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# ASSESSMENT OF THE IMPACTS DUE TO THE ALTERNATION OF GROUND CONDUCTIVITY OVER THE EARTH WAVE FIELD INTENSITY IN MW BAND

**S. V. Al-Din Makki**

Department of Electrical Engineering
Engineering Faculty
Razi University
Tagh-e-Bostan, Kermanshah 67149, Iran

**T. Z. Ershadi**

Electrical Faculty
KHaje Nasir Toosi University
Seyed KHandan Bridge, Tehran 16315, Iran

**F. Pahlavani**

Research Center, Radio Transmitter Group
Technical Deputy
Islamic Republic of Iran Broadcasting
Jam-e-Jam, Tehran 19395, Iran

**Abstract**—Based on theoretical calculations, the field intensity resulting from a transmitter of medium wave (waves propagation) enjoys a significant increase in the paths where ground conductivity increase and in special environmental conditions even if far away from the transmitter. This phenomenon distinguishes coverage areas of a transmitter from common procedures of determining coverage. This article examines and observes the above-mention issue and its results.

## 1. INTRODUCTION

Medium waves propagation band is done through two methods: ground and sky. Ground conductivity plays a special role in wave's propagation, also measuring the Ground Conductivity needs to difficult methods [1, 2]. In sky waves, propagation depends on conditions of layers of ionosphere whose examining is very important especially at night when reflection from E layer and interference with ground waves which causes fading areas (ground waves interference) [3].

According to theoretical calculations and contrary to common predictions ground waves field intensity in Medium wave band and in paths with indeterminate conductivity increases if wave enters much high conductivity coefficient from a low one field intensity usually decreases when going away from the transmitter and increasing the distance. This so called E-rising phenomenon in this article is shown in Fig. 1.

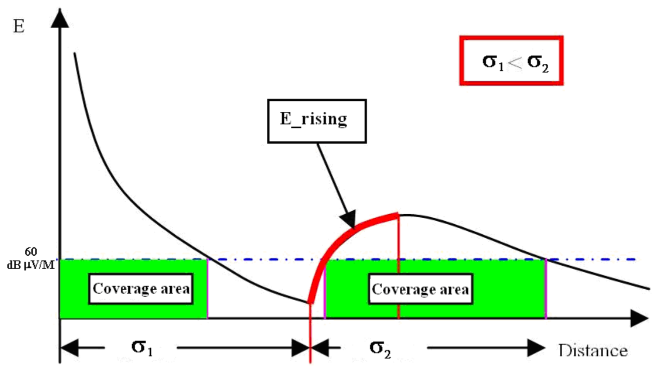


**Figure 1.** Showing the E-rising.

As can be seen, the normal field intensity decrease is reversed in E-rising area while getting away from the transmitter. Change of ground conductivity to $\sigma_2$ increase field intensity beyond coverage limit to 60 dBuV/M [4] and causes, creation of a new coverage area out of the previous area. This happening makes prediction and also measurement of transmitter's coverage areas different from habitual mode. Transmitter's coverage areas should be measured again. Habitual measurement procedures of medium wave transmitter's coverage are performed in the way that a proper distance is considered away from the transmitter so that critical field intensity's coverage is obtained and approximate coverage area is determined after tracing a closed curve in the boundary line through several measurements in area and recording them on the map. In case where a closed curve is drawn from coverage area, if after exiting coverage area an area with a higher ground conductivity exists, there is the possibility that a new closed curve exists out of the previous curve which is not considered in the current measurements. This phenomenon is shown somehow in Fig. 2. There is a new coverage area in $\sigma_3$, since $\sigma_1 \ll \sigma_3$.

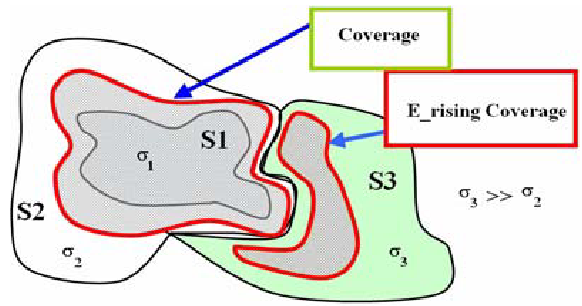


**Figure 2.** A new coverage area with E-rising.

## 2. ELECTRIC FIELD INTENSITY OF ANTENNA

Scientist considered the issue of electric field intensity around a current element in the two free and ground half spaces in the early twenties. Arnold Sommerfeld was among the first who considered this issue during 1909–1926 and in the first study considered current element vertical and on the intersection of the two half spaces Fig. 3.

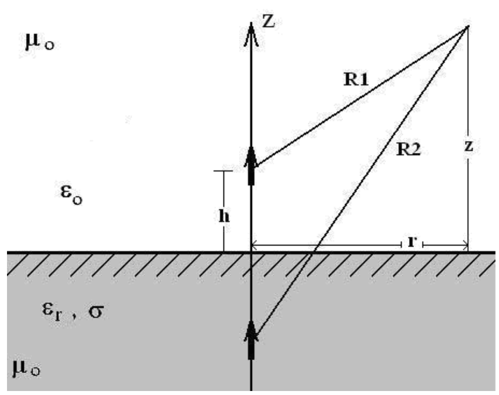


**Figure 3.** Current element near ground in Sommerfeld's integral.

He presented a solution to the complex integral with pole to reach electric field (Hertz Potential vectors). The cause of complex integral was ground conductivity. If it's wanted to reach Hertz Potential in a spot with an $r$ distance and a $z$ height from antenna the relations are as followed.

$$A_z = \frac{\mu_0}{4\pi R_1} e^{jk_0 R_1} - \frac{j\mu_0}{4\pi} \int_0^\infty \Gamma(w) e^{j\gamma_0(z+h)} \frac{J_0(wr)}{\gamma_0} w dw$$

$$\gamma_0 = \sqrt{k_0^2 - w^2}, \quad \gamma_1 = \sqrt{k_2^2 - w^2}, \quad \Gamma(w) = \frac{\gamma_1 - K\gamma_0}{\gamma_1 + K\gamma_0} \tag{1}$$

$$k_0 = \omega\sqrt{\mu_0 \varepsilon_0}, \quad K = \varepsilon_r + \frac{j\sigma}{\omega\varepsilon_0}, \quad k_2 = \sqrt{K} k_0$$

$$A_z = \frac{\mu_0}{4\pi} \left( \frac{e^{jk_0 R_1}}{R_1} - \frac{e^{jk_0 R_2}}{R_2} \right) + \frac{j2K\mu_0}{4\pi} \int_0^\infty \frac{e^{j\gamma_0(z+h)}}{K\gamma_0 - \gamma_1} J_0(wr) w dw \tag{2}$$

To solve Sommerfeld's integral solutions are presented whose major are as follow:

A- K. A. Norton presented a somehow simple approximation which is used today in most of the cases [5]. It should be noted that ground conductivity is not considered in the aforementioned procedure which will take the form of additional drop in paths grater than 70 km. The aforementioned procedure is used in prediction of electric field intensity in short paths.

B- J. R. Waite proposed a procedure in 1953 which solution of the above integral resulted in calculation of an error-function by argument [6].

C- R. W. P. King proposed a procedure in 1969 and 1998 which solution of the integral resulted to calculation of Frensel integral [7, 8]. It should be noted that King examined the issue in the two flat and spherical ground models. Of course these proposed relations enjoy a proper credit in frequencies beyond 1–30 MHz and in great ground conductivity; therefore the reached field in medium wave band is less than what is expected. A so, discontinuity in flat ground model to spherical one is obvious in Fig. 4 in 70 km distance.

D- R. E. Collin proposed a procedure in 2004 which solution of the integral resulted to calculation of error-function with complex argument [9]. In Fig. 4 electric field of an antenna is traced using A, B, C and D analysis.

Following is what is explained in ITU (using Norton procedure)

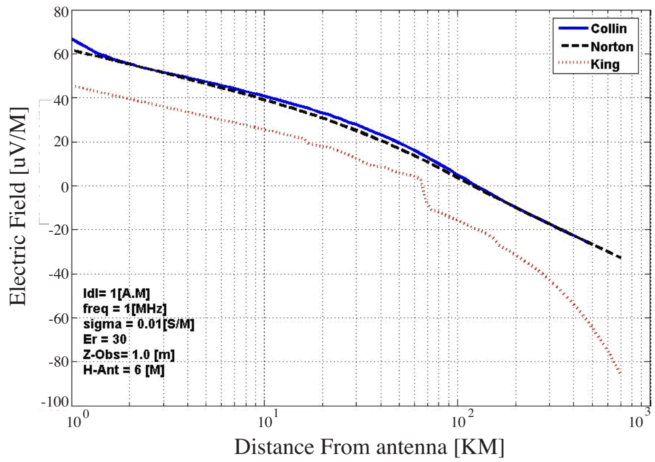


**Figure 4.** Sommerfeld's integral in A, C and D methods.

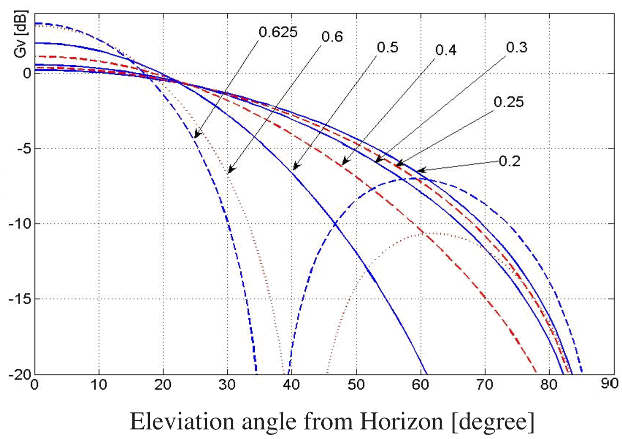


**Figure 5.** $G_v$ amount of antenna with $0.2\lambda$ to $0.625\lambda$ wave length.

regarding electric field intensity:

$$\begin{aligned} E &= \frac{E_0 A}{R}, \quad E_0 = \sqrt{60 P_t G_v} \\ A &= e^{(-0.43 P_0 + 0.01 P_0^2)} - \sqrt{\frac{P_0}{2}} \sin(b) e^{-5/8 P_0}, \quad P_0 \le 4.5 \\ A &= \frac{1}{2P_0 - 3.7} - \sqrt{\frac{P_0}{2}} \sin(b) e^{-5/8 P_0}, \quad P_0 \le 4.5 \\ P_0 &= \frac{\pi R_{(KM)} f_{(MHz)}^2 \cos(b)}{45 \times 10^2 \sigma}, \quad b = \tan^{-1} \frac{(\varepsilon_r + 1) f_{(MHz)}}{18 \times 10^3 \sigma} \end{aligned} \tag{3}$$

In these relations, field intensity $E_o$ is 1 watt in 1 k standard distance from Isotropic antenna [10]. Transmitter's power $P_t$ is based on KW and vertical gain of antenna $G_v$ in the direction of horizon. In Fig. 5 antenna gain is traced for several different lengths of antenna.

In Fig. 6 electric field of antenna is traced as one-forth of wave length with different ground conductivities (as defined by ITU in Table 1) [11]. As suggested in the Fig. 6 path attenuation is increased during attenuation of ground conductivity [12].

**Table 1.** Ground conductivity as defined by ITU.

| **Ground kind** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| **Er** | **13** | **15** | **22** | **30** | **40** | **70** |
| $\Sigma$ **(mS/M)** | **0.3** | **1** | **3** | **10** | **30** | **5000** |

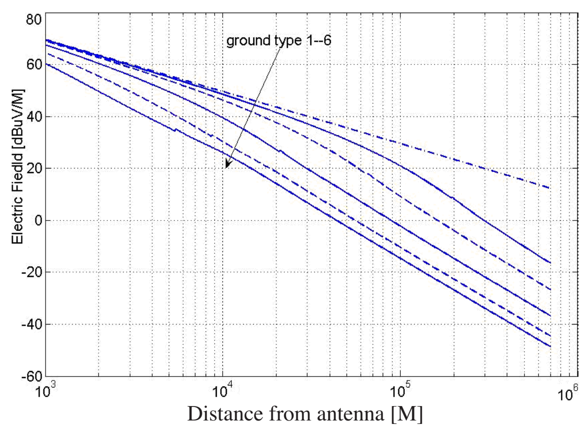


**Figure 6.** Field intensity in different ground conditions.

In the above procedure, calculations are done for fixed ground conductivity through the propagation path, but ground conductivity changes in wave propagation on the real ground. It will be very difficult to solve the problem if previous analytic examinations are going to be applied (of course the problem is solved in arrangement of parallel laminas of the intersection-multilayered ground) [13]. G. Millington proposed a simple and practical procedure in 1949 based on Norton's calculations.

If it is supposed indeterminacy of ground conductivity in all distance, therefore wave attenuation should be parallel to wave attenuation in the new area. Discrepancy amount of the two

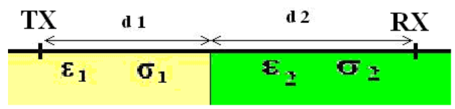


**Figure 7.** Distance between TX and RX with 2 kind of earth.

attenuation curves regarding crossing a good to a bad conductivity or vice versa is called Sea Gain (SG) or Land Loss (LL).

The procedure to calculated Mix paths is based on calculating field intensity in the second area-supposing the whole path is made of second area's substance and then adding the related LL or SG amount and in order to increase accuracy changing the transmitter and Receiver position and repeating the calculations. The final electric field intensity is the average of these two amounts.

$$\begin{aligned} E &= \frac{E_{TR} + E_{RT}}{2} \\ E_{TR} &= E(\sigma_2, d_1 + d_2) + \{E(\sigma_2, d_1) - E(\sigma_1, d_1)\} \\ E_{RT} &= E(\sigma_1, d_1 + d_2) + \{E(\sigma_1, d_2) - E(\sigma_2, d_2)\} \end{aligned} \tag{4}$$

Ground wave propagation is traced on a ground with low and high conductivity. The above procedures can be expressed for multi conductivity paths using induction. Fig. 8 demonstrates field increase or attenuation as a result of indeterminacy of ground conductivity.

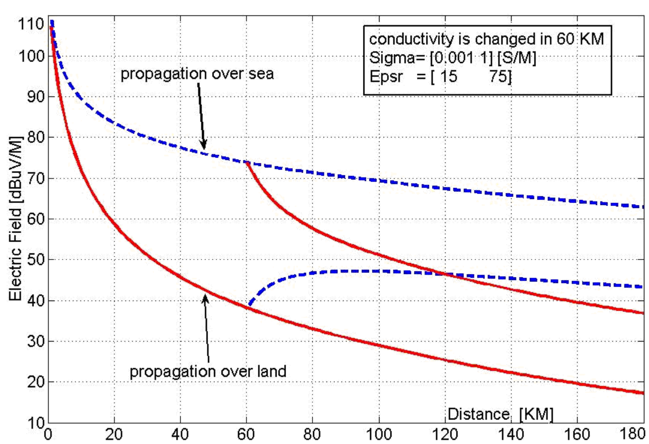


**Figure 8.** Field strength under kind of grounds.

## 3. MEASURING AND EXAMINING E-RISING IN KISH ISLAND

An experiment and measurement was designed and implemented in Kish and the surrounding sea areas in order to examine this phenomenon move accurately. Kish was a suitable place to do this experiment since:

(a)- Ground conductivity in Kish is reported to be much bad ($\sigma = 1\,\mathrm{mS/M}$). (b)- Conductivity of the seas around is much high ($\sigma = 5\,\mathrm{S/M}$). (c)- The Island level is almost flat and are can discard the height factor in calculations. (d)- There is at least on medium wave transmitter in the island to measure field intensity. (e)- This phenomenon can be observed in a distance less than 5 km to the island coast.

### 3.1. Theoretical Examination of E-rising Phenomenon in Kish

Kish transmitter is located at northwestern part of island and broadcasts on 1224 KHz frequency. Transmitter's radium distance from the island coast changes between minimum 500 m and 14 km in different angles. The island ground substance is coral and with low conductivity. According to current documents the island's ground conductivity is reported around 1 mS/M.

The distance between northwestern coast of the island and the transmitter about 10 km Fig. 9 and calculation of field intensity in land and sea was done with some approximation based on the relations in recommendation letter [14–16].

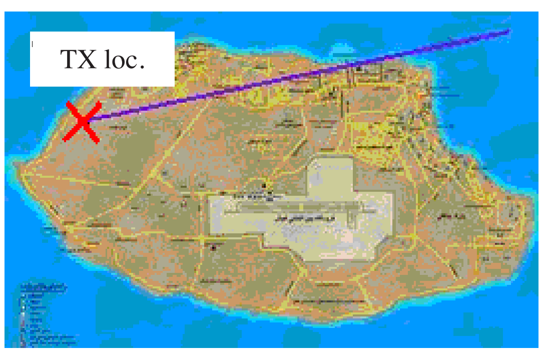


**Figure 9.** Transmitter's location in Kish and the proper approximate direction for measurements.

The theoretical examinations suggest if transmitter's distance is supposed 10 km and land and sea conductivity respectively $\sigma_1 = 1\,\text{mS/M}$ and $\sigma_2 = 5\,\text{S/M}$, E-rising phenomenon is observed in 10 to 14 km distance from the transmitter. These conditions exist in northeastern coast of the island and near harbor establishments Fig. 9.

### 3.2. Measurement in Kish Island

Using the preliminary studies and the proposed predictions in the previous paragraph, the necessary measurements were done using a POTOMAC field intensity measurement device, model FIM-41 and a GPS device. The measurements were done during the day and clear weather. The island ground was dry. The field intensity measured data were traced after preliminary processes and drawing out of the useful data and were compared with the results of the theory. Fig. 10 traced for the most proper data measurement in northern degree angle of 78 toward the transmitter demonstrates a signal difference between measurement data and previous predictions. The 1 mS/M greater conductivity of the island level.

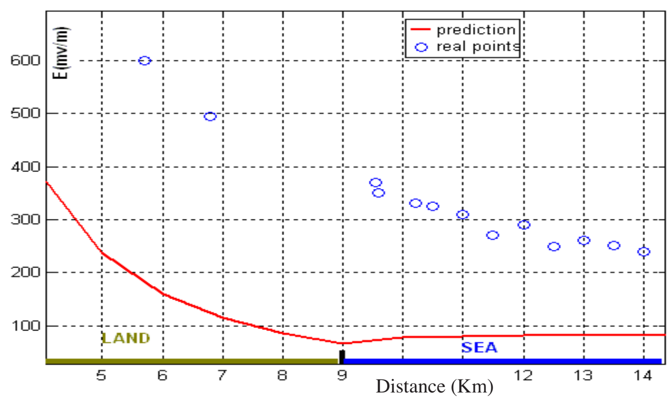


**Figure 10.** Difference between predictions and measurement as a result of difference in ground conductivity.

### 3.3. Measurement Results Analysis

Based on ground conductivity drawing out theoretical curves are traced again based on new conductivity and are demonstrated in Fig. 11 which shows conformity of theatrical and practical results.

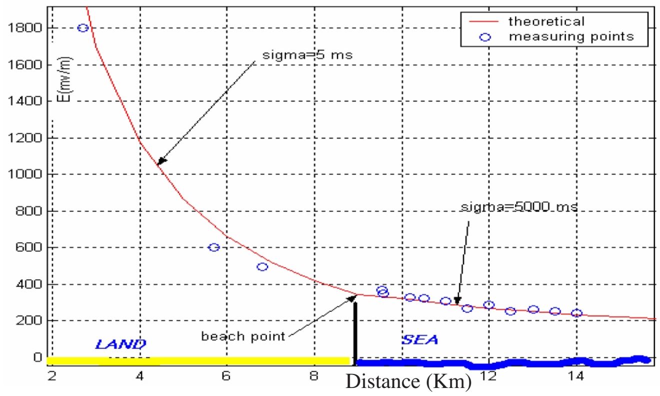


**Figure 11.** Conformity of predictions with measurement based on ground conductivity equal to $\sigma_1 = 5\,\mathrm{S/M}$.

## 4. MEASUREMENT AND EXAMINATION OF E-RISING IN ZANJĀN

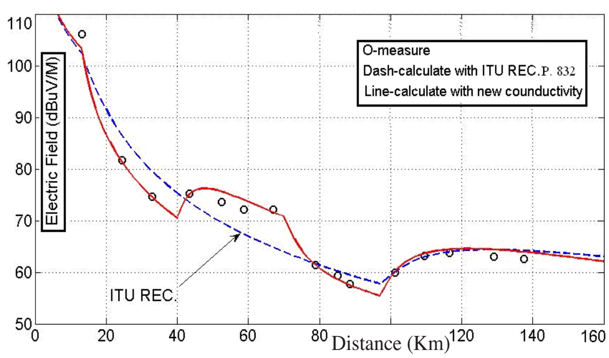


**Figure 12.** Measurement results, calculations based of REC. and verification of recommendation amounts.

E-rising can be observed in new measurements sent for Zanjān's transmitter. The measurements for Zanjān's transmitter are done in one path in the direction of Zanjān's to the northeastern part of the transmitter (Rasht). As a result of the presence of Tarom Area Mountains and decrease of conductivity in the path, the field intensity is lowered, but in Gilān plain ground conductivity is increased and therefore field intensity is expected to increase. Based on ITU documents ground conductivity is 10 mS/M in Zanjān's, 1 mS/M in Alborz Mountains and 30 mS/M in Gilān plain. The field measurement is traced on recorded points in Fig. 12 which suggest the production of an additional coverage area out of coverage area. The significant point is that the introduced ground conductivity from Rasht to Zanjān's includes three areas (transverse line), but the results of the measurement suggests 5 areas (circles) based on which calculations are repeated (straight line). It seems increase of ground conductivity in Rūdbār area has not been considered [17, 18]. The important is that contrary to Kish coast ground conductivity in Zanjān's area does not change immediately and this very fact cause field indiscriminate behavior slow down in indiscrimate conductivity points. In Fig. 13 Zanjān antenna measured coverage is shown. It is obviously shown that field intensity is lowered in Alborz mountain chain to less than coverage limit. It is then enjoying a high conductivity and increase beyond coverage limit in Gilān plain.

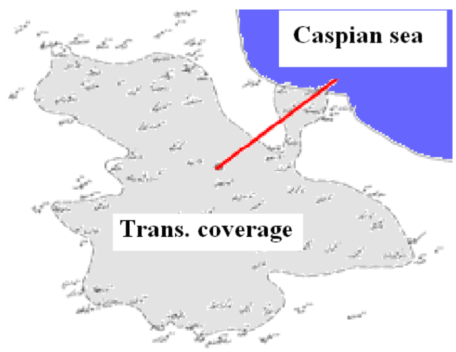


**Figure 13.** Zanjān antenna measured coverage and the path E-rising can be observed in direct line.

## 5. CONCLUSIONS

According to related remarks in Kish Island and Zanjān area, holding (correct) ground conductivity information and its determining factors like precipitation level, humidity, ... can increase accuracy in later studies and specially regarding SFN in DRM (Digital Radio Mondiale) who need coverage area be determined more carefully, ground conductivity information is much important.

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