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Standardization of attenuation formula for radio waves propagation through free space (LOS) communication links

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Abstract

This article presents the review and derivation of new attenuation formula for the radio waves propagation in free space communication links, based on the existing radio propagation loss formula for the same links. The new and existing formulas are computed numerically and validated by experimental measurements of the free space propagation loss characteristics of 92.1MHz radio wave propagating at 2.5kW from the transmitter antenna as the receiving antenna is moved away every 1km from the transmitting antenna up to about 64km. The two formulas correlate very well (R^2 value = 1), but the root mean square error (*rmse*) between the two formulas is ~0.11%. Also, the formulas show good correlation (R^2 value~0.81) respectively with the measurements, but *rmse* of the new and existing formulas when compared with the measurements are ~0.27% and ~0.38% respectively. It is evident in this study that the new formula, as well as the existing formula, can also be employed to determine the propagation loss of the radio waves propagation through free space communication links.

Keyword: Line of Sight, Free Space, Attenuation, Formula, and Radio propagation.

Introduction

The importance of attenuation prediction for radio waves propagation can never be over emphasize by the communication researchers when dealing with planning, budgeting and design of high performance communication systems (Bostian et al., 1993; Lee, 1998; Rhodes, 1999; Kai, 2000; Wesolowski, 2002; Seybold, 2005; Prasad et al., 2006). There are many attenuation formulas available in the open literatures depending on the communication links (channels) (Kobayashi and Patrick, 1992; Meng, and Ng, 2009; Masson et al, 2011; McLarnon, 1997). It is expedient to discuss and understand the attenuation of the radio waves propagation through the free space communication links (LOS) first, so to appreciate other propagation losses due to complex communication links such as buildings, ice, tunnels, forests and other atmospheric conditions etc. Attenuation (A) is defined as the reduction in magnitude of a radio frequency signal from the transmitting station on passing along any transmission path (Lee, 1998; Kai, 2000). It is directly proportional to the frequency and distance of transmission. The general formula is given as:

$$A = 10\log_{10}\left(\frac{P_R}{P_T}\right), \ \text{dB} \qquad (1)$$

Where, P_R = Signal Power received by the receiver in Watts, P_T = Signal power Transmitted by the transmitter in Watts. In the existing radio propagation loss in free space by (McLarnon, 1997; Gurung, and Zhao, 2011), using the basic physics principle, the free space path loss was determined and substituted into the Friis transmission formula which describes the power P_R received by receiving antenna in a communication system as shown in the figure 1(Kraus, 1988; Kraus et al, 2002; Balanis, 2005). Having known the power received by the receiving antenna and the transmitting antenna' power, the attenuation of the propagating radio waves can be computed by Equation 1. This approach is too long and computational intensive to determine the attenuation of propagating radio waves in free space (Line of Sight, LOS). However how long the method may be, it gives me insight to understand another simple way to calculate the attenuation based on the same basic physics principle and definition of attenuation in Equation 1.

In this paper, a simple attenuation formula which I called free space attenuation (FSA) formula is derived for radio waves propagation in the free space communication channels. The free space and Friis attenuation formulas are used to compute the free space propagation loss characteristics of 92.1MHz radio waves propagating at 2.5kW from a transmitter antenna as the receiving antenna is moved away from the transmitting antenna. Experimental measurements are presented for verification of the two formulas.

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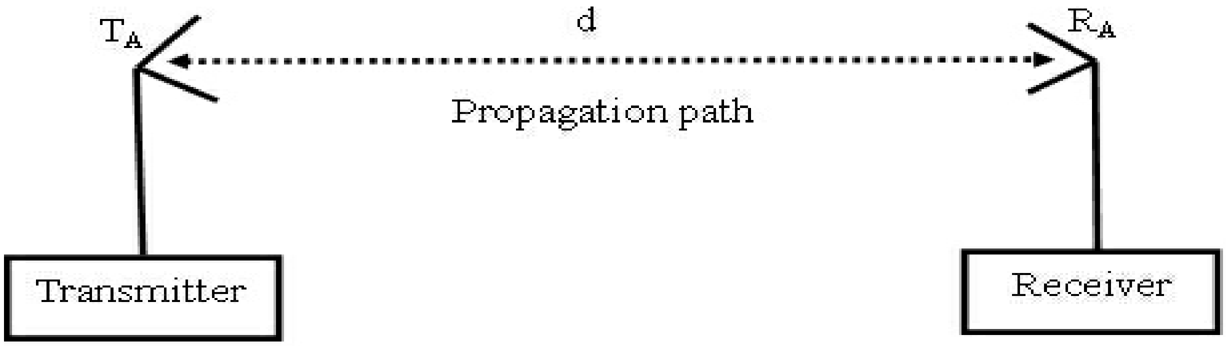

Figure 1: Showing a basic communication system.

2. Review of the existing formula and Derivation of the new formula

In Kai (2000), McLarnon (1997), Kraus (1988), Kraus et al., (2002) and Balanis (2005), formulas for calculations of free space transmission power received and loss (path loss, FSL) are presented by considering a transmitter with power P_T coupled to an antenna which radiates equally in all directions. The (LOS) free space path loss is calculated, having considered the scattering effects of reflection, refraction and diffraction along the radio free space communication links as suggested by the Huygens' Principle. At a distance d from the transmitter, the radiated power is distributed uniformly over an area of $4\pi d^2$ (i.e. the surface area of a sphere of radius d), so that the power flux density, S is given as:

$$S = \frac{P_T}{4\pi d^2} \quad \text{Watt/m}^2, \qquad (2)$$

The transmission loss then depends on how much of this power is captured by the receiving antenna, along the possible free space communication links. If the capture area, or effective aperture of this antenna is A_R, then the power P_R which can be delivered to the receiver (assuming no mismatch or feed line losses) is simply given as:

$$P_R = SA_R \quad \text{Watt}, \qquad (3)$$

For the hypothetical isotropic receiving antenna (Kraus, 1988),

$$A_R = \frac{\lambda^2}{4\pi} \quad \text{m}^2 \qquad (4)$$

Combining equations (2) and (4) into (2), yield:

$$P_R = P_T\left(\frac{\lambda}{4\pi d}\right)^2, \text{ Watt} \qquad (5)$$

The free space path loss between the isotropic antennas is P_R/P_T. Substituting $\lambda = c/f$ (where c, is the speed of light~3.0 × $10^8 ms^{-1}$) into Equation 5 to get:

$$FSL = \left(\frac{4\pi}{c}\right)^2 f^2 d^2, \qquad (6)$$

When Equation 6 is expressed logarithmically, it yields:

$$FSL = 32.4 + 20\log_{10} f + 20\log_{10} d \quad \text{dB}, \qquad (7)$$

Substituting Equation 7 into the Friis transmission formula which is given by (Prasad et al., 2006; McLarnon, 1997; Gurung, and Zhao, 2011):

$$P_R = P_T - FSL + G_T + G_R - L_T - L_R \quad \text{dBm}, \qquad (8)$$

It yields:

$$\therefore P_R = P_T + G_T + G_R - 32.4 - 20\log_{10} f - 20\log_{10} d - L_T - L_R \quad \text{dBm}, \qquad (9)$$

Where, f = resonant frequency in MHz, d = distance covered by the radio waves in km, P_T = transmitter power output in dBm, G_T and G_R = transmit and receive antennas gain in dBi respectively, L_T = transmission line lose between transmitter and transmit antenna in dB, L_R = transmission line loss between receiver input and receive antenna in dB.

Now, instead of finding the ratio: P_T/P_R, from the Equation 5, let us find the ratio P_R/P_T, which yields:

$$\frac{P_R}{P_T} = \left(\frac{c}{4\pi f d}\right)^2, \qquad (10)$$

When Equation 10 is substituted into Equation 1, it yields a standard free space attenuation formula:

$$A = 147.5571 - 20\log_{10} f - 20\log_{10} d \quad \text{dB}, \qquad (11)$$

Where, f = resonant frequency in Hz, d = distance covered by the radio waves in meters.

3. Computations and Experimental Measurements

As a case study a radio station with the actual radiated power of 2.5kW from the transmitting antenna (130m high), 92.1MHz, 3.5kW transmitter is employed for the experimentation. Considering 2.5kW power directly radiated (P_T) from the transmitting antenna, transmission line loss L_T between the transmitter and the transmit antenna T_A is negligible. Also, since the length of the 5C–2V 75Ω coaxial cable connecting the receiving antenna to the receiver is about 0.25m, the transmission line loss L_R between receiver input and receive antenna R_A is negligible. Therefore Equation 9 becomes:

$$\therefore P_R = P_T + G_T + G_R - 32.4 - 20\log_{10} f - 20\log_{10} d \quad \text{dBm}, \qquad (12)$$

P_T = 2.5kW (dBm), G_T = 9.54dBi, G_R = 1.76dBi, f = 92.1MHz, and d varied from 1km to 64km (coverage area of the transmitter) are substituted into Equation 12 to compute P_R. Then P_R obtained and converted to Watt (W) and P_T = 2500W are substituted into Equation 1 to yield the Friis Attenuation (FA) of the radio waves. Equation 11 is computed to yield the Free Space Attenuation (FSA) of the radio waves.

The experimental measurement set up is shown in the figure 2. The experimental measurements were carried out by moving the suitably designed receiving dipole antenna well connected (matched) to the receiver system (GSP810-Analyser) to measure the signal power (in dBm or mW) received at 1km interval from the transmitting antenna up to 64km along possible line of sight (LOS). The signal power P_R received in dBm is converted to Watt and P_T = 2500W are substituted into Equation 1 to yield the measured attenuation.

(a)

(b)

Figure 2: Showing the experimental measurement set-up: (a) the receiver system and (b) the transmitter antenna.

4. Results

In this paper, the existing Friis attenuation (FA) formula is reviewed and a convenient attenuation formula called free space attenuation (FSA) formula is derived for radio waves propagation in the free space communication channels. The two formulas (FA and FSA) are computed numerically and validated by experimental measurements of the free space propagation loss characteristics of 92.1MHz radio wave propagating at 2.5kW from the transmitter antenna as the receiving antenna is moved away every 1km from the transmitting antenna up to about 64km. All the computations were performed with the aids of Microsoft office Excel 2007 software, and the data obtained were analyzed with the aids of matlab software.

The Figure 3 shows the plots of FA and FSA against the distance, comparing the two formulas. While Figures 4 and 5 show the plots of the FA and measured attenuation; and FSA and measured attenuation respectively against the distance for comparison. The Figure 6 is the plots of the FA, FSA and measured attenuation against the distance comparing together all the theoretical and the experimental measured results. The two theoretical formulations (FA and FSA) correlate very well with the R^2 value equal to 1, but the root mean square error (*rmse*) between the two formulas is ~0.11%. Also, the FA and FSA show good correlation (R^2 value~0.81) respectively with the measurements. The root mean square errors of FA and FSA when compared with the measurements are ~0.38% and ~0.27% respectively. These inaccuracies of the formulas with the experimental measurements results may be due to the fact the two formulas are based on the radio waves propagation through the (LOS) free space communication links, and whereas the location of the measurements are surrounded with forests. Loss due the ground, the contours and canopy reflections may be contributing factors.

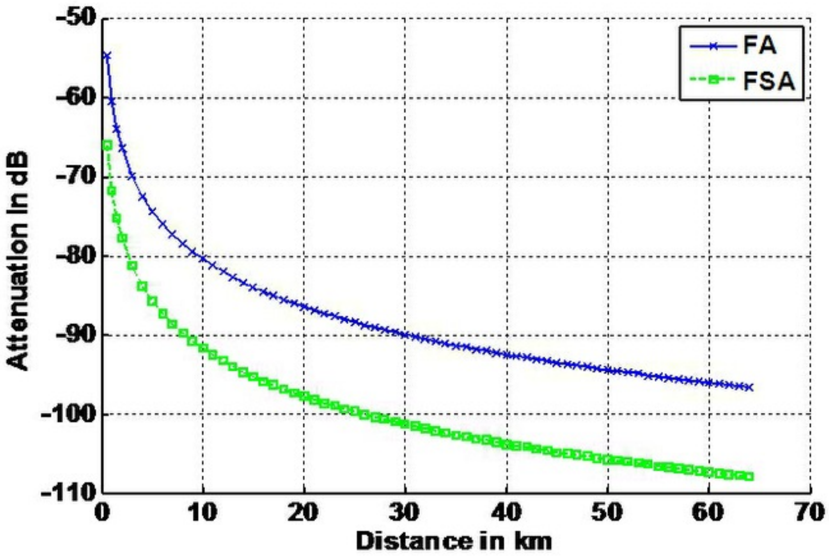

Figure 3: Showing the plots of FA and FSA versus Distance.

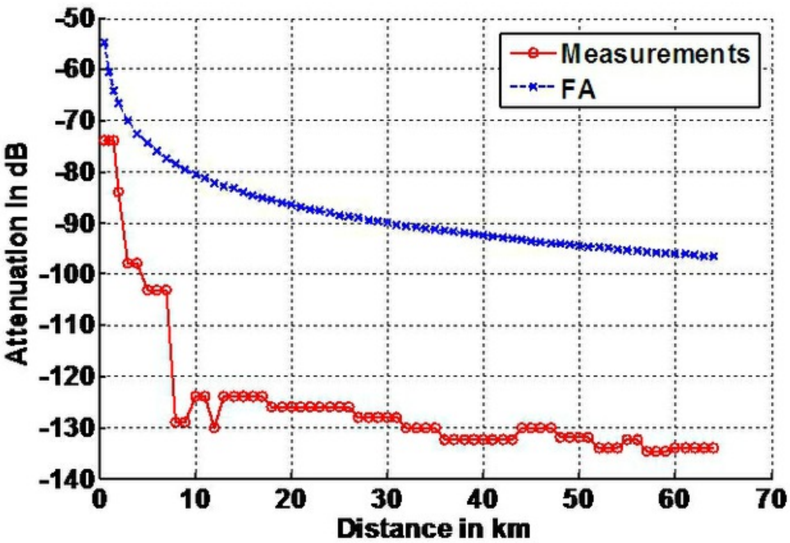

Figure 4: Showing the plots of the FA and Measured Attenuation versus Distance.

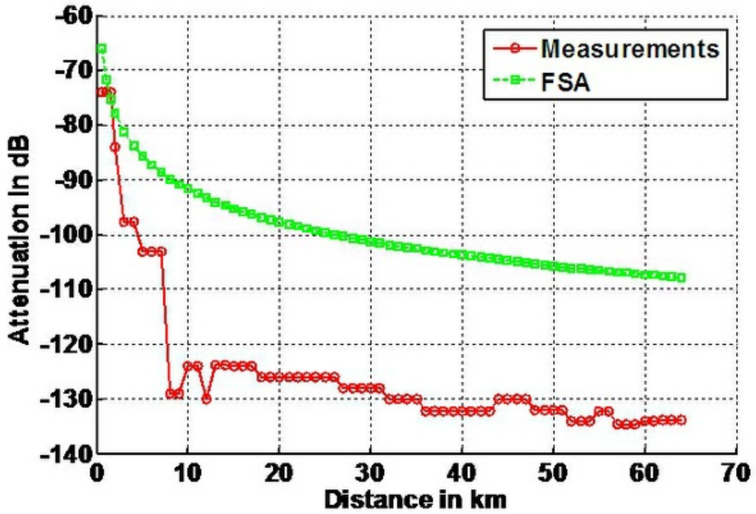

Figure 5: Showing the plots of FSA and Measured Attenuation versus Distance.

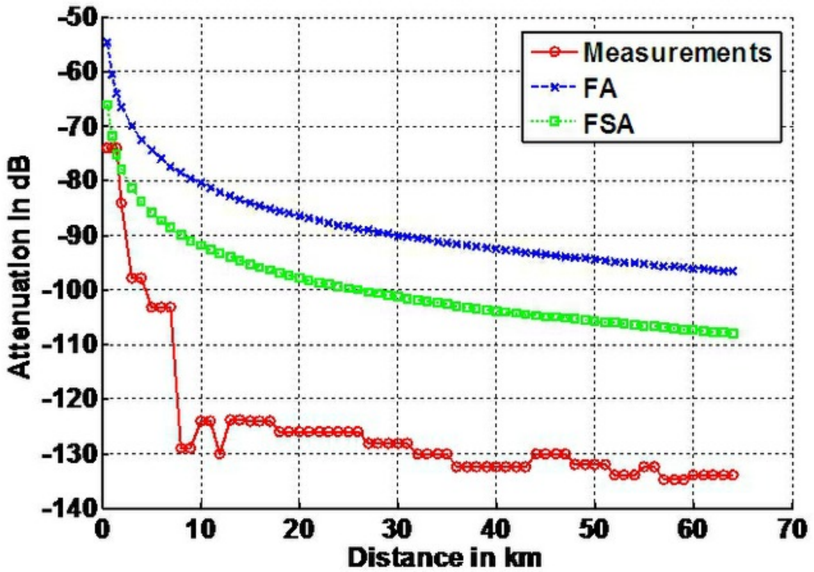

Figure 6: Showing the plots of FA, FSA and Measured Attenuation versus Distance.

5. Conclusion

Therefore, from the results obtained, it is evident in this study that the attenuation formula (FSA) derived, as well as the existing formula (FA), can also be employed to determine the propagation loss of the radio waves propagation through free space communication links. The large errors and inaccuracies of the formulas with the experimental measurements results may be due to the fact the two formulas are based on the radio waves propagation through the free space communication links, and whereas the location of the measurements are surrounded with forests, there is no real (LOS) free space in the links.

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