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Amplitude Site Error of Magnetic Direction Finder

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Abstract: Lightning peak current is one of the most important lightning parameters. Lightning Location Systems infer the peak current from the peak magnetic field. The lightning peak current is calculated from the averaged range normalized signal strengths of the detecting sensors multiplied by a calibration factor [Diendorfer et.al, 1998].

The accuracy of the peak current estimate mainly depends on

- **the applied calibration factor and**
- **the signal attenuation as a result of finite ground conductivity along the travel path of the signal.**

Additionally to these two well known effects on the amplitude measurement we will show in this paper that the so called "site error of a direction finder does not only have an influence on the angle measurement of a lightning location system but also on the amplitude measurement. This so called "amplitude site error" is a function of the angle of field incidence similar to the angle site error.

Keywords: Lightning location systems, site errors.

1. INTRODUCTION

A lot of efforts have been made in the past to understand and correct for the so called angle site error of magnetic direction finder (MDF). The term angle site error means a systematic angle error which is caused by nearby metallic objects and the power and communication cable to the sensor [Schulz et. al, 1998]. A simple explanation of how the connecting cables create angle site errors is given in Schulz et al. [1998]. Site error correction algorithms allow to determine and correct the main part of the systematic angle error but the larger the angle site error the larger the residual angle error after correction. Therefore it is still important to select good sites for the installation of MDF sensors resulting in small angle site errors (<5°).

According to the basic concept describing one origin of angle site errors in Schulz et. al [1998], there should be also a systematic amplitude error related to the existing systematic angle error. This systematic amplitude error, in the following called amplitude site error, was the first time mentioned in the literature by Chisholm et al. [1985].

2. AMPLITUDE SITE ERROR (THEORY)

In Schulz et al. [1998] it is shown how the connecting cables introduce site errors. According to this simple concept shown in Fig. 1 the lightning electromagnetic fields induce currents on the shielding wires of the cables and this currents cause an error field H_{Error} perpendicular to the cable. Together with the lightning field $H_{Lightning}$ the sensor measures the total field H_{Total}. The angle dα between the total field and the lightning field represents the well known angle site error.

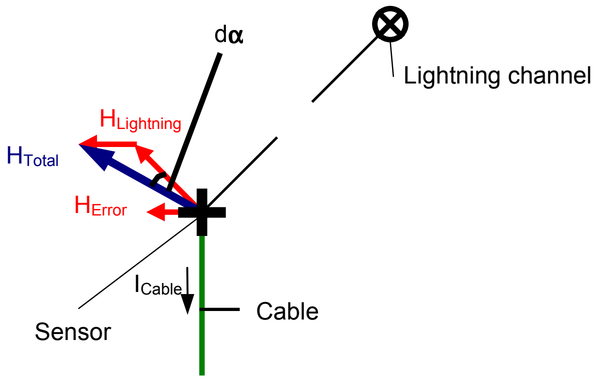

Fig. 1: Sketch of different field components caused by a stroke if an underground cable is present.

It is obvious from Fig.1 that in addition to the angle error there is $|H_{Total}| \neq |H_{Lightning}|$. The field component H_{Error} introduces an amplitude site error and for the simple assumption of an underground cable $|H_{Total}|$ is always greater or equal than $|H_{Lightning}|$. According to Fig. 1 the phase of the amplitude site error is only related to the direction of the cable and the direction to the stroke location. The maximum of the amplitude site error is related to the ground conductivity because the current in the cable shield is zero for infinite ground conductivity and greater than zero for finite ground conductivities. Therefore a lower ground conductivity is related to a higher current in the cable shield and results in a larger amplitude site error.

In Fig. 2 we have calculated the amplitude error as a function of angle for assumed site error functions with maximum angle site error between 1° and 10° and an arrangement of sensor and cable as shown in Fig. 1. The amplitude error in Fig. 2 is calculated according to Eq. (1).

$$\text{Error}[\%] = \left(1 - \frac{H_{Lighnting}}{H_{Total}}\right) * 100 \quad (1)$$

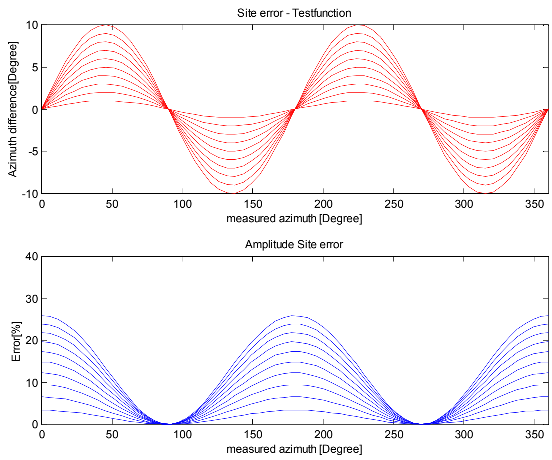

Fig. 2: Amplitude site error as a function of an assumed angle site error.

This theoretical approach shows that the amplitude site error caused by cables is always positive and that there is a relation between the maximum amplitude error and the maximum site error. If the site error is zero the amplitude error is either zero too or reaches its maximum. Therefore the amplitude site error has also a sinusoidal form.

3. EVALUATION OF AMPLITUDE SITE ERROR BASED ON REAL DATA

As already mentioned it is difficult to separate the effects of signal attenuation due to field propagation over paths of finite ground conductivity and the amplitude site error. The peak field reported by the sensor is the superposition of attenuated field arrived at the sensor site and the field enhancement due to the amplitude site error. To be able to justify the shown concept it is necessary to separate the amplitude site error from the remaining attenuation as good as possible.

Therefore we extracted data for an area of 50 km around each sensor for our investigation. For strokes in this area close to the sensor site the amplitude site error of the sensor should be dominant. We have done our investigation with a network of IMPACT sensors only because amplitude measurements of LPATS sensors are not calibrated and therefore may introduce an additional amplitude error.

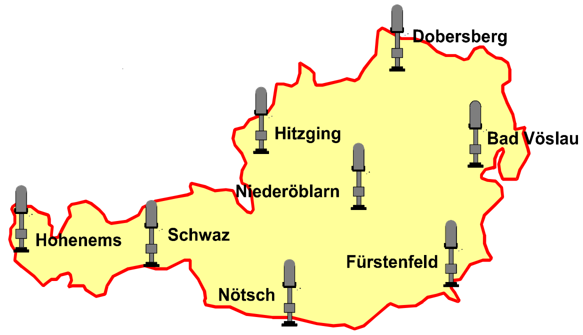

Fig. 3: Eight sensor IMPACT network used for the investigation.

We have extracted data from 1996 and 1997 and we have further limited the dataset to strokes detected by at least six sensors to have sufficient redundancy in the available information.

We calculate an amplitude correction in percent as a function of angle. It is not possible to calculate a correction in absolute values e.g. V/m or LLP-units because a stroke with greater amplitude causes also a larger amplitude error. Therefore we calculate for each stroke in our data set a correction in %. Eq. (2) gives this correction factor where SS_{mes} is the measured amplitude of the sensor under investigation.

$$\text{Correction}[\%] = \left(1 - \frac{SS_{calc}}{SS_{mes}}\right) * 100 \quad (2)$$

SS_{calc} is calculated from the mean Range Normalized Signal Strength (mean RNSS) of the stroke and the distance D between the stroke and the sensor (Eq. 3).

$$SS_{calc} = \frac{\overline{RNSS} * 100}{D} \quad (3)$$

In a second step we are calculating a fit of a sinusoidal function (Eq. 4) to all the data points to define for each sensor an analytical function similar to the angle site error function.

$$\text{error}[\%] = a_o + \sum_{j=1}^{Nh} [a_j * \sin(j * \alpha) + b_j * \cos(j * \alpha)] \quad (4)$$

α in Eq. (4) denotes the measured angle, N_h is the number of harmonics and a_j, b_j are the parameters of the fitted function. Contrary to site error correction no iteration is performed. The following Fig. 4 shows the amplitude site error calculated with Eq. (2) for two sensors of the Austrian lightning location system. Sensor #1 with a small and sensor #4 with a more pronounced angle site error.

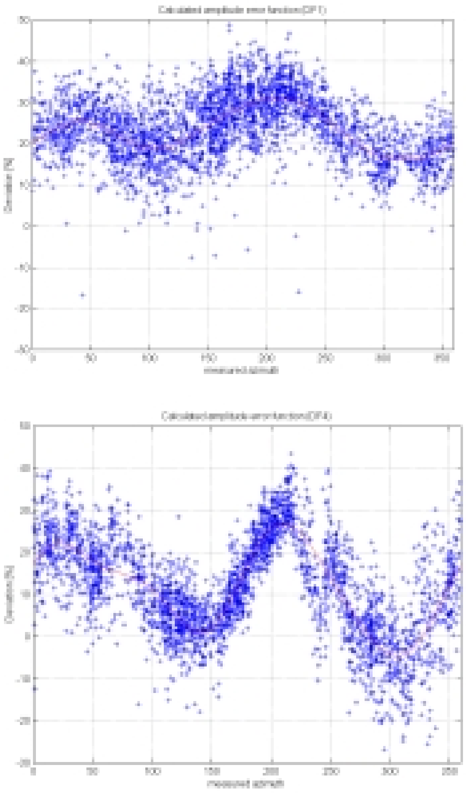

Fig. 4: Amplitude site errors for two Austrian sensors

It can be seen that there is a large scatter of the individual measurements around the fitted function. The reasons for this large scatter are the different damping errors along the different travel paths to the involved sensors. The amount of the error between zero and the lowest value of the error function for sensor 1 is related to the damping error. Fig. 4 further shows that the amplitude error exhibits a 2 cycle sinusoidal form and that the amplitude error is mainly positive. The small amount of negative data especially for sensor 4 has its reason also in the bias of this investigation by the attenuation effects.

Contrary to Chisholm et. al [1985] the amplitude site error in this investigation is always positive as predicted by theoretical considerations. A possible reason for the result of Chisholm et. al is that they probably did not limit the strokes used for the investigation, to striking points in a small circle around the sensor and therefore mixed up the amplitude site error with the attenuation effects due to finite ground conductivity.

An iterative determination process for the amplitude site error, as with angle site errors, is not possible because the correction does not converge. This is due to the reason that all the amplitude site errors are always positive and therefore the difference between measurement and calculation becomes larger with each iteration.

In Fig.5 we have plotted the maximum angle error versus the maximum amplitude error. The line in Fig. 5 shows the theoretical relation and the points show the results of our analysis for different sensors of the Austrian network with different maximum site errors. The error bars for all the evaluations show the standard deviation of the residual amplitude error for the individual sensor. No data for the sensors in the west part of Austria (Sensor #2 and #3) are given because there was too few data for sensor 3 available and no significant site error exists for sensor 2.

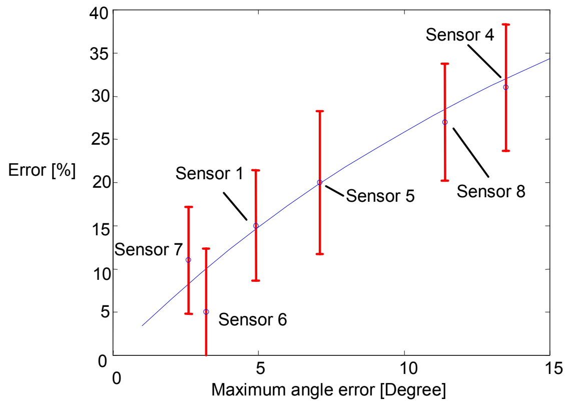

Fig. 5: Maximum angle error versus maximum amplitude error (solid line … theory, points with bars … real data)

It is important to note that according to Fig. 5 a maximum site error of about 10° results already in a maximum amplitude error of about 25 %.

We tried to correct the individual sensor amplitudes with the determined amplitude error functions and found that the mean standard deviation (after correction) decreases slightly but all amplitudes are smaller than before. Because of the low ground conductivity in Austria we still have a large remaining amplitude error and therefore it is not possible to evaluate the improvement due to a correction of the amplitude site error. Probably the damping error and the amplitude site error have to be corrected together.

4. SUMMARY

This paper shows that a systematic amplitude error exists and that this error is related to the systematic angle error. Due to the reason that the systematic angle error is called angle site error we call the systematic amplitude error amplitude site error. We have further shown that this amplitude site error, for a simple configuration of a direction finder with a connecting cable, is only positive and has a two cycle sinusoidal form.

The coincidence between the angle of one zero crossing of the site error function with the direction of the cable and the coincidence between the maximum of the amplitude site error between theory and real data indicate that the origins of the site errors in Austria are mainly the underground connecting cable to the sensors and not some obstacles as power lines or houses in the surrounding of the sensor.

We further showed that a large angle site error results in an amplitude site error of some ten percent and that therefore, without correction of the amplitude error, sensor sites with angle site errors greater than 10° are not acceptable. For the development of a sufficient correction of these errors further investigations are necessary.

5. REFERENCES

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