

Analysis of Measurement Systematic Error in the Near Field Region

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Abstract. This article deals with determination of systematic error, which occurs in the measurement of near field of the source electromagnetic field. Systematic error depends on the size of a sensor. We consider inhomogeneous distribution of electromagnetic field in this paper. In article there is shown what maximum dimension of the sensor is, if we want to measure with precision $\pm 3\%$ in the near field zone. This dimension of the sensor depends on the wavelength. Electromagnetic field is created by an electrical dipole.

Keywords: Sensor, Systematic Error, Near Field, Source Dipole

1. Introduction

Measurement of the electromagnetic field has its own specifics. The most important is the fact that it is necessary to measure two elements of the vector: electrical field \vec{E} and magnetic field \vec{H} . High importance is given to the selection of the correct borders of the elements of the field in places where these elements are measured. In the case that the point of measurement is very near the source dipole, \vec{E} and \vec{H} vectors are not orthogonal to each other. Vectors contain elements of the field x, y, z (r, Θ, Φ). If electric dipole is the source of electromagnetic field, then elements E_r, E_Θ and H_Φ (1), (2), (3) in its vicinity exist. If the source of electromagnetic field is electric loop or magnetic dipole respectively, then elements of the field H_r, H_Θ and E_Φ in its vicinity exist. Because the intensities of electric and magnetic field are vectors we need to measure individual elements of these vectors. Value of the elements in the vector depends on the distance from the source dipole. Based on the distance from source dipole we can subdivide the field into several regions:

- If $kr > 1$ we talk about far field region and must apply $r \gg \lambda / 2\pi$ (Fig.1, dashed line).
- If $kr \equiv \lambda / 2\pi$ we talk about transient field region. All elements of the electromagnetic field are expressed in this region (Fig.1, crossed marks)
- If $kr \ll 1$ we talk about near field region, specifically about static region and must apply $r \ll \lambda / 2\pi$ (Fig.1, black dotted line)
- If $kr < 1$ we talk about near field region, specifically about inductance region and must apply $r \ll \lambda / 2\pi$ (Fig.1, starred line) [1]

Where: k – wave number; r – distance from source dipole; λ – wavelength

Additional distribution of this space around the antenna we can subdivide into the three regions: reactive near field, radiating near field (Fresnel) and far field (Fraunhofer) regions. More information about this distribution is in the literature [2].

In this article we deal with the error which arises from the measurement of the source of electromagnetic field \vec{E} in near region by the source. Electromagnetic field is radiated by the electric dipole which dimensions are much smaller than the wavelength λ of the RF signal input.

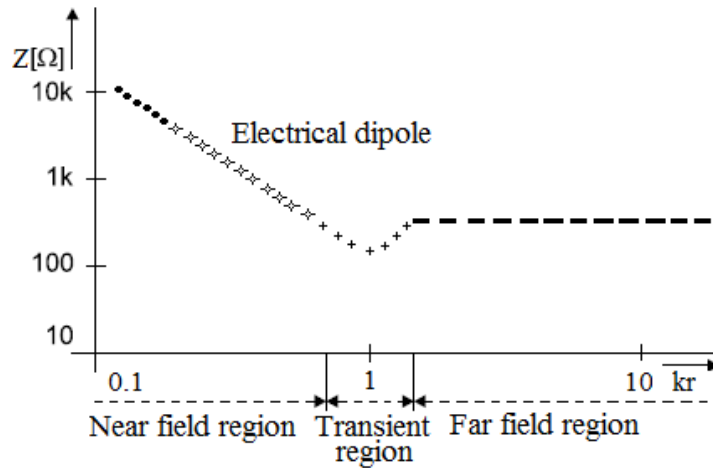


Fig. 1. Dependence of wave impedance on the distance from the source

The elements of the electromagnetic field and their amplitudes could be defined in spherical coordinate system [2]:

$$E_{\theta} = -j \frac{LIk^3 \sin \Theta}{4\pi\omega\epsilon} \left(\frac{1}{(kr)^3} + \frac{j}{(kr)^2} - \frac{1}{kr} \right) e^{-ikr} \quad (1)$$

$$E_r = -j \frac{2LIk^3 \cos \Theta}{4\pi\omega\epsilon} \left(\frac{1}{(kr)^3} + \frac{j}{(kr)^2} \right) e^{-jkr} \quad (2)$$

$$H_{\phi} = \frac{LIk^2 \sin \Theta}{4\pi} \left(\frac{1}{(kr)^2} + \frac{j}{kr} \right) e^{-jkr} \quad (3)$$

Where: L – length of dipole; I – electric current; ω – angular velocity; ϵ – permittivity

Two elements of the electrical field E_{θ} and E_r exist in the near region of the dipole. These elements are orthogonal to each other. The element of the electrical field E_{θ} is oriented tangentially to the source dipole and element E_r is oriented radially to the source dipole [4]. If we want to measure the field in the near region of the dipole, we must measure each element of the field separately [3]. This is because sensor of the electric field is also electric dipole. Dimension of the sensor cannot be neglected in this case. Therefore, the output RF voltage from the sensor is not an amplitude of electrical field vector at the point of measurement, but average field value over the volume of the sensor „ V “. Volume of the sensor is created by the own dimension of the sensor [3].

2. Computing of measurement error

The equations (1) and (2) are used for the analytical calculation of the individual elements of the electric field E_{θ} and E_r in the near field region. Total electric field E we get from individual elements of the electric field, see equation (4).

$$E = \sqrt{E_{\theta}^2 + E_r^2} \quad (4)$$

The electric field reaches high value of intensity that is caused by considerable amplitude of the power supply and also by vicinity of the source dipole. Radial and tangential fields have $|\sin(\Theta)|$ respectively $|\cos(\Theta)|$ function pattern in the space. The fields are mutually shifted in $\pi/2$ in the direction Θ . In Fig.2 we can see that the radial element of the electric field

dominates in the near field region. The magnitudes of radial and tangential fields are considered to be true values of the fields.

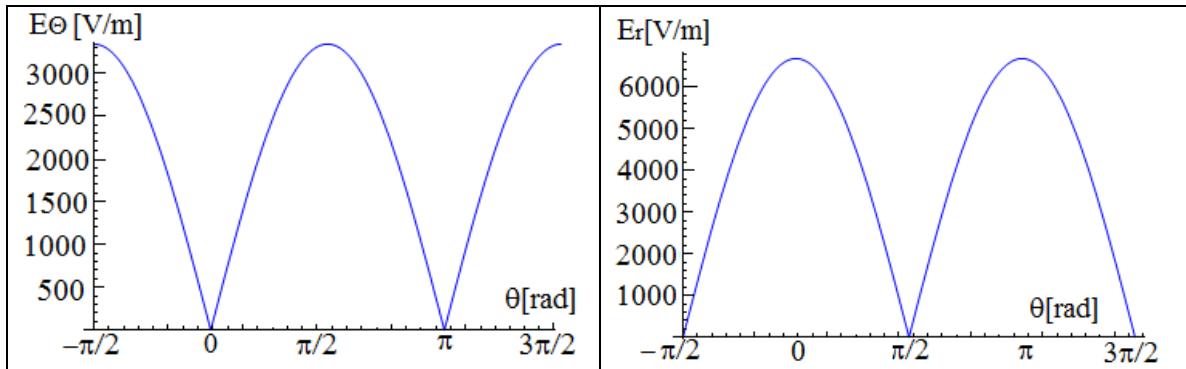


Fig. 2. Near field pattern of the electrically short dipole

If the individual elements of the electric near field are measured by the sensors, which have non-zero dimensions, we will get the results influenced by error (the sensor is averaging the measured values). Shape of the measured radiation characteristics is different in comparison to analytical model. If we want to determine relative error between ideal and measured near field, we must create near field measurement model with use of an electrically short dipole. By comparison of results from numerical near field model to value of the analytical near field model we get measurement error of the electric field in the near region of the source for each model. More about analytical model and relative error calculation of measurement near field is described in [3]. In that article systematic error for different lengths of the sensor is expressed. There is also proved that the systematic error decreases with reduces of the size of the sensor. We used the results from [3] to specify the dependency of the systematic error on the dimension of the sensor.

3. Results

We got values of maximum δ_{MAX} and minimum δ_{MIN} errors from values of systematic error. These errors are dependent on the length of the sensor. Wavelength is 30 m for this sensor.

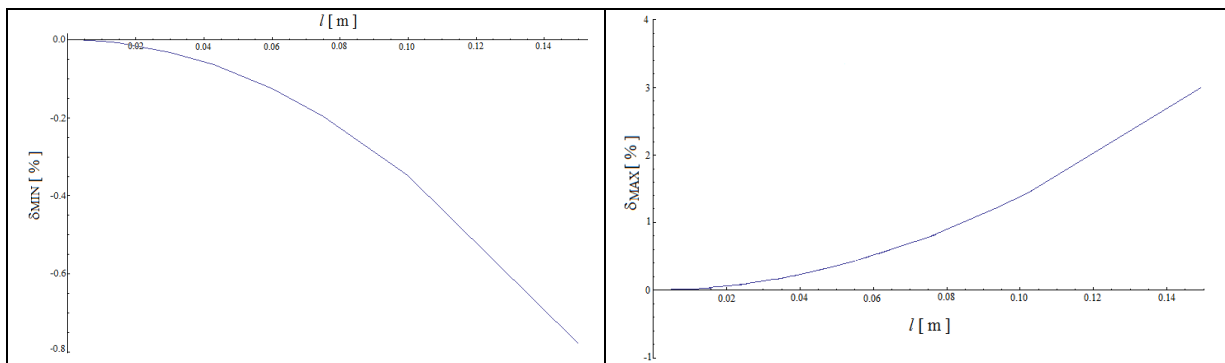


Fig. 3. a) Dependence of the error δ_{MIN} on length of the sensor for static region
b) Dependence of the error δ_{MAX} on length of sensor for static region

In Fig.3a we can see the dependence of the minimum error on the length of the sensor in the near region of the source, specifically in the static region. In Fig.3b the dependence of maximum error on the length of the sensor in the same region as a minimum error is shown. We can see that the values are changing with enlarging dimensions of the sensor, mainly with its length. If the dimension of the sensor is bigger, then the error is bigger, too. It could be proved that waveforms of δ_{MIN} and δ_{MAX} errors are changed by a function of the third order.

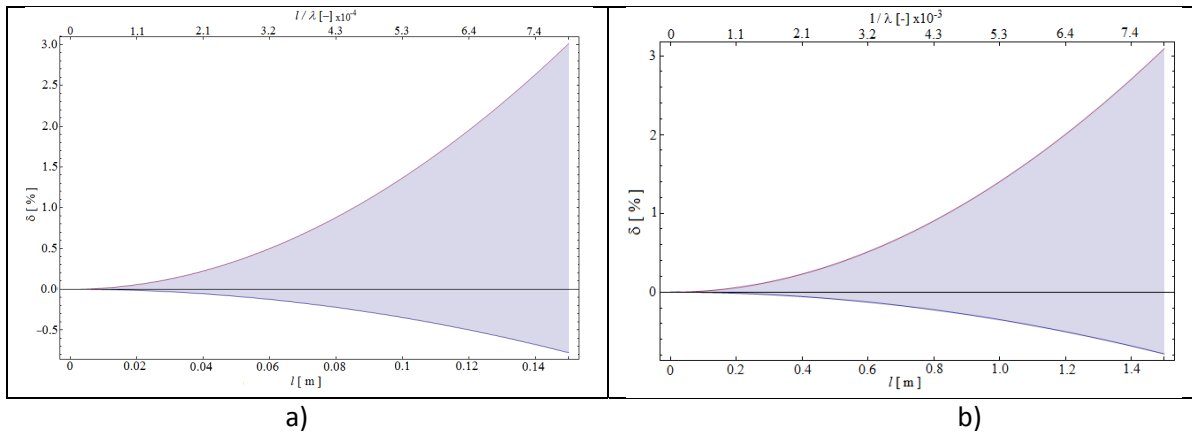


Fig. 4. Dependence of systematic error on ratio l/λ for near region

After drawing both characteristics δ_{MAX} and δ_{MIN} into one graph (Fig.4a) we can see how the systematic error is changing with the ratio l/λ for static region. We can see that systematic error is rising with increasing the ratio sensor length to wavelength. Ratio sensor length to wavelength is on the order of 10^{-4} . In Fig.4b the change of systematic error for near field region (inductance region) is shown. Systematic error is rising with ratio sensor length to wavelength, too. But ratio sensor length to wavelength is only on the order of 10^{-3} . When we compare both figures (Fig.4a and Fig.4b), we can see that maximum length of the sensor for static region must be smaller as a maximum length of the sensor for inductance region.

4. Conclusions

In process of measurement of the near field the error of measured field changes with value of sensing elements. In this article the impact of the systematic error to the changes of sensor value was described. For examples, when we want to measure with precision $\pm 3\%$ in inductance region, the sensor must have maximum length $l \leq 7\lambda/1000$. However this formula is valid only for inductance region. The length of the sensor must be almost 10 times smaller than the length of sensor in the inductance region, if we want to reach similar error, in static region. In this case the maximum sensor length must be $l \leq 7\lambda/10000$.

Acknowledgements

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