# A Computational Model for Calculating the Electric Field Strength of Radio Transmissions

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*Abstract* – **This paper presents a computational model to calculate the electric field strength of radio waves due to a given transmitter. The developed software is based on ray optics theory and it can determine the field strength in double quick time and the electric field strength can be graphically illustrated. This model can also be used to predict the location of a new transmitter providing optimum coverage. By using this model we attempted to identify the field strength distribution in selected areas of the Rathnapura district, Sri Lanka, from a given transmitter. Good agreement was seen in the computed shadow areas and the areas where no radio signals were observed in the field strength measurements carried out by the Sri Lanka Broad Casting Corporation in 1997 for the Yatiyanthota and Radella transmissions. Where measurable signals were present, the measured and computed signal strengths were different. This is possible since atmospheric absorption, reflections from mountains among other effects were not considered in the computations. This computational model is useful in planning and operation of radio communication systems so as to optimize radio coverage and cost.**

## I INTRODUCTION

There are various field strength prediction methods available in the literature, which are described under two main categories, the outdoor and indoor propagation models. Outdoor propagation models can be subdivided as macro cell and micro cell models depending on the size of the coverage area. These models can be either empirical or theoretical or a combination of the two. While empirical models are based on measurements, theoretical models deal with the fundamental principles of radio wave propagation phenomena [1].

The influence of environmental factors are taken into account in empirical models. The accuracy of these models depends not only on the accuracy of measurements, but also on the similarities between the environment to be analyzed and the environment where the measurements have been carried out. These models have greater accuracy. One of the widely used macro cell propagation models is the model of Okumura et al. It is based on empirical data collection. Theoretical models usually require a huge database of environmental characteristics and the algorithms are usually very complex and lack computational efficiency. The Two Ray model is one of the common theoretical models used widely. It is based on ray optic theory. This model consists of the direct wave and the ground reflected ray. Heights of transmitter and receiver antennas, distance between transmitter to receiver and transmitter power are taken into account to calculate the received signal power, in the two-ray model.

In principle, once started EM waves can travel through space, indefinitely. However in the real world an EM wave is attenuated by the atmosphere and other factors as mentioned above. Whatever power is used for transmission, the received signal gets weaker the further the distance from the transmitter. After a certain point, the signal is so weak that natural and atmospheric noises are greater than the original signal. For medium wave stations, the International Consultative Committee for Radio (CCIR) recommends a minimum field strength of 2.2 mV/m(= 67 dBu, in decibel notation) at the receiving antenna for signals between 525 - 900 kHz, and 0.8 mV/m (58 dBu) for signals between 1250 - 1605 kHz. The minimum values vary from 2.2 to 0.8 mV/m in the 900 - 1250 kHz band. For FM Stations, the CCIR recommends field-strengths of at least 0.05 mV/m (34 dBu) for mono, and at least 0.25 mV/m (48 dBu) for stereo, "in the absence of interference from industrial and domestic equipment." However, hills, buildings and trees weaken radio waves, and radio noise from TV sets, manufacturing defects, and other broadcasts raises the minimum needed for good reception. Therefore, the CCIR recommends these minimum field strengths for mono FM reception: 0.25 mV/m (48 dBu) in rural areas, 1 mV/m (60 dBu) in urban areas, and 3 mV/m (70 dBu) in big cities. For FM stereo the minimums are 0.5, 2 and 5 mV/m (54, 66 and 74 dBu, respectively) [2].

Radio and television service providers in Sri Lanka have not used any software tools to predict radio link performance before designing transmission stations. Unfortunately commercially available software is expensive [3]. In Sri Lanka all the calculations are done manually. For each receiver point they draw a profile of the land along the path between transmitter and receiver by using a contour map, taking into account the “bulge” of the earth. If there is a direct path, the free space path loss is calculated and the finally received signal level is predicted using the sums of gains and losses. This is a rather inefficient method.

In this case we have chosen a theoretical model, the Two Ray model [1] to find the field strengths at the reception point. It is assumed that all the reception points are in the far field of the transmitter and the height of the receiver antenna is 10 meters of a mast. Electromagnetic energy tends to travel in a straight line between transmitter and receiver with the speed of light, most of the time. Unfortunately there is an unavoidable fact that we live on a round earth. Because of this, only transmitter and receiver points separated by a distance of 40 km or less is assumed to be in a flat terrain. Above a distance of 40 km between receiver and transmitter the curvature of the earth's surface must be taken into account when determining the antenna heights. If there is no direct wave reaching the receiver point, that point is considered to be in a shadow region (zero strength). To get more accurate values for field strength we must also consider the diffraction loss. Due to the mountains there are a few diffraction rays reaching the receiver point. Here we considered only one diffracted ray that which is, caused by the heights of mountains in the path between transmitter and receiver. Therefore some points receive three rays: the direct ray, ground reflected ray and diffracted ray. To determine the strength at such points we have to find out the intensity at that point by considering the three waves assuming that the direct and ground reflected waves have the same magnitudes of field at the receiver antenna. It is a good approximation since the distance between the two antennas is much larger than the height of the antennas. To find the field magnitude of the diffracted wave at the reception point Fresnel Zone clearance was taken into account. The arrival time difference between the above three rays at the receiver can be neglected, because the three rays have approximately equal path lengths. Generally a region within a line of sight distance from the transmitting antenna is regarded as a service area. By assuming that the surface of the earth is smooth spherical it is checked whether the reception points are in the service area or not. Each of these steps is discussed in the proceeding sections of this paper.

## II METHODOLOGY

### A Calculation of Field Strength on Line of Sight Link

In the absence of an atmosphere, the intensity of a propagating wave radiated by an isotropic point source decreases with distance from the transmitting source as energy spreads over the surface of a radiating spherical surface. For a point source radiating isotropically, the free space rms field strength at a distance $d$ (m) from a transmitter is $E_0$ (Vm$^{-1}$) can be derived as (1) [4, 5].

$$E_0 = \frac{(30P_t g_t)^{1/2}}{d} \qquad (1)$$

Where $P_t$(W) is transmitter power and $g_t$ is the power gain of the transmitter. It should be noted that this equation assumes 100% energy transfer from the transmitter to the receiving antenna and that the antenna has unity gain. In practice there are losses in coupling the signal from transmitter to antenna and also losses in the antenna it self.

### B Propagation Over Plane Earth (Two Ray model)

The receiver gets a wave traveling in free space directly from the transmitter along a line-of-sight path, but it also receives another wave, which is reflected from the ground as shown in Fig. 1.

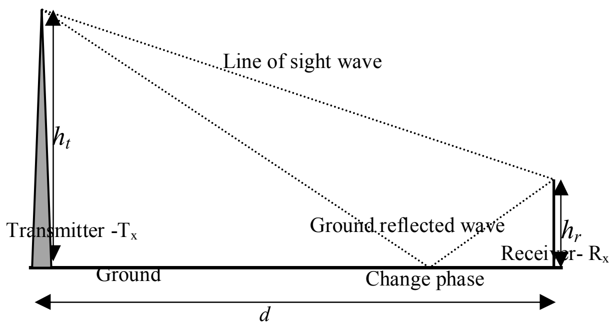


Fig. 1 Two ray model

In a very simplified analysis we can assume that the distance $d$ (m) is so large compared to the heights $h_t$ (m) and $h_r$ (m) of the transmitting and receiving antennas above the ground, that for all practical purposes, we can regard the ray to be incident on the ground at grazing incidence. Therefore both paths are nearly parallel and it can be assumed that those paths are equal in length. According to (1) the two waves reaching the receiver along two paths have equal magnitude, but they differ in phase due to the phase reversal that occurs on reflection, irrespective of whether the wave is horizontally or vertically polarized. This means that the reflection coefficient is taken as –1 [6, 7]. Finally we can derive the resultant electric field strength $E$ (Vm$^{-1}$) at the reception point which is given in (2).

$$E = 2\frac{(30P_t g_t)^{1/2}}{d} \sin\frac{2\pi h_t h_r}{\lambda d} \qquad (2)$$

Where $\lambda$ (m) is the wave length of the transmission.

### C Effect of the bulge of the Earth

For transmitter – receiver separation $d$ below 40 km, (2) can be applied by taking the plane profile. For values of $d$ above 40 km, the curvature of the earth's surface must be taken in to account when determining the antenna heights (see Fig. 2)

The formula for calculating the earth is curvature is [8]

$$h_b = \frac{0.079\, d_1(d - d_1)}{k} \qquad (3)$$

Where $h_b$ is the vertical distance in meters between flat earth (k=∞) and the effective earth (see Fig. 2), at any given receivers point and $d_1$ and $(d\text{-}d_1)$ are the distances in km between a given point and each end of the path.

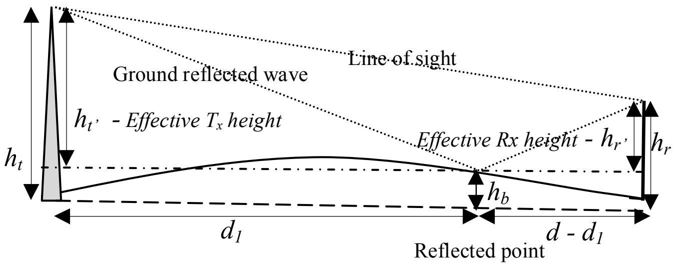


Fig. 2 Effect of the bulge of the Earth

The factor $k$ is defined as the ratio between the effective radius of the earth and the true radius of the earth.

$$k = \frac{\text{effective radius of the Earth}}{\text{true radius of the Earth}}$$

But here we assume that electromagnetic radiation travel along a straight line. For a straight-line $k$ = 1.0. The distance $d$ (>40 km) is so large compared to the heights of antennas above the ground ($h_{t'}$ and $h_{r'}$). Then by using trigonometry the equation relating the effective antenna heights is given by (4).

$$\frac{h_t - h_b}{d_1} = \frac{h_r - h_b}{d - d_1} \qquad (4)$$

By solving (3) and (4) for each point that the receiver is separated from the transmitter by more than 40 km, the effective antenna heights above the ground $h_{t'}$ and $h_{r'}$ can be determined. The resultant field strength can be calculated by substituting $h_{t'}$ and $h_{r'}$ to the (2).

### D Diffraction loss due to a knife-edge

Diffraction occurs at the obstacle edges where the radio waves are scattered, and as a result they are additionally attenuated [1,3,9,10]. To get more accurate values for the field strength the diffraction loss is taken into account. Due to the mountains there are a few diffraction rays that reach the receiver point. Here it is considered only one diffracted ray that which is, caused by the heights of mountains in the path between transmitter and receiver by assuming it has a knife-edge. The receiver antenna receives three waves if line of sight conditions are satisfied; the direct wave, the ground reflected wave and the diffracted wave as shown in Fig. 3. The electric field strength of the diffracted wave is given by [10]

In the following equations, $E_o$ is the free space field strength in the absence of both ground reflection and knife-edge diffraction and $F(v)$ is the approximate value of the Fresnel Integral. A glancing deflection changes the angle of the wave very little, so it

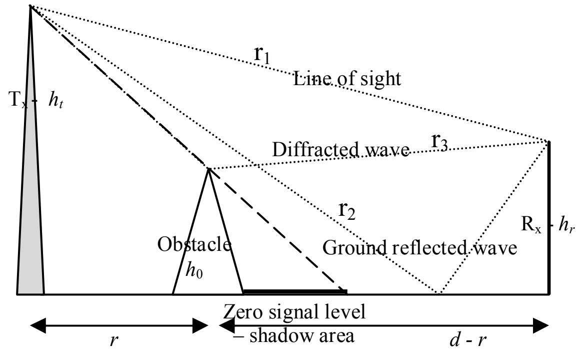


Fig. 3 Three waves reaching to the receiver

remains generally in phase with the wave at the center lobe. Within the signal span, there are zones where deflected signals are generally in phase with the center lobe signal, and there are other zones where deflected signals are generally out of phase with the center lobe signal. We refer to these zones as Fresnel zones. The first Fresnel zone surrounds the center lobe where the RF signal is strongest. If more than 40% of the first Fresnel zone is obstructed, our RF line of sight is not sufficiently clear [8].

For a horizontal distance $d$(m) between the transmitter (Tx) and the receiver (Rx) having heights $h_t$ (m) and $h_r$ (m) above the ground level respectively and tallest obstacle situated at a horizontal distance $r$ (m) from the transmitter, the square of the electric field $E$ (V m$^{-1}$) is given by (5)

$$E^2 = E_0^{\,2}[2 + F(v)^2 - 2\cos k(r_2 - r_1) + 2F(v)\ \cos k(r_1 - r_3) - 2F(v)\cos k\,(r_2 - r_3)] \qquad (5)$$

where $k = \dfrac{2\pi}{\lambda}$ and $\lambda$ is the transmission wavelength, Distances $r_1$,$r_2$ and $r_3$ are indicated in Fig. 3. $F(v)$ is the Fresnel integral with $v$ given by (6),

$$v = \sqrt{\frac{2}{d}}\left[\frac{r(h_0 - h_r) + (d - r)(h_0 - h_t)}{\sqrt{\lambda r(d - r)}}\right] \qquad (6)$$

When LoS conditions are satisfied $v$ will be negative.

TABLE 1
Relation between $v$ and $G_d$

| Range of $v$ | Diffraction loss $G_d$ (dB) |
|---|---|
| $v \leq -1$ | 0 |
| $-1 < v \leq 0$ | $20 \log_{10} (0.5\text{-}0.62\ v)$ |

If the approximate value of the Fresnel Integral $F(v)$, the diffraction loss will be $G_d$ [10] ,

$$Gd\ (dB) = 20 \log_{10} |\ F(v)\ | \qquad (7)$$

According to Table 1, Fresnel Integral *F(v)* can be calculated by using (7).

*E Shadow Area due to an Obstacle and Service Area*

As shown in Fig. 3 shadow area occurs when the direct line-of-sight (LoS) propagation between the transmitter and the receiver is obstructed by an opaque obstacle. If there is no direct wave reaching the receiver point, that point is considered to be in a shadow region (zero strength).

To find out whether the reception point is in the service area, it is assumed that the surface of the Earth is smooth and spherical, the height of the transmitting antenna from the earth's surface is $h_t$ (m), the height to receiving antenna from the spherical earth surface is $h_r$ (m) and the maximum surface distance between the transmitting and the receiving point on the earth is given by *D* (km) [6].

$$D = 3.57\left(h_t^{1/2} + h_r^{1/2}\right) \qquad (8)$$

Here we assumed that radio waves travel along straight lines. For each reception point we must find out whether the receiver point lies in the service area by using the (8).

Using the equations given above we can calculate the field strength at each reception point in the units of Volts per meter ($Vm^{-1}$). Field strength is given by $10 \log_{10} E^2$.

If there is a diffraction loss (dB) it should be reduced to get the final signal level. To convert the practical antenna to an isotropic antenna we must add 2.15 dB more [2]. If we add 120 to the final field strength, it will give the field strength in micro decibel (dBu) units. For FM stations, the CCIR recommends field strength of at least 0.05 $mVm^{-1}$ (34 dBu) for mono and at least 0.25 $mVm^{-1}$ (48 dBu) for stereo transmissions. For values of $d > 40$ km, the curvature of the earth becomes significant and $h_t$ and $h_r$ were replaced by the effective heights of the transmitter and receiver considering this curvature.

## III RESULTS AND DISCUSSION

By using this model we attempted to identify the field strength distribution in selected areas of the Rathnapura district (see Fig.4). The table 2 gives the signal strengths measured in decibels ($\mu Vm^{-1}$) by the Sri Lanka Broadcasting Corporation (SLBC) in 1997 along with the values computed in this study for SLBC transmissions from the stations at Yatiyanthota and Radella.

According to accepted standards, mono and stereo FM signals should have minimum signal strength levels of 34 and 48 dBu respectively for good reception. Locations where weak signals or no signal was measured (indicated by N/S in the table) are found to be in shadow areas (indicated by Shad.) by the computations except for a few locations. This could be due to the uncertainty in the exact locations where the signals were measured. (The longitudes and latitudes were found using a map.) Computed signal levels are significantly higher than the measured signals in most of the locations where a measurable signal was present. This can be attributed to the energy losses that can possibly occur by atmospheric absorption which has not been taken into consideration in this study. However, the differences in the signal levels seem to agree fairly well.

Further to this, we investigated the possibility of finding the location for a transmitter that could give a better coverage for the area studied than those already in existence. According to our computations a transmitter located at Botiyatenna ($80^0$ 34' 19", $6^0$ 26' 13", and 1300 m) provides a better. Our results are shown in Fig. 5.

TABLE 2
Measured and Computed Field Strength Values in dBu for SLBC Transmission (1997)

| | Yatiyanthota Transmitter $7^0$ 2' 46" / $80^0$ 23' 00" 1000m 1kW 0 dB | | Radella Transmitter $6^0$ 57' 49" / $80^0$ 43' 20" 2000m 1kW 0 dB | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 92.2 MHz | | 87.5 MHz | | 94.4 MHz | | 106.9 MHz | |
| | Measured | Computed | Meas. | Comp. | Meas. | Comp. | Meas. | Comp. |
| Dodampe (0 m) $6^0$ 43' 48" /$80^0$ 20' 22" | 38 | 81 | 40 | 72 | 42 | 75 | 30 | 78 |
| Lellopitiya (100m) $6^0$ 40' 00"/$80^0$ 28' 54" | 07 | Shadow | 14 | 74 | 19 | 72 | 13 | 79 |
| Rathnepura (0m) $6^0$ 41' 21"/$80^0$ 24' 11" | N/S | Shadow | 28 | Shad. | 32 | Shad. | 38 | Shad.- |
| Dela (100m) $6^0$ 37' 23"/$80^0$ 27' 30" | N/S | Shadow | 03 | Shad. | 07 | Shad. | 05 | Shad. |
| Palawela (0m) $6^0$ 38' 45"/$80^0$ 21' 41" | N/S | 79 | 15 | 71 | 12 | 75 | 19 | 78 |
| Karawita (100m) $6^0$ 35' 13"/$80^0$ 24' 46" | N/S | Shadow | 32 | Shad. | 34 | Shad. | 35 | Shad. |
| Pimbura (200m) $6^0$ 35' 3"/$80^0$ 21' 28" | 12 | Shadow | 16 | Shad. | 16 | Shad. | N/S | Shad. |
| Nivitigala (0m) $6^0$ 35' 39"/$80^0$ 27' 33" | N/S | Shadow | 04 | Shad. | 06 | Shad. | 06 | Shad. |
| Thiriwanketiya(100m) $6^0$ 40' 00"/$80^0$ 26' 11" | N/S | Shadow | 05 | Shad. | 08 | Shad. | N/S | Shad. |

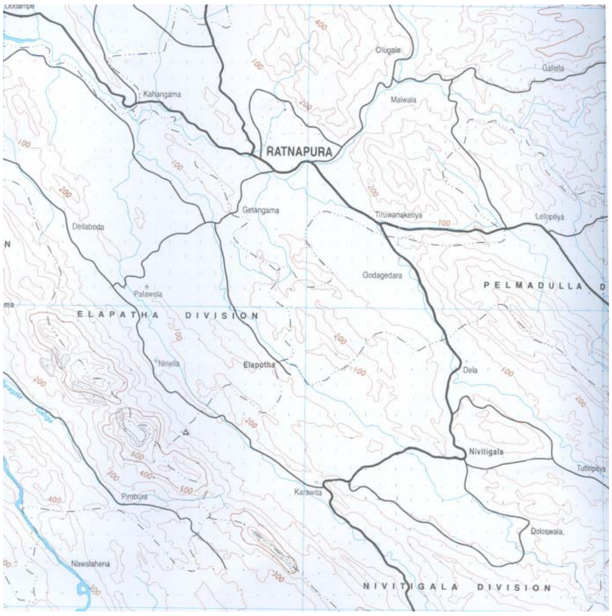


Fig.4 Height Contours of the Target Area

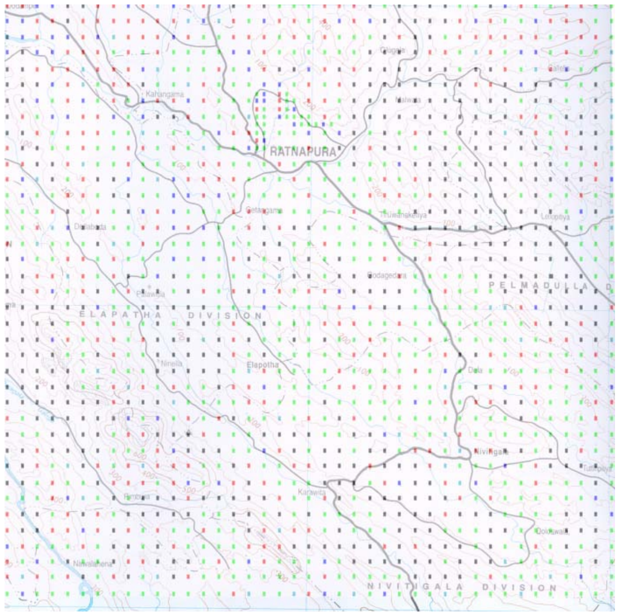


Fig. 5 Computed Field Strength Distribution due to Botiyathanna Transmitter

## IV CONCLUSIONS

Radio propagation is a vast topic, and we have only scratched the surface here. Hopefully this paper has provided some insight into the problems and solutions associated with setting up links in the VHF to microwave spectrum.

Radio waves may be propagated in one or more modes, depending upon the medium into which they are launched and through which they pass. Radio wave propagation is therefore essential in planning and operation that communication can be established and that there is an optimum solution between cost (capital and running cost) and link availability.

Field strength at a given place not only depends on the transmitter power and the distance, but also it varies with height of the transmitter and receiver antennas and frequency.

To provide a better coverage for the area considered, service providers must mount a transmitter at Botiyathanna as discussed above. It will cover a larger area than that covered by the transmission station located at Yatiyanthota, Radella, Deniyaya and Suriyakanda.

The computed values of the field strength were in good agreement with those measured in areas where the radio reception is poor (shadow regions).

Altogether radio propagation is seldom 100% predictable, and one should never hesitate to experiment. It is very useful, though to be equipped with enough knowledge to know what techniques to try, and when there is little probability of success.

## ACKNOWLEDGMENT

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