Electromagnetic Field Polarization Parameters Measuring Method

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Abstract

An amplitude measuring method of electromagnetic field polarization parameters is presented in the paper. Influence of auxiliary antennas on the precision of the measuring method is estimated and the measuring error caused by this influence is determined as well.

1. Introduction

In light of wide use of polarization properties of electromagnetic field in the construction of modern communication systems that receive/transmit information over the radio-channel (polarization multiplexing, polarization adaptation) a necessity of high-quality measurements of polarization parameters (PP) and characteristics arises. Moreover it is followed by the need of antennas and antenna systems polarization certification. At the same time the choice of a certain polarization measuring procedure depends first of all on the complexity of hardware realization and the required level of precision.

Nowadays the following basic methods of research of antennas polarization properties and electromagnetic fields formed by them are used:

- method of revolving of antenna with linear polarization (method of polarization pattern);
- method of two antennas with circular polarization;
- method of electromagnetic wave resolution into the orthogonal polarization components;
- method of several antennas;

These methods can be divided into two groups. The first group (method of revolving of antenna with linear polarization, method of two antennas with circular polarization, method of several antennas) assumes the instrumentation antenna to be actually a "polarization filter" that allows polarization selection of electromagnetic waves. This approach is preferable for wire antennas research. The second group (method of electromagnetic wave resolution into the orthogonal polarization components) could be realized with the help of antenna systems that allow radiating (receiving) of electromagnetic waves of any polarization structure because the analysis of electromagnetic waves polarization characteristics takes place in an antenna-feeder path before (after) antenna.

Polarization measuring methods could also be divided into amplitude-phase and amplitude ones. Amplitude-phase measuring method supposes the estimation of both amplitude and phase ratios between the orthogonal linear components of the radiation field. Meanwhile the need of phase measurement makes the measuring system much more sophisticated and results in the rise of measuring error. This in turn affects the precision of investigated field PP calculation.

Amplitude measuring methods make it possible to determine PP without phase measurements. This is a great advantage for the practice. The method of revolving of antenna with linear polarization and method of two antennas with circular polarization (electromagnetic wave resolution into the orthogonal polarization components in the circular polarization basis) are frequently used. Taking into account the simplicity of the method of revolving of antenna with linear polarization it meantime allows determining PP of the field only for each certain direction. It makes the measuring procedure more complex in case PP should be determined for example within the beamwidth of investigated antenna. Another considerable problem of this method is the dependence of measurement precision on the radiowaves propagation conditions, that take place when multibeam propagation exist under the real measuring ground conditions. The use of the second method – the method of electromagnetic wave resolution into the orthogonal polarization components in the circular polarization basis has not got such disadvantages, however two identical auxiliary antennas (AA) able to form orthogonal circular polarization radiation fields are needed for the realization of the method. Spiral antennas that are used for the purposes have proved themselves to be highly directed wideband antennas with close to circular radiation polarization. In light of stated above facts polarization certification of AA has got particular importance because just characteristics of AA finally determine the precision of radiation field PP determination.

2. Amplitude Measuring Method of Antenna Polarization Parameters

The goal of the present research was to develop the method of electromagnetic wave resolution into the orthogonal polarization components in the circular polarization basis (method of two antennas with circular polarization) by considering non-ideal parameters of AA and estimation of the antenna radiation field PP determination error, which appear while using this method.

It is known that an arbitrary polarized field could be represented in the form of superposition of two orthogonally polarized components. These components could be of elliptical polarization with opposite direction polarization vector circulations:

$$\vec{E} = E_{rt}\vec{e}_{rt} + E_{lt}\vec{e}_{lt}, \quad (1)$$

where $\vec{e}_{rt}, \vec{e}_{lt}$ – basis orts of elliptically polarized components of the field respectively of right and left directions of polarization vector circulations;

E_{rt}, E_{lt} – complex amplitudes of corresponding electromagnetic field components.

If the circular components are used as ortogonally polarized basis, then after measuring of the amplitudes of corresponding radiation field components $\left|E_{rt}^{c}\right|$ and $\left|E_{lt}^{c}\right|$ an equation for the axial ratio (AR) of investigated field determination could be written in the following form:

$$K_{ar} = \left[1 - \frac{\left|E_{rt}^{c}\right|}{\left|E_{lt}^{c}\right|}\right] \cdot \left[1 + \frac{\left|E_{rt}^{c}\right|}{\left|E_{lt}^{c}\right|}\right]^{-1}, \quad (2)$$

where $K_{ar} < 0$ – indicates the left circular polarization component of the field, and $K_{ar} > 0$ – indicates respectively the right circular polarization component.

Thus AR of the field could be determined on the basis of amplitude measurements of the corresponding components of the investigated field with the help of Eq. 2. Moreover the direction of polarization vector circulation could be determined as well. It is clear from the Eq. 2 that relative values of the field could be measured in the space point instead of absolute ones. However in case of polarization characteristics of AA different from the ideal ones i.e. fields radiated (received) by them are not circularly polarized the use of Eq. 2 for AR determination will result in the error appearance.

To estimate the error of AR determination and for further considering of the influence of non-ideal AA parameters we suggest that generally these antennas have elliptically polarized radiation field which is characterized by corresponding values of AR $K_{ar\,rt}, K_{ar\,lt}$ and $\beta_{ar\,rt}, \beta_{ar\,lt}$, and the polarization of the investigated field is characterised by K_{ar}, β_{ar}, where $\beta_{ar\,rt}, \beta_{ar\,lt}, \beta_{ar}$ are the angles between the major axes of polarization ellipses (PE) and the defined coordination axis. In Fig. 1 PEs of AA are depicted in comparison with the PE of investigated field. The angles between the major axes of PEs and coordination axis and the directions of polarization vectors rotation are shown as well.

The notion of polarization coupling factor is used for the further analysis of polarization structure of the investigated field.

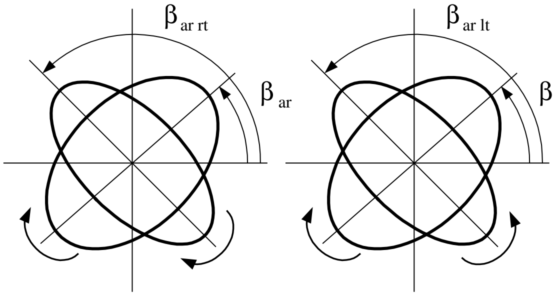

Fig. 1: Polarization Ellipses of Auxiliary Antenna in Comparison With Polarization Ellipse of Electromagnetic Field

The polarization coupling factor let estimate the power normalized to radiated power of the investigated field that is induced in the AA considering their PP. Then taking into account that the power of the radiated field is proportionate to the square of the field intensity amplitude $P_{\Sigma} \sim \left|E_{\Sigma}\right|^2$ and using notations that were previously given the following equation could be written:

$$\left|E_{rt}\right|^2 = \left|E_{\Sigma}\right|^2 \left[\frac{1}{2} \pm \frac{4K_{ar\,rt}K_{ar}}{2\left(1+K_{ar\,rt}^{2}\right)\left(1+K_{ar}^{2}\right)} + \frac{\left(1-K_{ar\,rt}^{2}\right)\left(1-K_{ar}^{2}\right)\cos\left(2\Delta\beta_{ar\,rt}\right)}{2\left(1+K_{ar\,rt}^{2}\right)\left(1+K_{ar}^{2}\right)}\right], \quad (3)$$

where $\Delta\beta_{ar\,rt} = \beta_{ar} - \beta_{ar\,rt}$ – the angle between the major axis of PE of the AA with right circular polarization and the one of the investigated field; $\left|E_{\Sigma}\right|^2$ is square of field intensity amplitude; sign «+» corresponds to the same directions of circulation of polarization vectors of AA and the investigated field and sign «–» corresponds to the opposite ones.

The Eq. 3 is correct for polarization interrelation of the AA with left circular polarization and investigated field as well. To obtain the equation for the left circular polarization component all the indices in Eq. 3 corresponding to the right polarization component should be substituted with ones for left polarization components.

The further analysis of Eq. 3 is realized considering the following assumptions: the polarization vector of the investigated field rotates in the right direction; additional tuning is available to obtain maximum or the minimum of the signal by the rotation of the AA around its axis. The last assumption corresponds to either the case when major axes of PEs lie on the same line, i.e. $\Delta\beta_{ar} = 0$, or they are orthogonally situated i.e. $\Delta\beta_{ar} = \pi/2$. The Eq. 3 could be transformed in the following forms:

$$\left|E_{rt}^{\max}\right|^2 = \left|E_\Sigma\right|^2\left[\frac{\left(1+K_{ar\,rt}K_{ar}\right)^2}{\left(1+K_{ar\,rt}{}^2\right)\left(1+K_{ar}{}^2\right)}\right]; \quad (4)$$

$$\left|E_{rt}^{\min}\right|^2 = \left|E_\Sigma\right|^2\left[\frac{\left(K_{ar\,rt}-K_{ar}\right)^2}{\left(1+K_{ar\,rt}{}^2\right)\left(1+K_{ar}{}^2\right)}\right]; \quad (5)$$

$$\left|E_{lt}^{\max}\right|^2 = \left|E_\Sigma\right|^2\left[\frac{\left(1-K_{ar\,lt}K_{ar}\right)^2}{\left(1+K_{ar\,lt}{}^2\right)\left(1+K_{ar}{}^2\right)}\right]; \quad (6)$$

$$\left|E_{lt}^{\min}\right|^2 = \left|E_\Sigma\right|^2\left[\frac{\left(K_{ar\,lt}-K_{ar}\right)^2}{\left(1+K_{ar\,lt}{}^2\right)\left(1+K_{ar}{}^2\right)}\right]. \quad (7)$$

Any pair of stated above Eq. 4–7 allows determining of the AR and the direction of circulation of investigated field polarization vector on the basis of amplitude relations measurements and known PP of AA. Generally all this assumes six different measurement algorithms and corresponding investigated field PP computation techniques.

Some of the algorithms are further analyzed. Suppose one AA is used. The maximum and the minimum values of the induced fields are measured with the help of the AA. Then solution of the Eq. 4 jointly with the Eq. 5 will produce the following result:

$$K_{ar} = \left[K_{ar\,rt} - \frac{\left|E_{rt}^{\min}\right|}{\left|E_{rt}^{\max}\right|}\right]\cdot\left[\frac{\left|E_{rt}^{\min}\right|}{\left|E_{rt}^{\max}\right|}\cdot K_{ar\,rt} - 1\right]^{-1}.$$

If antenna with linear polarization is used as the AA ($K_{ar\,rt}=0$) the following known equation will be obtained as the result $K_{ar} = \left|E^{\min}\right|\cdot\left|E^{\max}\right|^{-1}$. This equation is used in the method of revolving of antenna with linear polarization. The information about the direction of investigated field polarization vector circulation is lost when using this algorithm of PP determination. The precision of PP determination in this case will depend on the dynamic range of $\left|E\right|$ measurement.

Another algorithm of the investigated field PP determination is based on the use of two AA with orthogonal elliptical polarizations. It is clear that to increase the quality of the measurements the maximum values of the induced field should be measured. The joint solution of the Eq. 4 and Eq. 6 will produce the following result:

$$K_{ar} = \frac{\sqrt{1+K_{ar\,rt}{}^2}\dfrac{\left|E_{rt}^{\max}\right|}{\left|E_{lt}^{\max}\right|} - \sqrt{1+K_{ar\,lt}{}^2}}{K_{ar\,lt}\sqrt{1+K_{ar\,rt}{}^2}\dfrac{\left|E_{rt}^{\max}\right|}{\left|E_{lt}^{\max}\right|} + K_{ar\,rt}\sqrt{1+K_{ar\,lt}{}^2}}. \quad (8)$$

One should be mentioned that if antennas with elliptical radiation polarization are used as the AA $K_{ar\,rt} = K_{ar\,lt} = 1$ then Eq. 8 transforms into the Eq. 2.

The results of computation are shown in Fig. 2 where the ARs versus the ratio $\left|E_{rt}^{\max}\right|/\left|E_{lt}^{\max}\right|$ of measured radiation field amplitudes are depicted. It is supposed that $K_{ar\,rt} = K_{ar\,lt}$. It is clear from the figure that high precision of PP determination (the maximal steepness of the curves) could be reached for the field of linear polarization ($K_{ar}=0$), even when non-ideal AAs are used. Considerable errors occur when computing the circularly polarized field PP because the value of AR depends both on the dynamic range of $\left|E_{rt}^{\max}\right|/\left|E_{lt}^{\max}\right|$ change and on the PP of AA. In particular when using AA with AR $K_{ar\,rt} = K_{ar\,lt} \cong 1{,}0$ the AR of the investigated field could be determined up to the values $\pm 0{,}82$ ($\pm 0{,}98$) in the dynamic range 20 dB (40 dB). PP of the investigated field could be determined with higher precision in the narrower dynamical range $\left|E_{rt}^{\max}\right|/\left|E_{lt}^{\max}\right|$ when using the AA with elliptical polarization ($K_{ar\,rt} = K_{ar\,lt} \neq 1{,}0$) under condition of taking into account the PP of AA (see Eq. 8). For example when $K_{ar\,rt} = K_{ar\,lt} = 0{,}9$ (0,8) the AR measurement within the range $\pm 1{,}0$ is achieved in the dynamical range equal to 26 dB (19 dB). This case is quite feasible in practice.

The estimation of the measurement error when measuring the AR of AA with non-ideal circular polarizations is simply performed by the comparison of the results that were obtained in calculations with the help of the Eq. 2 and Eq. 8. If $K_{ar\,rt} = K_{ar\,lt} = 0{,}8$ the relative error is respectively 20% and if $K_{ar\,rt} = K_{ar\,lt} =$ 0,9 the error decreases to 10%.

Thus amplitude method of radiation field PP determination namely the method of electromagnetic field resolution onto the circular polarization components in the circular polarization basis makes it possible to calculate the radiation field PP on the basis if the Eq. 2 with practically acceptable precision. The precision of the PP determination can be increased even in the limited dynamical range $\left|E_{rt}^{\max}\right|/\left|E_{lt}^{\max}\right|$ with the help of previous certification of AA and further considering their PP (see Eq. 8)

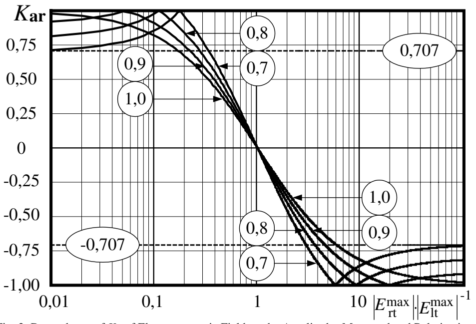

Fig. 2: Dependence of K_{ar} of Electromagnetic Field on the Amplitudes Measured and Polarization Parameters of the Auxiliary Antenna

3. Conclusion

In such a way the amplitude method of two antennas with circular polarization ("relative" method) has been chosen as the basic one after the analysis of different methods of antenna polarization parameters measuring. The further development of the method was presented. The affection of the non-ideal parameters of AA on the measuring method as well as their influence on the error of investigated field AR determination were researched. The following was showed:

- the precision of the determination of AR of investigated antennas radiation field by the presented method depends both on AR of AA and dynamical range of the radiation field measurement;
- the maximal error of the investigated field AR determination if $K_{ar\,rt} = K_{ar\,lt} = 0{,}9$ (0,8) is respectively 10% (20%);
- the use of AA with elliptical radiation polarization and their additional tuning allow receiving wide effective range of the AR measuring in the narrower dynamical range (if $K_{ar\,rt} = K_{ar\,lt} = 0{,}9$ (0,8) the change of the AR within the range $\pm$ 1,0 is achieved in the dynamical range 26 dB (19 dB)).