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Computer-Aided Technique for the Determination of Reflection Point in a Microwave Path Profile Design

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Abstract: Microwave link design is assuming a software approach that eliminates the rigours of conventional methods, fastens design procedures and provides for optimized communications systems. In this study therefore, computer-aided technique to determine the position of the reflection point is presented. The importance of reflection point in the overall system design of microwave relay links is highlighted. A brief description between reflected and direct wave is introduced vis-à-vis the physical application of reflection point. The use of software to generate Tabless for various combinations of antenna heights to optimize design time is included. The Tabless generated by the software conform with known theory thus proving the efficacy and efficiency of the software developed. Recommendations for further works are also stated.

Key words: Electromagnetic, interference, fading, microwave, reflection, software

INTRODUCTION

Information carrying electrical signal is usually launched into space as an electromagnetic radiation using an antenna[1]. The antenna functions as a transducer which converts energy from the form of voltage/current to frequency. As a result, a single antenna may be used to launch as well as abstract energy from an Electromagnetic (EM) wave in a region where the radiation field exists. When this translation of voltage/current occurs at a very high frequency greater than 300MHz, the radiation is said to be in the microwave region. Propagation in this region is usually by Line-of-Sight (L.-O-S).

Since most radio systems that generate this information carrying signal operate in the lower part of the atmosphere called the troposphere, they are affected by all the changes in weather phenomena that occur within this region[2]. The dominant property of the atmosphere which affects the radio signal is the radio refractive index otherwise known as radio refractivity.

This radio refractive index is a function of the various meteorological variables in the atmosphere namely water vapour, the air temperature and the pressure. In a standard atmosphere, water vapour, pressure and temperature decrease with height and this leads to a decrease in radio refractivity with height at a rate of about 0.04 units/metre[3]. It is in fact this variation of radio refractive index with height that gives rise to the transmission phenomena like radio reflection, radio refraction, duct transmission and radio signal scattering.

These phenomena could be a source of worry in the design of microwave transmission links. This study looks at the concept of reflection in microwave transmission with a view of using computer-aided technique to determine the point of reflection along a wave transmission path. However, a general description of microwave beam is given below to help appreciate the importance of the reflection point in microwave systems.

Description of microwave beam: For simplicity, the microwave beam is treated as a line representing the longitudinal centre of the beam or main lobe[4]. When discussing line-of-sight systems, the microwave beam behaves much like a light beam in so far as atmospheric influences are concerned and is subject to other external influences like intermediate terrain between sites and obstacles. It tends to follow a straight line in azimuth unless intercepted by structures in or near the path. In traveling through the atmosphere, it usually follows a slightly curved path in the vertical plane. That is, it is refracted vertically due to the variation with height in the dielectric constant of the atmosphere, generally slightly downwards, so that the radio horizon is effectively extended. The amount of this refraction varies with time due to changes in temperature, pressure and relative humidity which controls the dielectric constant of the atmosphere.

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At the point of grazing over an obstacle, the microwave beam is diffracted and there is very small shadow area where some energy is redirected in a narrow and rapidly diminishing wedge toward total shadow[3]. As the beam encounters an obstacle, there is a loss of energy reaching the far antenna. The loss ranges from 6dB to 20dB depending on the type of' surface over which the diffraction occurs. For a smooth surface such as flat terrain or water bed, the loss is maximum (≈20dB) while a knife edge diffraction will produce a loss of 6dB at grazing. In other to minimize these losses, L-O-S microwave paths are designed to have better than grazing clearance even under the most adverse atmospheric conditions. Most other physical objects such as houses also block the microwave path.

The microwave beam is reflected from relatively smooth terrain and water surfaces just as light beam is reflected by a mirror. An important concept in analysing microwave propagation effects particularly those of reflection, refraction and diffraction is that of the Fresnel zone[3,5,6]. The Fresnel zones are a series of concentric ellipsoids surrounding the path. The first Fresnel zone is the surface containing every point for which the sum of the distances from that point to the two ends of the path is exactly one-half wavelength longer than the direct end-to-end path. The first Fresnel zone radius is used to measure path clearance and their effects at the frequency of operation. The second and higher other Fresnel zones are also very important under certain conditions such as highly reflective paths.

Reflection in microwave systems: Reflections in microwave links are particularly troublesome when the path has to go across large water surfaces and smooth surfaces. The effects of reflection tend to be more severe on profile paths in rural areas where there are large stretch of land than in urban settings. In urban settings, the ground reflection path is seriously reduced because of blockages by cluster of buildings[7]. In microwave paths over relatively smooth ground such as large bodies of water, ground reflections can be a major cause of signal attenuation. For any microwave link, it is worthwhile to study the path profile to see if the ground reflection has the potential to negatively impact on the throughput of the system or not.

Assuming there is no atmospheric refraction taking place in the atmosphere and the earth surface is smooth as shown in Fig. 1, the received signal by the receiving antenna will be a function of the Direct Wave (DW) and the Reflected Wave (RW). If the surface is not smooth, many reflected waves arrive at the receiving antenna as shown in Fig. 2 and it becomes difficult to determine the total field at the receiving antenna. Studies[8,9] show that the transformation of signal as it is reflected from the earths surface have a complex reflection coefficient which

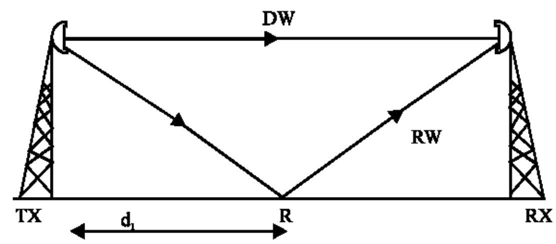

Fig. 1: Transmission over smooth earth surface

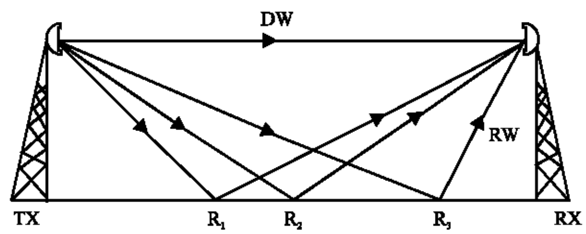

Fig. 2: Transmission over rough earth surface

is a function of the angle of incidence, the dielectric constant of the earth and the conductivity at the point of reflection. Generally, when the received signal is a vector sum of two or more waves, the path difference measured in wavelength changes with variation in frequency and this implies that a composite signal tend to reinforce or cancel each other differently. This results in frequency distortion and the received signal has poor quality[10,11] (selective fading).

The importance of locating the reflection point in microwave link design lies in the fact that an artificial earth block can be arranged thereby preventing the Reflected Wave (RW) from reaching the receiving antenna especially when it is causing destructive interference.

Reflection point calculation: Reflection point along a microwave path is not necessarily at the midpoint of the path unless the transmitting antenna and the receiving antenna are of the same height and the ground is not sloped in the reflection region[3]. For a simple case where the earth is assumed to be flat (K = ∞)*, a simple relationship exists between two antenna heights, the terminal points and the distances to the reflection point. K is known as the earth radius factor that takes care of the undulating nature of the earths' surface. The relationship is shown in Eq. 1.

$$\frac{h_1}{h_1 + h_2} = \frac{d_1}{d_1 + d_2} = \frac{d_1}{D} \qquad (1)$$

where

h_1= elevation of the lower antenna in metres
h_2= elevation of the higher antenna in metres

d_1= distance in kilometers from h_1 end to the reflecting point
$d_1 + d_2 = D$ = path length in kilometers.

For the condition where $h_1 = h_2$, it implies that $d_1 = d_2$ and the reflection point is midway between the terminals. For flat earth condition i.e. $K = \infty$, the relationship in Eq. 2 exists.

$$d_1 = nD \quad (2)$$

and

$$n = \frac{h_1}{h_1 + h_2} \quad (3)$$

Studies show that when the antennas are at different elevation the reflection point moves along the path as the height varies and nearer to the antenna with lower elevation. Therefore, choosing a suitable value for h_1 and h_2 will place the reflection point at a suitable place.

For values of K other than infinity and for unequal antenna heights, the geometric relation involves cubic Eq.s whose solution is somewhat cumbersome. A graphic solution for the conditions K = 2/3 and 4/3 exists and by using these charts, an approximate value of n in Eq. 3 for each condition can be determined and the corresponding values of d_1 calculated. The graphic solution provides accuracy only adequate for some links and where greater accuracy is required, the following relationships are useful.
For K = 2/3

$$\frac{h_1}{d_1} - d_1 = \frac{h_2}{d_2} - d_2 \quad (4)$$

For K 4/3

$$\frac{h_1}{d_1} - \frac{d_1}{2} = \frac{h_2}{d_2} - \frac{d_2}{2} \quad (5)$$

The knowledge of the path length helps to determine the approximate values of d_1 and d_2 which are substituted in equation 4 or 5 depending on the value of K. If the reflection point is correct, the two sides will be equal, if not, d_1 is increased by a small amount and d_2 is decreased by the same amount. If this causes the inequality to increase, the procedure is reversed. The iteration is continued until a value is reached for which the sides are equal or very closely so. This iteration is very cumbersome and can hardly be done manually. This paper introduces the software that carries out this iteration to locate the reflection point given the two antenna heights.

K	2
h_1	150
h_2	70
d_1	8
d_2	30
Inc	0.9
R	0.058565
TD	38

h_1= elevation of the lower antenna in metres
h_2= elevation of the higher antenna in metres
d_1= distance is km from h_1 end to the reflection point R
d_2= distance is km from h_2 end to the reflection point R
K = Earth radius factor (1for K=infinity, 2 for K 2/3, 3 for K=4/3)
Inc* = The incremental value while computing the smallest R value
TD = Total distance between the two antenna in km.

Fig. 3: Screen interface for input

Use of software for reflection point calculation: Our program studys on the principle that for the reflection point position to be accurate, the two sides of Eq.s 4 and 5 must be equal or very close i.e. R = 0 (where R is the difference between the LHS and the RHS of either Eq. 4 or 5). We developed a simple program based on MS™ Visual Basic which enables the designer to enter the values of K, d_2, h_1 and h_2. A snapshot to the program interface is shown in Fig. 3.

Enter the values of h_1, h_2, d_2, Inc, A and TD at the appropriate cells.

From the program interface of Fig. 3, the designer inputs the values in the appropriate cells and clicks the RUN macro button and the system computes the reflection point position that is most approximately equal to zero (i.e. the difference between the right hand side and the left hand side of Eq. 4 or 5) and generates, an output as shown in Table 1-4.

The Inc value plays an important role in determine level of accuracy of the reflection point calculation. From our trials, the smaller the Inc value, the higher the accuracy of the reflection point calculation.

*Inc value of zero will result in an endless loop. It is the value by which the two sides will be increased or decreased as the case may be in order to balance the inequality or find when the value R is closest to zero.

Importance of reflection point: The basic purpose of analyzing and computing accurately the reflection point in microwave path profile design is to determine the most suitable value for h_1 and h_2 for any particular terrain and condition in such a way as to position the reflection point vis-a-vis the reflected wave in a location that will not negatively affect the transmission. In most designs the reflection point is made to fall within building structure or other objects to prevent the reflected wave from reaching the receiver terminal and affect the reception. The reflected waves most times have canceling effects especially when they arrive in an out-of-phase relative to the direct wave.

Transmissions over flat and smooth terrain like river beds make extensive use of the knowledge of reflection point to minimize the path loss in transmitted waves. In such designs, the antenna heights are adjusted to either

Table 1: Reflection point chart for K = 2/3, Inc = 0.01 and D = 48 km

h_1/h_2	150	140	130	120	110	100	90	80	70	60	50	40
150	24.00	23.83	23.66	23.49	23.31	23.14	22.96	22.78	22.59	22.40	22.21	22.02
140	24.16	24.00	23.83	23.66	23.48	23.30	23.13	22.94	22.76	22.57	22.38	22.18
130	24.23	24.16	24.00	23.82	23.65	23.47	23.29	23.11	22.93	22.74	22.75	22.23
120	24.50	24.33	24.17	24.00	23.82	23.65	23.47	23.28	23.11	22.91	22.72	22.53
110	24.68	24.51	24.34	24.17	24.00	23.82	23.64	23.46	23.28	23.09	22.90	22.70
100	24.85	24.69	24.52	24.34	24.17	24.00	23.82	23.63	23.46	23.26	23.07	22.88
90	25.03	24.86	24.70	24.52	24.35	24.17	24.00	23.81	23.63	23.44	23.25	23.06
80	25.21	25.05	24.88	24.71	24.53	24.36	24.18	24.00	23.81	23.62	23.43	23.24
70	25.40	25.23	25.06	24.89	24.72	24.54	24.36	24.18	24.00	23.81	23.62	23.42
60	25.59	25.42	25.25	25.08	24.90	24.73	24.55	24.37	24.18	24.00	23.80	23.61
50	25.78	25.61	25.44	25.27	25.09	24.92	24.74	24.56	24.37	24.19	24.00	23.8
40	25.97	28.81	25.64	25.46	25.29	25.11	24.93	24.75	24.57	24.38	24.19	24.00

Table 2: Reflection point chart for K = 2/3, Inc = 0.5 and D = 48 km

h_1/h_2	150	140	130	120	110	100	90	80	70	60	50	40
150	23.50	23.50	23.50	23.00	23.00	23.00	22.50	22.50	22.50	22.00	22.00	22.00
140	24.00	23.50	23.50	23.50	23.00	23.00	23.00	22.50	22.50	22.50	22.00	22.00
130	24.00	24.00	23.50	23.50	23.50	23.00	23.00	23.00	22.50	22.50	22.50	22.00
120	24.50	24.00	24.00	23.50	23.50	23.50	23.00	23.00	23.00	22.50	22.50	22.50
110	24.50	24.50	24.00	24.00	23.50	23.50	23.50	23.00	23.00	23.00	22.50	22.50
100	24.50	24.50	24.50	24.00	24.00	23.50	23.50	23.50	23.00	23.00	23.00	22.50
90	25.00	24.50	24.50	24.50	24.00	24.00	23.50	23.50	23.50	23.00	23.00	23.00
80	25.00	25.00	24.50	24.50	24.50	24.00	24.00	23.50	23.50	23.50	23.00	23.00
70	25.00	25.00	25.00	24.50	24.50	24.50	24.00	24.00	23.50	23.50	23.50	23.00
60	25.50	25.00	25.00	25.00	24.50	24.50	24.50	24.00	24.00	23.50	23.50	23.50
50	25.50	25.50	25.00	25.00	25.00	24.50	24.50	24.50	24.00	24.00	23.50	23.50
40	25.50	25.50	25.50	25.00	25.00	25.00	24.50	24.50	24.50	24.00	24.00	23.50

prevent the reflected waves from reaching the receiver or to arrive in phase with the direct waves thus acting as a boost to the transmission.

RESULTS AND DISCUSSION

The data presented in Table 1, 2, 3 and 4, are the results of the computer execution of the codes written in Microsoft Visual Basic. The vertical and the horizontal bars of the Table h_1 and h_2 represent the tentative heights of the transmitting and receiving antenna. The design engineer has the option of choosing different antenna heights that he wants to compute the reflection point. The height of antenna so chosen can be affected by other factors like cost, climate and environmental conditions.

For this study, we considered antenna heights in the range of 40metres to 150 metres and path lengths of 38km, 43km and 48km and value of K = 2/3 and 4/3. Other distances can also be computed by changing the value of TD field in the program snapshot in Fig. 3. Table 1,2,3 and 4 show printouts for various values of K and Inc.

As earlier stated, the values of d_1 and d_2 are iteratively increased or decreased by equal amount and in opposite direction until a zero or near zero value is obtained. The program developed in this study does this iteration automatically and to a very high degree of efficiency as set out by the designer through the Inc value. The final value of d_2 at the lowest iteration (that is the value when the reflection point value is zero or close to zero) is noted for all the various combination of the antenna heights h_1 and h_2. The value of d_2 is recorded in the Table against the corresponding values of h_1 and h_2.

From Table 1, when h_1 = 100m and h_2 = 100m and K = 2/3, the value of d_2 when Inc = 0.5 is 23.5km, but 24km when Inc = 0.01 which is half of 48km as shown in Table 2. Also, with K = 4/3 and equal antenna heights, the reflection point falls midway i.e. 24km from the h_1 end (Table 3) with Inc value of 0.01 while Inc value of 0.5 shows a variation of 0.5 (Table 4). This difference of 0.5 is due to the different Inc value used in the computation. The Inc value in the program plays an important role in determining the level of accuracy of the Reflection point computation.

The result from the Table also proves the point that the reflection point position moves closer to the antenna with the lower elevation. This attests to the fact that the data contained in the Table are reliable and forms a base to generate other Reflection point positions using any combination of antenna heights.

Future study: In further studies, the effects of divergence i.e. the scattering of reflected signal due to the curvature of the earth, terrain roughness, clearance, reflection coefficient, objects in azimuth can be included in the computation of the reflection point.

The antenna discriminations can be automatically factored into the results using the 3dB beam widths. Also, the use of different frequencies can be considered. All these variables can be presented in a format that when input into the computer, their effects on reflection point position can be determined if any.

Table 3: Reflection point chart for K = 4/3, Inc = 0.01 and D = 48 km

h_1/h_2	150	140	130	120	110	100	90	80	70	60	50	40
150	24.00	23.72	23.43	23.14	22.84	22.54	22.22	21.90	21.56	21.22	20.86	20.49
140	24.27	24.00	23.70	23.42	23.12	22.82	22.50	22.18	21.84	21.50	21.14	20.78
130	24.56	24.28	24.00	23.70	23.41	23.10	22.79	22.46	22.13	21.79	21.43	21.07
120	24.85	24.57	24.29	24.00	23.70	23.39	23.08	22.76	22.42	22.08	21.73	21.36
110	25.15	24.87	24.58	24.29	24.00	23.69	23.38	23.05	22.72	22.38	22.03	21.66
100	25.45	25.17	24.89	24.60	24.30	24.00	23.68	23.36	23.03	22.69	22.34	21.97
90	25.77	25.49	25.20	24.91	24.61	24.31	24.00	23.67	23.34	23.00	22.65	22.29
80	26.09	25.81	25.53	25.23	24.94	24.63	24.32	24.00	23.66	23.32	22.97	22.61
70	26.43	26.15	25.86	25.57	25.27	24.96	24.65	24.33	24.00	23.66	23.30	22.94
60	26.77	26.49	26.20	25.91	25.61	25.30	24.99	24.67	24.33	24.00	23.65	23.28
50	27.13	26.85	26.56	26.26	25.96	25.65	25.34	25.02	24.69	24.34	24.00	23.63
40	27.5	27.21	26.92	26.63	26.33	26.02	25.70	25.38	25.05	24.71	24.36	24.00

Table 4: Reflection point chart for K = 4/3, Inc = 0.5 and D = 48 km

h_1/h_2	150	140	130	120	110	100	90	80	70	60	50	40
150	23.50	23.50	23.00	23.00	22.50	22.00	22.00	21.50	21.00	21.00	20.50	20.00
140	24.00	23.50	23.50	23.00	23.00	22.50	22.00	22.00	21.50	21.00	21.00	20.50
130	24.50	24.00	23.50	23.50	23.00	23.00	22.50	22.00	22.00	21.50	21.00	21.00
120	24.50	24.50	24.00	23.50	23.50	23.00	23.00	22.50	22.00	22.00	21.50	21.00
110	25.00	24.50	24.50	24.00	23.50	23.50	23.00	23.00	22.50	22.00	22.00	21.50
100	25.00	25.00	24.50	24.50	24.00	23.50	23.50	23.00	23.00	22.50	22.00	22.00
90	25.50	25.00	25.00	24.50	24.50	24.00	23.50	23.50	23.00	23.00	22.50	22.00
80	26.00	25.50	25.00	25.00	24.50	24.50	24.00	23.50	23.50	23.00	23.00	22.50
70	26.00	26.00	25.50	25.00	25.00	24.50	24.50	24.00	23.50	23.50	23.00	23.00
60	26.50	26.00	26.00	25.50	25.00	25.00	24.50	24.50	24.00	23.50	23.50	23.00
50	27.00	26.50	26.00	26.00	25.50	25.00	25.00	24.50	24.50	24.00	23.50	23.50
40	27.50	27.50	26.50	26.00	26.00	25.50	25.00	25.00	24.50	24.50	24.00	23.50

CONCLUSION

The importance of reflection point position in any microwave relay link cannot be over looked. It is needed during the design stage to ensure minimum path loss and during maintenance stage to accommodate the eruption of obstructions in the path due to urban development and natural growths like trees. The use of computer-aided technique in the determination of reflection point position eliminates the onerous task designers of such links encounter in doing the iterations manually. Also, locating the exact position of reflection point enables the designer to design a path with minimum losses. The charts generated in this study based on standard Eq. (4 and 5) therefore provide a handy tool for designers to interpolate the reflection point positions for various antenna heights and K values thereby eliminating the onerous task of manual iteration involved in Eq. 4 and 5.

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