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Comment on "PERFORMANCE ANALYSIS OF EMI SENSOR IN DIFFERENT TEST SITES WITH DIFFERENT WAVE IMPEDANCES"

by S. Ghosh and A. Chakrabarty, in *Progress In Electromagnetics Research*, PIER 62, 127–142, 2006

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In this paper (PERFORMANCE ANALYSIS OF EMI SENSOR IN DIFFERENT TEST SITES WITH DIFFERENT WAVE IMPEDANCES), last paragraph on the page no. 131 is reproduced here for quick reference;

"Here, it should be noted that for free space $\eta_1 = 377\,\Omega$. But for an air-cored co-axial structure with characteristic impedance $50\,\Omega$ (e.g., GTEM Cell), which supports the propagation of TEM wave only, the TEM mode propagating in the medium has wave impedance of $50\,\Omega$."

My comments: It is **NOT true**. As far as my knowledge is concerned, the wave impedance inside a $50\,\Omega$ characteristics TEM cell is $377\,\Omega$ (or $120\pi\,\Omega$). The wave impedance is an intrinsic property and depends on only material of the medium. If the co-axial structure is air-cored (as authors are mentioning) then wave impedance will be;

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi \approx 377\,\Omega$$

and also,

$$\eta_0 = \frac{E}{H} = 120\pi \approx 377\,\Omega \quad \text{(for plane wave, TEM wave)}$$

and certainly **NOT** $50\,\Omega$ as authors are mentioning.

In the subsequent pages, authors had tried to explain that Antenna Factor (AF) measurement in GTEM Cell is differing from free space measurement. (Figs. 7, 8 and Table 1 etc.). This is also **NOT** true. Variation may be found in AF values measurement in GTEM Cell and that of free space but NOT because of change in wave

impedance values. At both places, the wave impedance is same, that is $377\,\Omega$ (free space wave impedance).

The probable reason for variation is AF values is due to existence of mutual capacitance and inductance between antenna and the septum of the GTEM cell in comparison to the free space AF measurement where such mutual inductance and capacitance is negligible if not zero. These values of mutual inductance and capacitance can easily be measured for a given GTEM cell and antennas and then can be applied to correlate AF values with that of free space measurements. However, finding out the exact reason for this variation and correction methods are not in the scope of this comment paper.

In fact, GTEM and TEM Cell are used as standard calibration equipment worldwide for calibration of broadband E-field and H-field probe. This method is invented and suggested by NIST and widely accepted. All commercial probe/antenna manufacturers are using GTEM and TEM cell for calibration with assumption that wave impedance inside GTEM/TEM is $377\,\Omega$. This fact is so well known that some time magnetic field probes are calibrated by calculation using electric field value and wave impedance because they hold a well defined relation i.e.,

$$\eta_0 = \frac{E}{H} = 120\pi \approx 377\,\Omega \quad (\text{for plane wave, TEM wave})$$

Now, if somebody (as mentioned by the authors, PIER 62, 127–142, 2006) that wave impedance inside a GTEM cell (that to air-core) is $50\,\Omega$, all the measurements worldwide stands wrong and lot of ambiguity will emerge among the users.

In the last, I would like to make a request that scientific facts are to be corrected in the paper so that it should not lead to any ambiguity among the users of such scientific fact, measurement, calibration etc.

I am quoting some references in support of my observations;

(1) A few related definitions are given here.

(2) E-mail correspondence with Mr. Clayton R. Paul, whose name is give as the first reference in the paper (PIER 62, 127–142, 2006). Mr. Clayton R. Paul is well known authority on the Electromagnetic and EMI-EMC.

(3) *Radio Frequency Principles & Applications*, Albert A. Smith, Jr., IEEE Press, 1998, ISBN 0-7803-3431-0

(4) *Electromagnetics*, John D. Kraus, Mcgraw-Hill International Book Company, International Student Edition, 1984 a. Definition of TEM wave - page no. 380

(5) "Generation of standard EM fields using TEM transmission cells", M. L. Crawford, *IEEE Transaction on Electromagnetic Compatibility*, Vol. EMC-16, No. 4, Nov. 1974

(6) Operation Manual, "Model 5400 Series Gigahertz Transverse Electromagnetic Cell (GTEM)", Make: ETS-LINDGREN, USA, Page No. 91

Related useful definitions:

TEM Cell: It is a rectangular coaxial transmission line, resembling a stripline, with a flat and wide centre conductor and outer conductors closed and joined together. The rectangular section is tapered at both ends and matched to a standard $50\,\Omega$ coaxial N-type/BNC connector. In TEM Cell, electromagnetic waves with TEM (Transverse ElectroMagnetic) mode are generated which has the wave impedance of $377\,\Omega$.

GTEM Cell: A modified TEM Cell with usable frequency range extended up to Gigahertz. Hence called as GigaHertz TEM (GTEM) Cell.

Wave Impedance (η): The wave impedance of a EM wave is defined as the ratio of the transverse electric field component to the mutually perpendicular transverse magnetic field component and it is equal to the intrinsic impedance of the medium.

Characteristics Impedance (Z_0): The characteristics impedance of a transmission line is defined as the ration of the voltage between the conductors to the current flowing on the conductor and it is a function of the geometry of the line and the medium.

Relation between wave impedance (η) and characteristics impedance (Z_0): They are related by the relation;

$$Z_0 = \frac{\varepsilon}{C}\eta \tag{1}$$

where,

ε is permittivity of the medium

C is the distributed capacitance