knife edge obstruction located along the signal path. The degree of obstruction is specified as line-of-sight (LOS) percentage clearance, Pc(%). Then, among other parameters, the received signal strength and the effective path length that will ensure that the specified link availability will be achieved at the worst case fade depth expected in the link is determined. Particularly, the mutually exclusive rain and multipath fading are used for the determination of the effective fade depth in the link. A sample link budget analysis for a 10 GHz Ku-band microwave link was carried out for a case of LOS percentage clearance , Pc(%) = 0%. The results show that the effective path length of 4.107 Km will ensure that the effective fade depth of 15.310 dB will be accommodated along with the knife edge diffraction loss of -6.021 dB and free space path loss of 124.670 dB. The results for another sample link budget for a 10 GHz Ku-band microwave link for Pc(%) ranging from -80% to 100% show that as the value of Pc(%) increases the absolute value of the knife edge diffraction loss increases and also the effective path length or transmission range of the link decreases. The mathematical model relating the effective path length (d) to Pc(%) is also derived. The ideas presented in this paper are useful to microwave link designers especially when they need to consider the effect of obstructions located along the signal path.**

Keywords*— *Link Budget, Microwave, Line Of Sight, Non-Line-Of-Sight Link, Percentage Clearance, Diffraction Loss

I. INTRODUCTION

Microwave signals travel in a straight line. As such, they are used in line-of-sight communications [1,2,3,4,5,6]. Usually, microwave link designers carry out link budget to ascertain that the received signal strength is strong enough to satisfy the required quality of service [7,8,9]. In most case, the link is assumed to be without obstruction or it is with a obstruction that has at most 60% line-of-sigh (LOS) percentage clearance of the first Fresnel zone. In this case, the effect of the obstruction is neglected and the free space path loss is used as the only path loss used in the link budget computation. However, when there is an obstruction with worse LOS percentage clearance than 60%, the diffraction loss need to be computed and also included in the link budget computation.

In this paper, a non-line-of-sight (NLOS) microwave link with single knife edge obstruction is considered [10,11,12]. The link budget for the NLOS link is carried out and the link availability is determined. In the link budget analysis, the diffraction loss due to the single knife edge obstruction is computed and the loss is added to the free space path loss to obtain the total path loss for the link. Also, the mutually exclusive rain fading [13,14,15] and multipath fading [16,17,18]are used for the determination of the effective fade depth in the link. Sample numerical example is used to show how the ideas presented in this paper can be applied in link budget analysis. Furthermore, the effective path length that will ensure that the maximum fade depth that can occur in the link is accommodated is determined for various LOS percentage clearance.

II. LINK BUDGET FOR TERRESTRIAL FIXED MICROWAVE LINK WITH SINGLE KNIFE EDGE OBSTRUCTION

Link budget is used to determine the received signal in a LOS microwave link and it is expressed as [19];

$$P_R = P_T + G_T - L_T + G_R - L_{FPSL} - L_{OPL} + G_R - L_R + F_M \quad (1)$$

Where P_R is the received power in dB, P_T is the transmitter power in dB, G_T is the transmitter antenna gain in dBi,L_T is sum of all the losses at the transmitter in dB,G_R is the receiver antenna gain in dBi,L_R is sum of all the losses at the receiver in dB,F_M is fade margin added to account for fading that will occuer in the link, L_{FPSL} is the free space path loss in dB which if expressed as [19];

$$L_{FPSL} = 32.4 + 20 \log (f) + 20 \log (d) \quad (2)$$

Where f is the frequency of the emitted signal in MHz andd is the length of the signal path in km. Furthermore, L_{OPL} are the other losses the signal will also sufferwhile propagating along the path. In this paper, the knife edge diffraction loss is considered. Such loss is used to account for the effect of obstructions like isolated tree, hill and in some cases building that are located along the LOS signal path. The knife edge diffraction loss,$\mathrm{G}_d(dB)$ is expressed in terms of LOS percentage clearance,P_c as follows [20]

$$\mathrm{G}_d(dB) = \begin{cases} 0 & \text{for } P_c < -70.7107\% \\ 20\log\left(0.5 - \left(\frac{P_c}{114.0495}\right)\right) & \text{for } -70.7107\% \le P_c \le 0\% \\ 20\log\left(0.5\exp\left(-\left(\frac{P_c}{74.43229276}\right)\right)\right) & \text{for } 0\% \le P_c \le 70.7107\% \\ 20\log\left(0.4 - \sqrt{0.1184 - \left(0.38 - \left(\frac{P_c}{707.1067812}\right)\right)^2}\right) & \text{for } 70.7107\% \le P_c \le 169.7056\% \\ 20\log\left(\frac{0.003181981}{P_c}\right) & \text{for } P_c > 169.7056\% \end{cases} \quad (3)$$

Another loss accounted for in the link design is the fade depth which in this paper two mutually exclusive fade mechanism are considered, namely, the rain fading ($\boldsymbol{R_{fd}}$) and the multipath fading (M_{fd}). The multipath fading, M_{fd}in dB, based on the International Telecommunication Union (ITU) quick planning applications model, is given as [16,17,18];

$$M_{fd} = 10(0.032f - 0.00085h_L) - (10)\log\left(\frac{Po}{\left\{K(d^{3.2})(1+|\varepsilon_p|)^{-0.97}\right\}}\right) \quad (4)$$

Where K is the geoclimatic factor given as:

$$K = 10^{(-4.2-0.0029(\mathrm{dN}_1))} \quad (5)$$

Where dN_1 is the point refractivity gradient at the height of 65 m from the ground.The path inclination, $\boldsymbol{\varepsilon_p}$ in mrad is given as:

$$|\boldsymbol{\varepsilon_p}| = \frac{(|\boldsymbol{h_r} - \boldsymbol{h_r}|)}{\boldsymbol{d}} \quad (6)$$

Where d is the signal path length in km, $\mathrm{h_t}$ and $\mathrm{h_r}$ are the transmitter and thr receiver antenna heights in m above sea level. $\mathrm{h_L}$ is the minimum of $\mathrm{h_t}$ and $\mathrm{h_r}$, f is the frequency in GHz and Po is the percentage of time that fade depth $\mathrm{M_{fd}}$ is exceeded in the average worst month .

The rain fade depth is given as

$$\boldsymbol{R_{fd}} = maximum\left\{K_h\left(R_{po}\right)^{\alpha_h}, \quad K_v\left(R_{po}\right)^{\alpha_v}\right\} \quad (7)$$

Where k_h, α_h are constants for the horizontal polarization; Kv, α_v are constants for the vertical polarization and R_{po} is the rain rate for the given link percentage availability , Po. The link is considered link is available if ;

$P_R \geq P_s$Where$P_s$is the receiver sensitivity (8)

In this study, the microwave link is examined under different LOS percentage clearance, Pc(i). For each Pc(i), the path length that will enable the link to remain available (that is $P_R = P_s$) is determined.

III. SAMPLE NUMERICAL COMPUTATION RESULTS AND DISCUSSIONS

A sample link budget for a 10 GHz Ku-band microwave link is carried out and the results are presented in Table 1 for a case of LOS percentage clearance, Pc(%) = 0%. The results show that the effective path length of 4.107 Km will ensure that the effective fade depth of 15.310 dB will be accommodated along with the knife edge diffraction loss of -6.021 dB and free space path loss of 124.670 dB.

Table 1 **The results for a sample link budget for a 10 GHz Ku-band microwave link for a case of LOS percentage clearance , Pc(%) = 0%.**

S/N	Link Parameters	Parameter Value	Class of parameter (Input or Output)
1	Frequency (GHz)	10	**Input**
2	Rain Zone	N	**Input**
3	Percentage Availability (%)	99.990	**Input**
4	Percentage Outage (%)	0.010	**Input**
5	Transmission Range or Path Length (Km)	4.107	**Input**
6	Transmitter Power (dB)	20.000	**Input**
7	Transmitter Antenna Gain (dBi)	18.000	**Input**
8	Receiver Antenna Gain (dBi)	18.000	**Input**
9	Transmitter and receiver antenna height (m)	50.423	**Input**
10	Receiver Sensitivity (dB)	-80.000	**Input**
11	Rain Rate mm/h	95.000	**Input**
12	LOS Percentage Clearance, Pc(%)	0 %	**Input**
13	Free Space Loss (dB)	124.670	**Output**
14	Diffraction Loss, G(dB)	-6.021	**Output**
15	Fade Margin(dB)	15.309	**Output**
16	Effective Rain Attenuation	15.310	**Output**
17	Multipath Attenuation (dB)	12.003	**Output**
18	Effective fade depth (dB)	15.310	**Output**
19	Dominant Attenuation(dB)	Rain Fading	**Output**
20	Received Power (dB)	-64.691	**Output**
21	Link Status	Link Is Feasible	**Output**

The results for another sample link budget for a 10 GHz Ku-band microwave link for Pc(%) ranging from -80% to 100% are presented in Table 2. The Pc(%) less than zero means that the obstruction is below the LOS while positive value of Pc(%) means that the obstruction extends above the LOS. In practice, the negative value of Pc(%) is preferred as it give lower diffraction loss, as shown in Table 2. Particularly, the results in Table 2 and Figure 1 show that as the value of Pc(%) increases the absolute value of the knife edge diffraction loss increases and also the effective path length or transmission range of the link decreases. The mathematical model relating the effective path length (d) to Pc(%) is given in Eq 9.

Table 2 **The results for a sample link budget for a 10 GHz Ku-band microwave link for Pc(%) ranging from -80% to 100%.**

PC (%)	G(dB)	d (Km)
-80	0.000	5.178
-40	-1.404	4.923
-20	-3.409	4.560
0	-6.021	4.107
20	-8.355	3.714
40	-10.688	3.338
60	-13.022	2.978
80	-14.761	2.720
100	-16.360	2.495

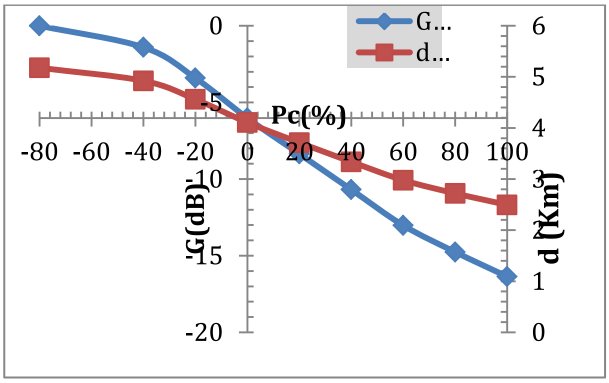

Figure 1 G(dB) and d(Km) versus Pc (%) for a given frequency.

$$d = \begin{cases} \frac{5.408245344(P_c)}{P_c - 3.762374154} & \text{for } P_c < 0 \\ 0.00005847079847(P_c^{\,2}) - 0.02213663405(P_c) + 4.117572778 & \text{for } P_c \geq 0 \end{cases} \quad (9)$$

IV. CONCLUSION

Link budget for non-line-of-sight (NLOS) microwave link is presented. Particularly, effect of single knife edge diffraction on the effective path length is examined. The degree of the knife edge obstruction is expressed in terms of LOS percentage clearance. Sample link budget analyses were carried out for a microwave link at Ku-band frequency. The variation of the effective path length with LOS percentage clearance is determined and a mathematical model was derived to compute the effective path length for any given LOS percentage clearance.

REFERENCES

1. Alsharekh, M. F., Ibrahim, A. H., & Islam, M. (2016). SOM Attributes for a Ubiquitous P2P Communication in Wireless LAN Application. *Trends in Applied Sciences Research*, *11*, 44-49.
2. Qureshi, U. M., Shaikh, F. K., Aziz, Z., Shah, S. M. Z. S., Sheikh, A. A., Felemban, E., &Qaisar, S. B. (2016). Rf path and absorption loss estimation for underwater wireless sensor networks in different water environments. *Sensors*, *16*(6), 890.
3. Harel, O., David, N., Alpert, P., & Messer, H. (2015). The potential of microwave communication networks to detect dew—Experimental study. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *8*(9), 4396-4404.
4. Angueira, P., &Romo, J. (2012). *Microwave line of sight link engineering*. John Wiley & Sons.
5. Ingason, T., & Liu, H. (2009). Line-of-sight MIMO for microwave links-adaptive dual polarized and spatially separated systems.
6. Khan, S. A., Tawfik, A. N., Gibbins, C. J., & Gremont, B. C. (2003). Extra-high frequency line-of-sight propagation for future urban communications. *IEEE Transactions on Antennas and Propagation*, *51*(11), 3109-3121.
7. Mawjoud, S. A. (2008). Evaluation of power budget and Cell coverage Range in Cellular GSM System. *AL Rafdain Engineering Journal*, *16*(1), 37-47.
8. Mämmelä, A., Kotelba, A., Höyhtyä, M., & Taylor, D. P. (2011). Link budgets: How much energy is really received. In *Vehicular Technologies: Increasing Connectivity*. InTech
9. Rehman, M. U., Gao, Y., Wang, Z., Zhang, J., Alfadhl, Y., Chen, X., ...& Bolin, T. (2010). Investigation of on-body bluetooth transmission. *IET microwaves, antennas & propagation*, *4*(7), 871-880.
10. Hansryd, J., Edstam, J., Olsson, B. E., & Larsson, C. (2013). Non-line-of-sight microwave backhaul for small cells. *Ericsson Review*, *3*, 2-8.
11. Rappaport, T. S., MacCartney, G. R., Sun, S., Yan, H., & Deng, S. (2017). Small-scale, local area, and transitional millimeter wave propagation for 5G communications. *IEEE Transactions on Antennas and Propagation*, *65*(12), 6474-6490.
12. Ezenugu, I. A., Edokpolor, H. O., & Chikwado, U. (2017). Determination of Single Knife Edge Equivalent Parameters for Double Knife Edge Diffraction Loss by Deygout Method. *Mathematical and Software Engineering*, *3*(2), 201-208.
13. Kestwal, M. C., Joshi, S., &Garia, L. S. (2014). Prediction of rain attenuation and impact of rain in wave propagation at microwave frequency for tropical region (Uttarakhand, India). *International Journal of Microwave Science and Technology*, *2014*.
14. Islam, R. M., Abdulrahman, Y. A., & Rahman, T. A. (2012). An improved ITU-R rain attenuation prediction model over terrestrial microwave links in tropical region. *EURASIP Journal on Wireless Communications and Networking*, *2012*(1), 189.
15. Andrade, F. J. A., Cruz, P. A., & da Silva Mello, L. A. R. (2015, November). Evaluation of ITU-R rain attenuation prediction methods for terrestrial links. In *Microwave and Optoelectronics Conference (IMOC), 2015*

SBMO/IEEE MTT-S International (pp. 1-4). IEEE.

16. Kelechi, E. G., Kalu, C., & Eunice, A. B. (2017). Differential Fade Depth with Path Length Adjustment (DFD-PLA) Method for Computing the Optimal Path Length of Terrestrial Fixed Point Line of Sight Microwave Link. *Mathematical and Software Engineering*, 3(1), 13-25.
17. Mohajer, M., Khosravi, R., &Khabiri, M. (2006) Flat Fading Modeling in Fixed Microwave Radio Links Based on ITU-R P. 530-11. In Microwaves, Radar & Wireless Communications, 2006. MIKON 2006. International Conference on(pp. 423-426). IEEE.
18. Nnadi, N. C., Nnadi, C. C., & Nnadi, I. C. (2017). Computation of Diffraction Parameter as a Function of Line of Site Percentage Clearance. *Mathematical and Software Engineering*, *3*(1), 149-155.
19. Emenyi M., Udofia K. M., Amaefule O. C. (2017) Computation of Optimal Path Length for Terrestrial Line of Sight Microwave Link Using Newton–Raphson Algorithm *Software Engineering*; 5(3): 44-50
20. Nwokonko, S. C. Onwuzuruike, V.K. Nkwocha C. (2017) Remodelling of Lee's Knife Diffraction Loss Model as a Function of Line of Site Percentage Clearance *International Journal of Theoretical and Applied Mathematics* 2017; 3(4): 138-142