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Site Errors in Magnetic Direction Finding Due to Buried Cables

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Abstract

Recent investigations of site errors have shown that site errors are not only caused by nearby visible objects (e.g. buildings, overhead lines) of a direction finder site. Site errors are also related to the direction and the grounding conditions of the buried power and communication cable connected to the direction finder.

In this paper we present measurements of lightning electromagnetic fields and corresponding induced currents in the shield of the communication cable. We show also that the amplitude of the induced current varies with angle between the direction of the cable and the direction to the lightning location. The induced currents in the cable shield due to the lightning electromagnetic field are causing a significant portion of the observed site error.

1. Introduction

Systematic angle errors of a direction finder (DF) used for lightning location are called site errors. The reason for the existence of site errors is the absorption and re-radiation of the incident lightning magnetic field near the DF antenna by metallic objects such as power lines, fences or any other electrically conducting objects. In a first approximation site errors caused by a single object like a power line or an antenna tower have a simple characteristic given by

$$\beta(\theta) = A \sin(2\theta + \varphi) \qquad (1)$$

where θ is the angle of field incidence measured by the DF, Φ is a constant and A is the maximum of the site error. A more detailed description of the principle of site errors is given by Schulz [1997]. Although site errors in literature are often represented as a two-cycle sinusoidal function [Hiscox et al., 1984; Passi and Lopez, 1989; Ito and Goto, 1957] there is some evidence for the existence of odd harmonics in the site error function [Kawamura et al., 1988; Miyake et al., 1995; Schulz 1997].

Generally it is assumed that site errors are mainly caused by nearby metallic objects above ground or by buried lines not directed to the DF mounting pad. In the following chapters we show that also buried lines directed to the DF mounting pad are significantly effecting the site errors.

2. Change of site error for DF 8 in Austria

In spring 1996 it was necessary to move one of the DF of the Austrian network (DF 8 - Dobersberg) by about 30 m in direction NNE. This DF is located at a small airport in the northern part of Austria . Fig. 2.1 shows a map of the site with the new and the old location of this DF.

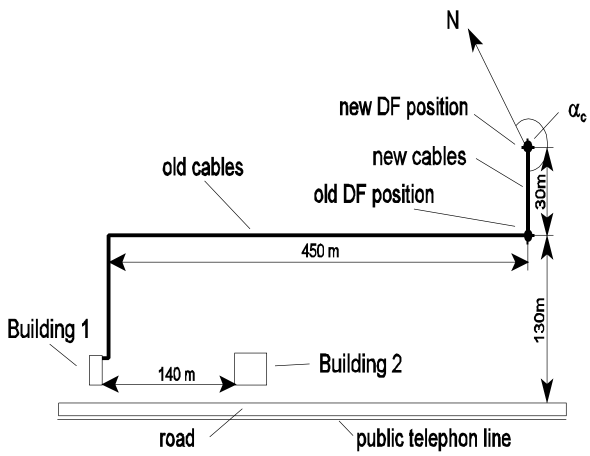


Fig. 2.1: Map of the site of DF 8

The DF is connected by two shielded cables to the telephone line and the local power supply in building 1. Fig. 2.2 shows the original grounding conditions for the power cable, where the cable shield was connected to ground at both ends.

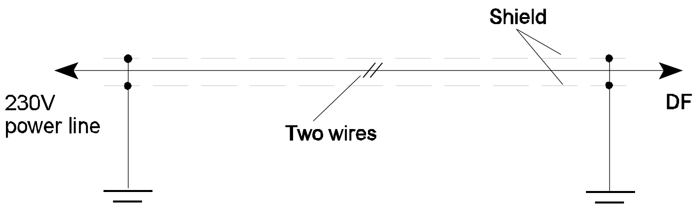


Fig. 2.2: Grounding conditions of the power cable

After the replacement of the DF the old cables were extended by new cables as shown in Fig. 2.1. The types of all the used cables are summarized in Table 1.

Table 1: Type of cables used for the connection of DF 8

	old cable	new cable
power supply	2 x 1.5 mm^2 + shield wire	5 x 2.5 mm^2 + shield wire
communi-cation	8 x 0.75 mm^2 + shield wire	8 x 0.75 mm^2 + shield wire

The shield wires of the cables were originally connected to ground at both ends. Grounding at the DF site is achieved by an earth wire 30 x 3 mm of about 10m length buried in the same direction as the cables.

It is important to note that there is no obstacle around the DF in a radius of about 300m except an overhead telephone line (see Fig. 2.1). With these site conditions in agreement with the requirements given by the manufacturer a site error with an amplitude of less than three degrees was expected.

Site error analysis performed before the movement of the DF revealed a maximum site error of about 5 degrees as shown in Fig. 2.3. The site error correction algorithm used for this study is described comprehensively in Schulz [1997]. A site error analysis after the movement of the DF (see Fig. 2.4) showed significant differences.

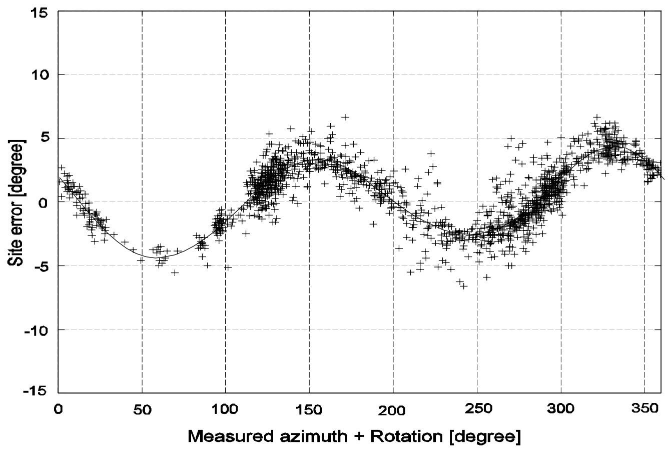


Fig. 2.3: Original site error of DF 8

The site error function of the original site is almost a two cycle sinusoidal function as predicted by theory.

The site error analysis performed after moving the DF by about 30m revealed a rotation of the DF (not shown in Fig. 2.3 and Fig. 2.4) of about 8° and an increase of the maximum error to about 13°. It was also checked that the rotation is not caused by a mechanical misalignment of the DF.

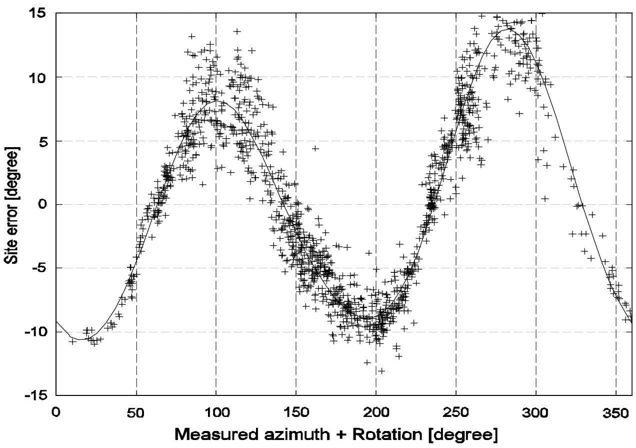


Fig. 2.4: Site error of DF 8 after moving the DF

Comparison of Fig. 2.3 and Fig. 2.4 shows that the error amplitude has increased significantly and that the phase of the error function has shifted. E.g. one zero crossing with positive slope of the old site error function at about 300° has shifted in the new site error function to about 230°.

Because the direction of the cable approaching the sensor (α_c) has changed from about 300° (see Fig. 2.1) in the old installation to about 220° in the new installation, a similar shift of the phase of the site error function suggested that the cable itself has a significant influence on the site error. We also realized that almost exactly in direction of the cable $\alpha_c = 220°$ (see Fig. 2.1) the site error function crosses the zero degree line with a positive slope. Based on this hypothesis we have investigated the site error functions of all the other DF's in Austria in more detail. As a result of this analysis we found that all the DF's with well defined site error functions show a zero crossing with positive slope almost exactly in the direction of the cables connected to the DF.

This observation could be explained in the following way: In Fig. 2.5 a lightning stroke with a lightning current flowing down to ground and a cable in a direction of $\alpha_c = 180°$ is assumed.

For infinite ground conductivity no horizontal electric field at ground level exists at far distances from the lightning stroke. Due to finite ground conductivity a small component of the pointing vector representing the electrical losses is pointing toward ground and thus in the example above the horizontal electric field E_H is in a direction shown in Fig. 2.5. The component of the horizontal field E_H parallel to the cable causes a current i_{error} in the cable (shield and wires), which is always flowing in cable direction (north south direction). The magnetic field H_{error} of this current is perpendicular to the induced current i_{error} in the cable.

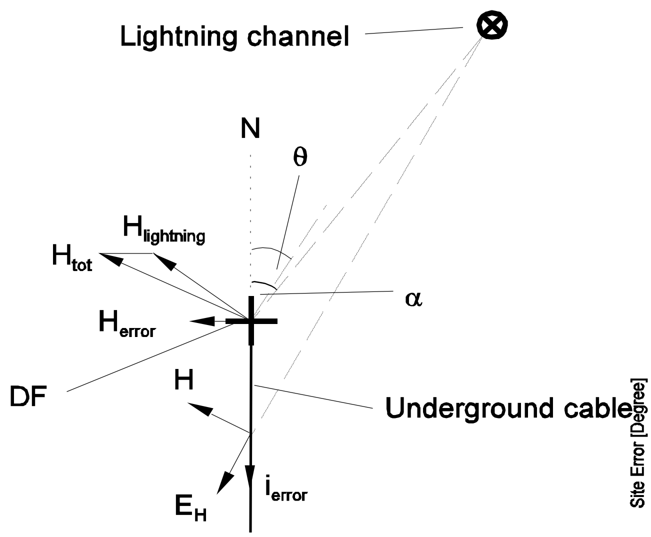


Fig. 2.5: Site error introduced due to an underground cable

Independent of the location of the lightning discharge, the re-radiated field H_{error} due to the current i_{error} is always in the east-west direction.
Thus an additional magnetic field H_{error} will be measured by the north-south DF loop, causing the DF to report an erroneous magnitude of the east-west field. The direction of the field H_{error} is drawn under the assumption that the magnetic field antenna is above ground and thus above the cable. In case of a lightning stroke in the first quadrant of the DF, the angle difference α-θ is greater than zero. The sign of the angle difference is independent of the polarity of the lightning current (pos. or neg. stroke). Lightning in the second quadrant of the DF causes an angle difference α-θ less than zero. In total this effect results in the well known two cycle sinusoidal site error function.

This simple and basic arrangement also predicts a zero crossing of the site error function in the direction of the cable. We observed this characteristic of the site error function for all the Austrian sensors with a well defined site error characteristic.

After we have realized the significant effect of the cable connections to the site error function we investigated in a next step, how the site error is affected by the grounding conditions of the shielding wires of the power and the communication cable. This analysis was done in three steps:
Step 1) Ground connection of the power cable shielding wire was opened at building 1 (see Fig. 2.1), the communication cable remained unchanged (grounded at both ends).
Step 2) The connection to ground of the power cable shield at the DF end was opened and the shield of the communication cable was still connected to ground at both ends.
Step 3) Connections to ground of the communication cable shield at both ends were opened. In this case the shields of both cables were floating.

After each change of the grounding conditions of the cable shields we collected sufficient lightning data to perform a new site error analysis. Fig. 2.6 shows the resulting site error functions for the four different grounding conditions.

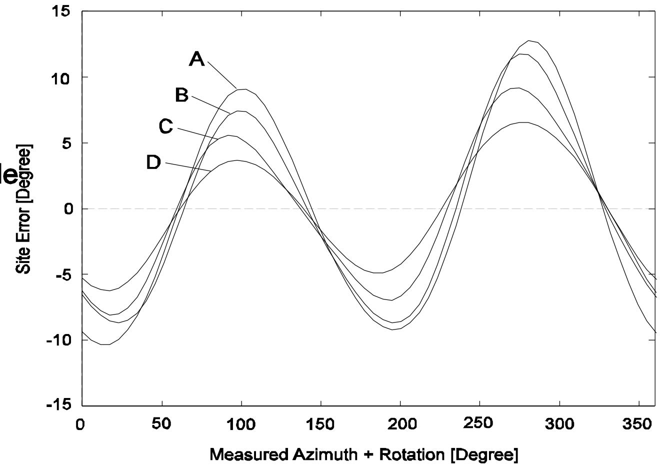


Fig. 2.6: Site error functions for the different grounding conditions of the cable shields

A) Original site error after the DF movement (both cable shields grounded at both ends).
B) Shield wire of the power cable grounded only at the DF end
C) Power cable floating, communication cable grounded at both ends
D) Both cable shields are floating

Fig. 2.6 reveals a 50 % reduction of the original site error and therefore justifies our assumption of a significant influence of the cable shield connections on the site error function. It is important to note that also the rotation (not shown in Fig. 2.6) decreased by about 50%.

3. Correlated lightning fields and cable shield currents

The results described above raised the idea of performing correlated measurements of the lightning electromagnetic fields and the corresponding induced currents in the shield wires of the cables. This measurements were done at a different DF site close to Vienna (DF7 Bad Voeslau). Fig. 3.1 shows the map of the site of DF 7. The closest conducting object is more than 170m distant from the DF. The direction of the cable close to the DF is 330°. The cables change direction on its way from the building to the DF. For the interpretation of the following results also the overall direction of the cable (about 300°) is important. By overall direction we mean the direction of a direct line from the DF to the cable endpoint at the building (see Fig. 3.1).

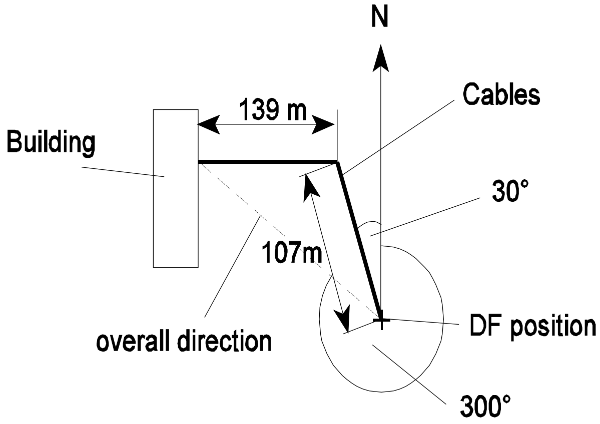


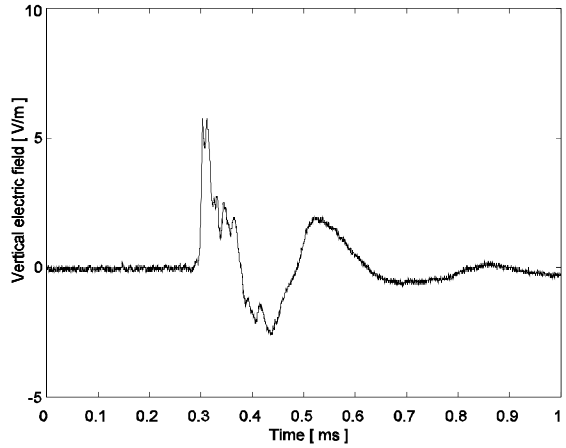
Fig. 3.1: Map of the site of DF 7

For field measurements we used a flat plate-antenna and a digital oscilloscope described in Maier et al. [1996]. Additional to the measurement of the vertical electric field described in Maier et al. [1996] one channel of the oscilloscope was used to measure the current in the shield of the communication cable (or PEN wire of the energy cable) simultaneously with the field. For this purpose a current probe (AC Current Probe Tektronix P6021, bandwidth 450 Hz - 60 MHz, range 2mA/mV) was used. As trigger we used a signal proportional to the dE/dt.

Similar to DF8 also for DF7 the local grounding at the sensor site is achieved by a 10m ground wire buried in the same direction as the cables. From the power cable not the shield wire but only the PEN wire was connected to local ground at the sensor site and at the building. The shield wire of the communication cable was connected to ground at both ends. The current was measured at the sensor site alternatively in the shield wire of the telecommunication cable and the PEN wire of the power cable.

Fig. 3.2 shows a typical lightning electric field waveshape with its correlated current pulse in the shield wire of the communication cable. For the representation of the electric field the traditional atmospheric electricity sign convention is used, where a positive vertical electric field corresponds to a negative lightning current. Therefore the field shown in Fig. 3.2 corresponds to a negative lightning stroke. It can be seen from Fig. 3.2 that there is a time correlation between the peak of vertical electric field and the peak of the current in the shield wire.

Due to the superposition of inductive and conductive coupling in connection with travelling wave effects on the cable wires (cable length is about 250 m) the overall waveshapes in Fig. 3.2 are similar but not identical.



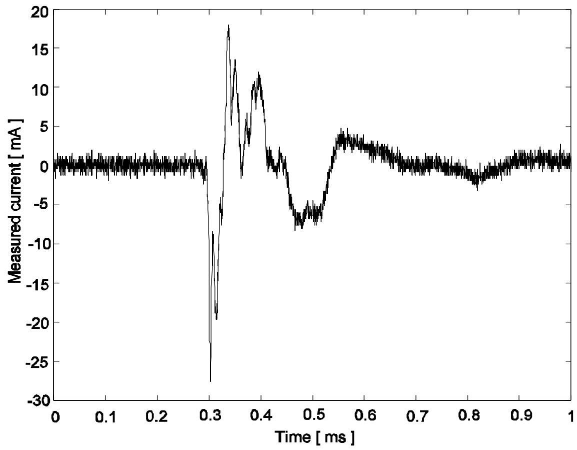


Fig. 3.2: Vertical electric field and induced current in the shield wire of the communication cable of a stroke (04.09.1997 13:38:07.375 UTC)

For the following investigations only the first peak of the current waveform is important (e.g. -28 mA in Fig. 3.2).

Fig. 3.3 shows the ratio of the measured peak fields and the measured peak currents in the cables versus angle of field incidence for 323 measurements. For this investigation we only use measured fields and current pulses corresponding in time with cloud-to-ground discharges detected by the Austrian lightning location system ALDIS. Although the ratio of measured peak fields and measured peak currents has no physical meaning it has been choosen to show the angle dependency of the induced currents. The resulting values of this ratio do neither depend on the sign of the field nor on the field amplitude. The overall inducing mechanism on buried cables should be comparable with the mechanism of voltages induced on overhead lines [Diendorfer, 1990]. We have to keep in mind that the risetime and the angle of the field incidence may influence the resulting value. If the risetime is in the range of the cable travelling time there are reflection effects at the cable terminations already before the current waveshape has reached its peak. This might be one of the reasons for some scattering in the data shown in Fig. 3.3.

The result shown in Fig. 3.3 is consistent with the model desribed in chapter 2. The maximum current is induced when the angle of field incidence is about 120° and 300°. For those lightning locations the horizontal electric field is in the direction of the overall direction of the cable. The line drawn in Fig. 3.3 is calculated by a linear least square analysis ($y=a_1*\sin(\alpha) + a_2*\cos(\alpha)$) for all the data points. A similar result is shown by Master et al. [1984] for induced voltages on an overhead line. This also indicates that the overall lightning inducing mechanism on buried cables is comparable with the mechanism of voltages induced on overhead lines.

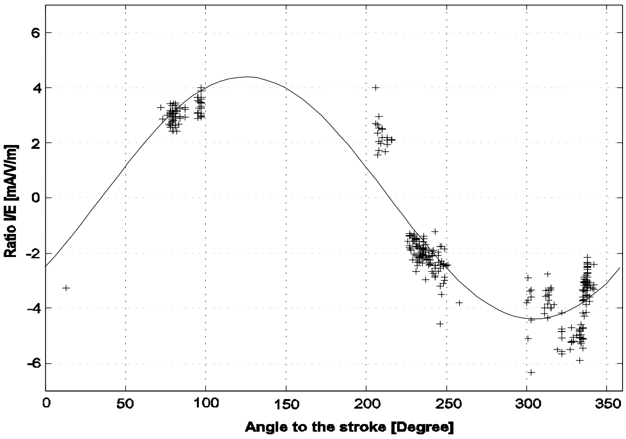


Fig. 3.3: Ratio between peak field and peak current in the cable shield as a function of angle to the lightning stroke

The dependency of the induced current on the angle as shown in Fig. 3.3 results in a site error function which crosses zero at four directions. Two zero crossings occur when there is no current induced and therefore no error field is present. The remaining two zero crossings are related to lightning strokes in the direction of the cable nearby the DF. If lightning occurs in the direction of the cable (150° and 330° respectively) a current is induced in the cable shield, but the direction of the error field created by this current is in the same direction as the lightning magnetic field and therefore no site error is introduced. A change in direction of the cable on its way from the building to the sensor distorts the ideal sinusoidal shape of the site error function. This overall behaviour of the resulting site error function can be seen in the actual site error function of DF7 shown in Fig. 3.4.

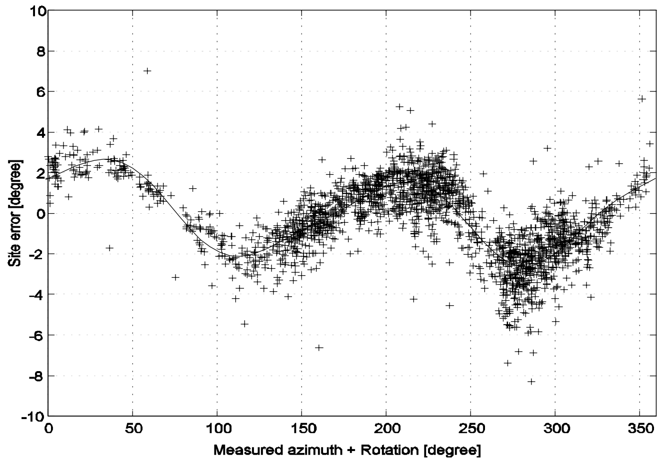


Fig. 3.4: Site error of DF 7

The deviations between the zero crossings of the site error functions calculated and predicted by the model could have several reasons:

- The local details of the cable connections at the sensor site could have a significant influence and they are not taken into account for the estimation.
- The angle determination of the cable direction is not very accurate.

It should be noted that the error field at the antenna is introduced by the resulting current including all the reflections and the currents in the local grounding conductor at the time of the direction measurement.

To check if the observed site error is in agreement with the measurements described above we can estimate the angle error for the event shown in Fig. 3.2 (angle to the stroke 322°, I_{max}=28mA, E_{max}=5.8V/m) under the assumption of the same induced current (28mA) in both cables. With the assumption of a pure radiation field the magnetic field of the lightning stroke can be calculated with the relation $B=E/c_0$. After the calculation of the magnetic field according to a current of 56mA we added both magnetic field vectors. The direction of the resulting field vector differs for this stroke by 1.8 degree from the direction of the lightning field. This result is in good agreement to the site error in the direction of 322° shown in Fig. 3.4.

4. Discussion

It is sometimes stated that there should be no site error introduced by cables if the cable is directed to the DF antenna mounting pad. It seems that for this statement the distance between the buried cable and the field antenna has been neglected. There is always a distance between the antenna (about 1.8 m above ground) and the cable (about 0.5 m beneath ground level).

We have shown that the cables connected to the direction finder and their gounding conditions have a significant influence to the site error function. The observation of a significant rotation after movement of one DF suggests that the change of the direction of the cable has a major influence on the rotation. It was proofed that the observed rotation is not caused by some mechanical misalignment. It is a rotation error introduced by the currents in the cables connected to the DF.

We further presented lightning field measurements with correlated measurements of the induced current in the shield wires of the cables. The results of these measurements are in good agreement with a basic concept presented in chapter 2. It seems also that with the presence of a cable the risetime of the electromagnetic field has an influence on the random error. The change of the cable direction 107m distant from the DF by about 60° does not have a significant influence on the resulting site error.

The error field due to the cable shield current does not only change the direction of the resulting field vector at the antenna, it also changes the amplitude of the resulting field vector. Therefore the sensor measures a wrong amplitude. Due to this erroneo
us amplitude also the so called onset time, which is used for the location calculation, is influenced.

As shown in Fig. 3.3 the normalized ratio of E_h versus I_{cable} is not a constant for a given angle. The significant scattering of this ratio could be caused by reflections at the cable ends. The random portion of the current introduces the random part of the error field. This random part of the error field is more important for the field measurement than background noise because it is present simultaneously with the lightning field and therefore at the most unfavourable time.

It would be interesting to test, if site errors could be further reduced in case of a DF not connected by any conducting cables (e.g. battery power supply and fiber optic data transmission).

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