OPTICAL MEASUREMENT OF NON-UNIFORM ELECTRIC FIELD VECTOR DISTRIBUTION IN A DIELECTRIC LIQUID USING TRIPLET MEASUREMENT SYSTEM

The paper by Ihori et al. [1] is misleading. The purpose of this communication is to point out the mis-statements and to identify the nature of the unstated approximations used in that work. The title clearly states that the subject of the paper is “optical measurements of non-uniform electric field” yet equations (1)-(9) are only valid for uniform electric field whose direction is constant along the light path. These equations are presented as if they are directly applicable to arbitrary non-uniform electric field distributions. In particular no attempt has been made to show how $E$ and $\beta$ in equations (1)-(9) relate to the actual non-uniform electric field distribution under investigation. In fact the rigorously correct mathematics for describing Kerr electro-optic field mapping measurements in three dimensions when the direction of applied electric field changes along the light path requires new solutions to Maxwell’s equations as developed in [2]. These solutions show that two measurable parameters, analogous to $E$ and $\beta$ in equations (1)-(9) and which we call $\gamma$ and $\alpha$ in [2], exist only under certain conditions: if the geometry is axisymmetric or approximately if the dielectric medium is not highly birefringent. Since the geometry used by Ihori et al. [1] is axisymmetric we do agree that actual measurements of two parameters which are analogous to $E$ and $\beta$ are meaningful and valid but these parameters are not the electric field magnitude and direction. However we also disagree that such measurements and the numerical algorithm used by Ihori et al. [1] are directly applicable to arbitrary 3D geometries. At best, their approach is a method for reconstructing axisymmetric geometries but cannot be applied in their present form to the full 3D problem. In fact even extending 2D Kerr measurements to axisymmetric geometries is difficult. The distinction between Kerr measurements in 2D and axisymmetric geometries is given in [3].

The main contribution of the paper by Ihori et al. [1] appears to be the “triplet measuring system” which, according to the authors’ claim, reduces the amount of measurement time for the construction of the electric field vector distribution without sacrificing much accuracy. We do agree that making three measurements at the same time instead of making three measurements in succession reduces the amount of measurement time and could be valuable for truly three-dimensional geometries. However we find conclusions based on an axisymmetric geometry to be very misleading and identify the following points of confusion:

1. Ihori et al. [1] stated that they reduced the number of measurement directions from 6 to 3. However since their geometry is axisymmetric, all the directions they use are identical. In fact a single measurement direction is sufficient. Their numerical algorithm does require multiple directions, but since the geometry is axisymmetric you can make measurements in just one direction and use these measurements in all 3 or 6 directions. In other words, if there were no experimental errors you can take measurements from a single direction and end up with the same reconstruction results that they are presenting. Of course, with three or six measurements the effects of white noise error is typically reduced; but then the contribution of this paper is not the reduction of measurement directions from 6 to 3 but rather is the ability to make 3 identical measurements at the same time and thus reducing the effects of white noise.

2. It would be interesting to see if they took measurements from only one direction and use that in their algorithm for all 3 or 6 directions, if the reconstruction result would be much different. We believe that the reconstruction result will be essentially the same. In fact there is no reason to limit the number of directions to 6 either; the measurement from only one direction can very well be used for more directions in the algorithm, say 12 or 24, since the geometry is axisymmetric. By using a single direction measurement in 24 directions in the algorithm it may very well be possible to reconstruct a more accurate result than 6 measurement directions in 6 directions in the algorithm.

3. The paper by Ihori et al. [1] does not discuss the details of their numerical method of reconstructing electric field from measurements but references their earlier work [4]. In that work they discretize their reconstruction region into rectangular regions and apply their equations (1)-(9) repeatedly for each region. In this sense, their method is similar to our published method which uses the “onion-peeling” algorithm [2, 5] for axisymmetric systems. We would like to stress that the onion-peeling method already uses measurements from a single direction and “reducing the number of measurement directions from 6 to 3” is not really an achievement for axisymmetric geometries.

4. If the claim here is that after reducing the number of directions from 6 to 3 the reconstruction results for truly three dimensional geometries will not lose much accur-
5. It is also important to point out that even when the number of directions is reduced to 1, measuring multiple parameters (\(E\) and \(\beta\) in Ihori et al. [1] or \(\gamma\) and \(\alpha\) in our papers) requires rotation of the analyzer and that procedure is still too slow compared to transient charge injection phenomena. We believe that the correct approach for transient analysis requires numerical methods that can be applied to measurements with one parameter such as our finite element based Kerr electro-optic reconstruction [FEBKER] developed in [6].

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Markus Zahn and Afsin Ustündag
Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
Laboratory for Electromagnetic and Electronic Systems
Cambridge, MA 02139

1Now with Epic Systems Corp., Madison, WI.

1 REPLY

Zahn et al. proposed the measurement of three-dimensional electric field vectors by the numerical method named onion-peeling method [2]. We think that their method should be evaluated as a high one in the measurement of symmetrical electric field distributions. However, their method is really different from our method. Our method is one of the valid methods to measure the electric field distribution. The following is our opinion about their claims:

In reply to points (1), (2) and (4), we have been investigating the determination of three-dimensional electric field distributions using an original method. The method combines the reconstruction technique modified by the computed tomography (CT) technique and Kerr electrooptic method. The CT method is known as the method to observe cross sections of an object, for example, the human body, in medical science. We emphasize that our method is made possible to measure non-symmetrical three-dimensional electric field distributions, as it is obvious that whether the object is symmetrical or non-symmetrical is not serious problem in CT. For example, we measured electric field vector distributions in a sphere-to-sphere electrode system of which the axes of the spherical electrodes differ and a twin spheres-to-sphere electrode system [7, 8]. The merit of the method is that the strength and the direction of the electric field at each position can be obtained for a symmetrical and non-symmetrical geometry. However, the method posed a problem in terms of measurement time, because we had to measure the light intensity in many directions and this measurement had to be carried out twice by changing the optical axis of the analyzer in order to measure one electric field distribution. In order to solve the problem, a new measurement system, called the simultaneous three-direction optical measurement system, was proposed in this paper [1].

In general, numerous measurement directions give high accuracy of the reconstructed distribution. The relationship between error of the reconstructed distribution and the number of measurement directions will be published [9]. Theoretically, as the discussers stated, the electric field distribution can be reconstructed using the data from one direction in all directions, if the measured distribution is a perfect symmetry. What they stated, “By using a single direction measurement in 24 directions in the algorithm it may very well be possible to reconstruct a more accurate result than 6 measurement directions in 6 directions in the algorithm”, is correct. However, this is restricted to the geometry of the perfect symmetry. The measured electric field distribution may not be a perfect symmetry as we made the electrode system. Even if the geometry is not a perfect symmetry, there is no problem in our method.

Consequently, the point of this paper is not that symmetrical electric field distribution can be decided by the measurement from three-direction, but that the electric field distribution can be obtained, even if the number of measurement directions is reduced from 6 to 3 in order to shorten the measurement time.

In reply to point (3), our reconstruction technique has been explained in our paper [10]. We add the following explanation about the reconstruction technique in order for one to understand the paper, easily. Certainly, equations (1)–(9) of [1] are only valid for two-dimensional electric fields whose direction is constant along the light path and perpendicular to the direction of the light path. But, an optical behavior of three-dimensional electric field vector is approximated by the projection component which is perpendicular to the direction of the light path [11]. And, the problem that electric fields are not constant along the light path is solved by our reconstruction method. As a fundamental theory for the reconstruction method, the measured light intensity data at many directions is equal to the light intensity data calculated analytically from the provisional field distribution, which must be satisfied as the necessary condition when the reconstructed distribution equals the measured field distribution. Instead of the light intensity data, we reconstruct the electric field distribution using \(E\) and \(\beta\). Therefore, \(E\) and \(\beta\) in our reconstruction technique should be considered as parameters for the reconstruction rather than the strength and the direction of the electric field. In order to avoid confusion, \(E\) and \(\beta\) are called reconstruction data for the strength and the direction, respectively.

The obtained field map may be an approximate value in a sense because we use an approximation. But, by our method, the electric field distributions can be obtained within an error of about 10% without difficult calculation for symmetrical and nonsymmetrical electric field.
In reply to point (5), already, by the two-beam method using non-polarizing beam splitter, this measurement system has been improved [12]. By further improvement, we can now measure the electric field distribution at 1 ms interval, continuously [13]. We will study the measurement of the electric field distribution by faster measurement time.

H. Ihori, M. Fujii and K. Arii
Department of Materials Science and Engineering
Ehime University
3 Bunkyo-cho, Matsuyama, 790-8577, Japan

REFERENCES