International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.03, Issue No.01, pp : 8- 12 1 Jan 2014

# 3D Sensitivity of 6-Electrode FIM through Experimental Study in a Phantom

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**Abstract:** ***Focused Impedance Measurement (FIM) is a relatively new technique developed in the Biomedical Physics Laboratory of Dhaka University which allows improved localization of a zone without much increase in complexity of the measuring instrumentation when the electrodes are applied on the skin surface with the organs inside contributing the measurement of impedance since the body is a volume conductor. The present work is an experimental study of the sensitivity of the 6-electrode FIM system at different depths and lateral positions inside a volume conductor with respect to the electrode-positions using a cubical phantom with saline. An object of different conductivity and of size smaller than the electrode separation was placed inside the phantom at different positions to measure the change of FIM value, called sensitivity This work will help standardize the application of 6-electrode FIM for determination of impedance of organs inside the human body.***

**Keywords** — ***Electrical Impedance, focused impedance method (FIM), phantom, sensitivity*.**

**Introduction:** Electrical impedance measurement techniques have been in use for over a century for characterizing physiological tissues and attempts have been made for detection and diagnosis of diseases and disorders, although with limited success [I]. Besides being non-invasive, electrical impedance measurement is also a potentially low cost and simple technique. Impedance is a characteristic property of any material, including biological materials [II]. Different body tissues may have different electrical conductivities, and which can again vary between health and disorder. Biological tissues exhibit two important passive electrical properties; electrical conductivity due to free charge carriers (ions etc.) and dielectric properties like relative permittivity due to bound charge densities. Localisation of a target organ therefore, was almost impossible, which is required for detection or diagnosis of human diseases or disorders. In the basic non-invasive electrical impedance measurement, two electrodes are placed on the surface of an object (a volume conductor) and the impedance measurement is used to determine the gross electrical characteristics of the whole volume of that object, with enhanced contribution from regions under the electrodes and the region in between the two electrodes. For the impedance measurement a known amount of alternating current is injected through the electrodes and the resulting electrical potential difference is measured. However, the contact impedances of the electrodes are added to the measured value which masks the values relevant to the bulk region inside in most cases. Typically the contact impedance is much larger than the bulk impedance and it is very difficult to extract the latter from the total measured value. To avoid this problem, TPIM (Tetra-polar or four-electrode Impedance Measurement) method evolved towards the end of the nineteenth century in which four electrodes were employed. In a typical configuration these are arranged in a line and current is injected at the two outer electrodes while the resulting potential difference is measured across the two inner electrodes giving a transfer impedance or admittance. It also gives some localisation, however, the zone of sensitivity is rather wide and a target organ cannot be separated from its neighbouring organs. In order to improve the localization of the target region inside the effective zone of impedance measurement, a new technique, known as the Focused Impedance Method (FIM) was conceived and developed at the Biomedical Physics Laboratory of the University of Dhaka [III, IV]. In the basic method transfer impedances are obtained using two orthogonal and concentric TPIM configurations and summing or averaging the two values, which has enhanced sensitivity at the central region compared to its surroundings. Therefore, in this basic technique, a total number of eight electrodes are required, four for introducing the two orthogonal currents and remaining four for recording two voltages. A 6-electrode version of FIM was achieved by placing two electrodes diagonally at the central region for potential measurements instead of the four required, being placed at the intersections of the relevant equipotential lines [III, IV]. These two electrodes could monitor the potentials for both the orthogonal current drive configurations. In electrical impedance measurements it is important to know where to put the electrodes on the boundary to get the maximum contribution of the target organ into the measured impedance. Organs at points with higher sensitivity contribute much more than those at points with low sensitivity. Understanding of the point-sensitivity is thus essential in order to achieve success in electrical impedance methods. Sensitivity of a tetrapolar impedance measurement at a point *p* can be defined as the scalar product of the sum of two vector current densities (the lead fields) for unit current injection between the two pairs of electrodes [V]. Due to movement of test subject, lack of precision in electrode placement and inexperience, internal target organs may shift from the intended position on the center axis, during the measurement process or even at the beginning. Furthermore, no experimental study had been done on the sensitivity measurement of basic 6-electrode system. The present study was therefore taken up to investigate the variation of 3D sensitivity inside a volume conductor at on and off-axis points using a small object in a phantom paving the way to more realistic application of 6-electrode FIM.

**Material and Methodology:** In this method impedance of the region of interest is measured from two mutually perpendicular directions simultaneously is the basis idea of the new technique.

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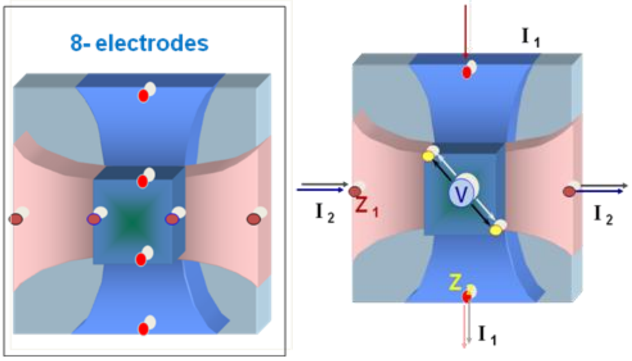
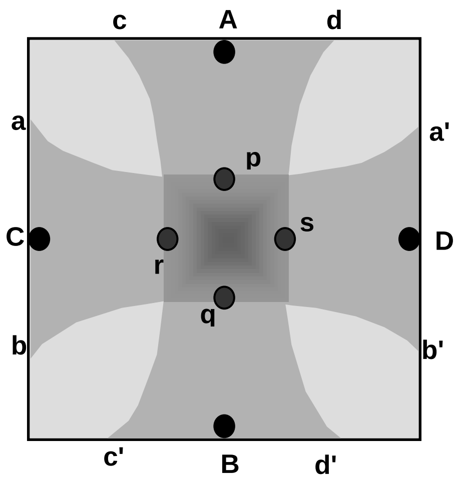
For this method two independent sets of four electrode system placed orthogonally to one another surrounding the region. Two current sources of same frequency, phase and amplitude are introduced simultaneously and resulting potentials are recorded. Impedance follows according to the Ohm's law (Z = V/I) where V is the combined potential and I is constant current passing through driving electrodes. The impedance of the region of interest contributes more than the neighboring regions as it is counted twice. Thus some degree of focusing on a particular region is expected to be obtained by our new technique. And as the region of interest is more focused compared to the other regions, the name has been offered to the proposed technique is Focused Impedance Method (FIM).

**SIX ELECTRODE FIM SYSTEM:** The focused system basically involves two independent four electrode measurements which need eight electrodes in all. To obtain this combined output the hardware may be simplified through some modified placement of measuring electrodes and by electrically isolating the two current drives so that they do not interact, it was possible to reduce the number of electrodes to six and to obtain the desired combined impedance through a single measurement as described below [VI, VII].




*(a)* *(b)*




Focused zone in 8-electrode FIM

*Figure 1: Reduced six electrode FIM*

*Figure 1,* electrode u can replace electrodes p and r for measurements in either of the perpendicular directions as it falls on the appropriate equipotentials *aa'* and *cc'* respectively. Similarly, electrode v can replace electrodes q and s for similar measurements. Now if the alternating currents through electrodes *AB* and *CD* can be made to have the same frequency, magnitude and phase but electrically isolated, the potential measured across uv will be directly proportional to the sum of the individual four electrode impedances. Thus the number of electrodes is reduced to six from eight and only one potential measurement circuitry is needed instead of the expected two (considering two separate four electrode measurements). The prototype was designed and fabricated following this concept as described below.

**INSTRUMENTATION FOR SIX ELECTRODE FIM**

A block diagram of necessary instrumentation developed for the FIM is shown in *Figure 2* [VIII].

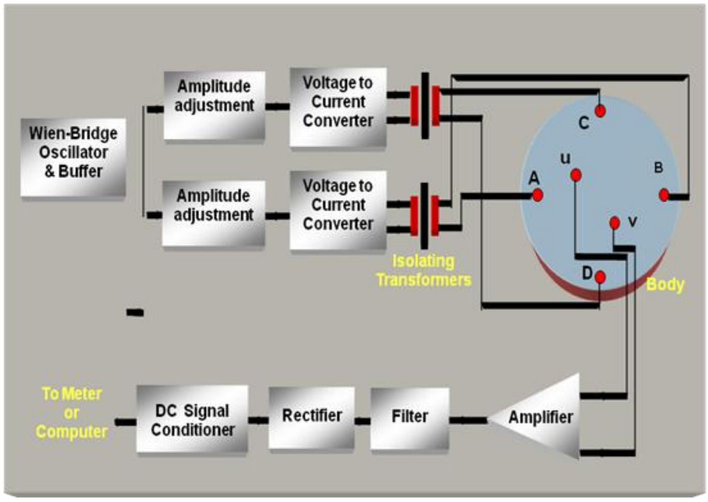



***Figure: 2** A block diagram of the 6-electrode FIM*

A sinusoidal signal at about 10 kHz is generated using a Wien Bridge oscillator. This is branched out to two isolated current drives (AB and CD) through appropriate voltage to current converters and isolating transformers. The necessary electrode connections are shown on a circular body. The current drives may be set in the same phase or in the opposite phase by simply reversing the electrode connections from one of the two isolating transformers. Since the two isolating transformers may not be exactly equal, two amplitude adjusting circuitry as shown were introduced to make the two perpendicular driving currents the same. The combined impedance measurement (sum) is carried out through measuring the potentials between electrodes u and v. The measured potential is amplified, filtered, rectified and smoothed out to obtain a dc voltage which is proportional to the combined impedance. This dc output voltage may be measured using a digital volt-meter for manual work or may be fed to a computer for automated data acquisition. [Rabbani, 1994].

**PHANTOM MEASUREMENT:** A phantom is a representation of a human body or an organ within a human body, which helps in carrying out simulated experiments. In other words, a phantom acts as a model of a specific organ or part of a human body where we presume that it matches the assumed arrangement inside the body for which the measurements are to be performed. Performing any experimental work on it is equivalent to performing the experiment on the actual organ and that the outcome predicted by the experiment can be taken as a first hand approximation to predict the outcome in real life. In our in our experiment a 3D phantom is constructed out of an almost rectangular plastic container. The container is about 30cm. long, 30cm. wide and the height is about 35cm.The thickness of the saline layer was 27cm.The photograph in figure 3 shows the phantom together with the electrodes and guiding frames for object placement.

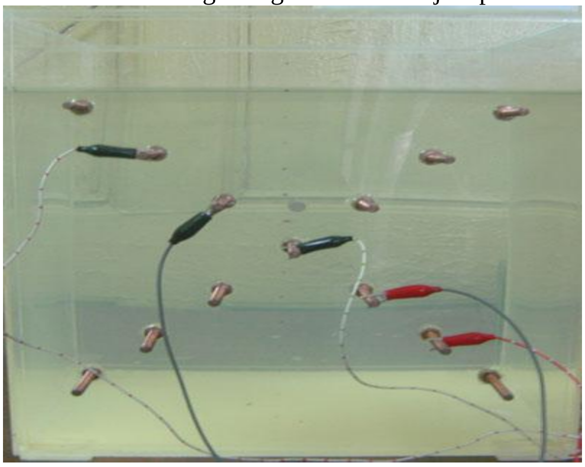


*Figure 3: The electrode box (Phantom). The electrode at the centre is the common or ground electrode.*

We fixed 13 carbon electrodes on one of the side walls of the phantom electrodes were made out of bronze screws. Holes were first drilled in the wall through which the electrodes were pushed tight. Araldite was used for sealing. An extra common electrode fixed at the centre of the opposite wall. The FIM method needs 4 electrodes for driving current and two electrodes for potential measurement. However to study the effect of separation of electrodes, two sets each of the above mentioned six (4+2=6) electrodes were used making a total of 12.

A nonconducting object (ball) was hung by cutton thread from the sliding scale of the phantom. The diameter of the ball was measured using a slide calipers. The position of the centre of the ball was recorded from the measuring scales. Length of the thread and radius of the ball with respect to the co-ordinate system were also measured. The centre of the FIM electrode system was at (0, 0, 0) with the Z co-ordinate decreasing with increasing depth from the FIM plane. Thus for example, if the position of the ball were (20, 0, 0) then the depth of the ball from the surface was 4cm (=25-21=4). Then the measuring electrodes measured the potential of the system.

**RESULTS AND OBSERVATIONS:** All collected data's are shown graphically in the following figures to have the understanding of the volume sensitivity of 3D FIM system. Here sensitivity differences were plotted as the position of the target object. The sensitivity is proportional to the difference of the impedance measured and the impedance of the background i.e. of the saline water. The Z-coordinate represents the position of the object inside the phantom and the Y-coordinate of object was changed at first (Figure 4). The data points represent the difference of impedances for each Y-value at different X-coordinates of the test object.

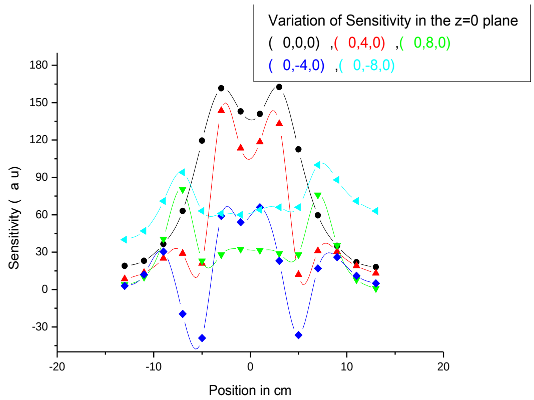



Figure 4

In this experiment current electrodes were placed at distance 8 cm and voltage electrodes were placed at distance 4 cm from the centre. These electrodes were extended to some extend in the backside of the phantom. When the non-conductor object touched these electrodes the hump nature of the figure 4 was seen. It blocked the current and gave rise to a large change in the measured value. This is the reason we observed humps in figure 4. If the object did not touch the electrodes, we would obtain a graph with a maximum at the centre.

**Variation of Sensitivity with respect to Z i.e. depth inside the phantom**

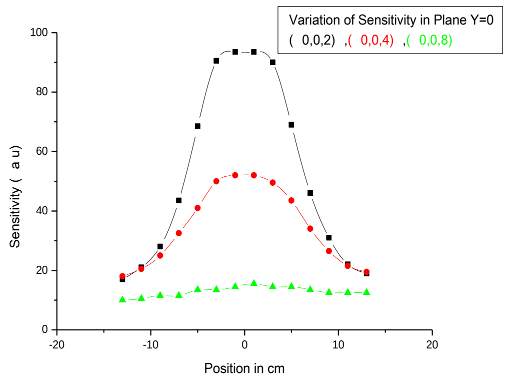



Figure 5

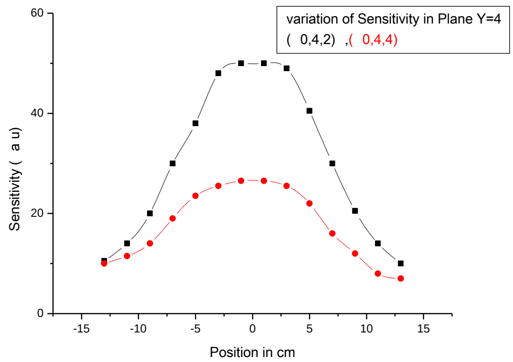



Figure 6

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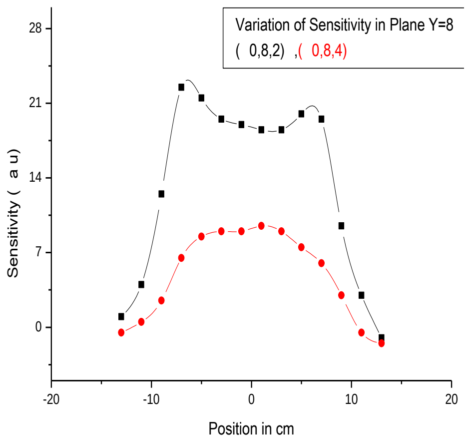


Figure 7

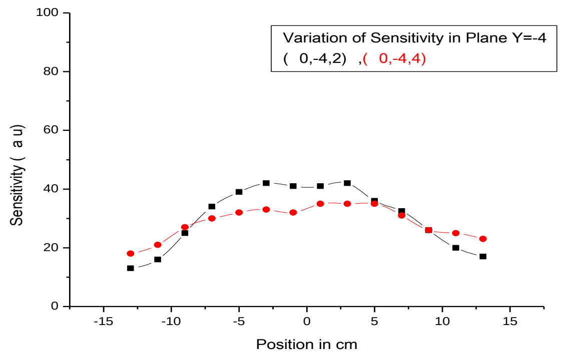


Figure 8

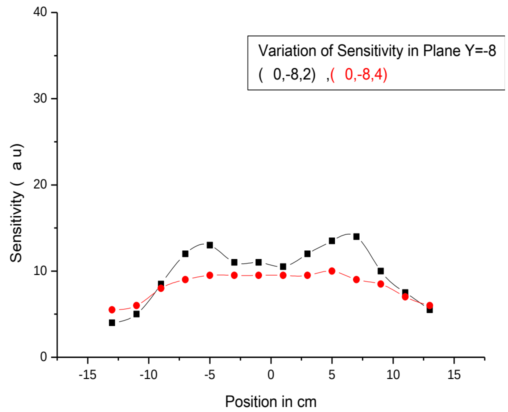


Figure 9

From the figures (5-9) we can see that the sensitivity was maximum at the center and low at a distance about 13 cm from the center and it increased near the centre and decreased away from the centre. The central region is the most sensitive zone because it was focused the best. 3D FIM system was very much volume sensitive for non-conductors. As the position of the spheres along the Z-direction increased from the electrode surface, the response of the system became smaller. Again for a fixed volume, the response decreased in a monotonically with respect to the increase of depth and reached the background response of 1.246 V at the depth of about 8-10 cm. The following graph shows the result (Figure 10).

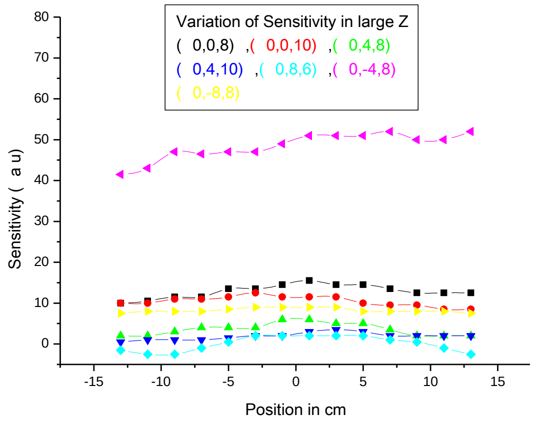


Figure 10

**Variation of Sensitivity Vs depth inside the phantom**

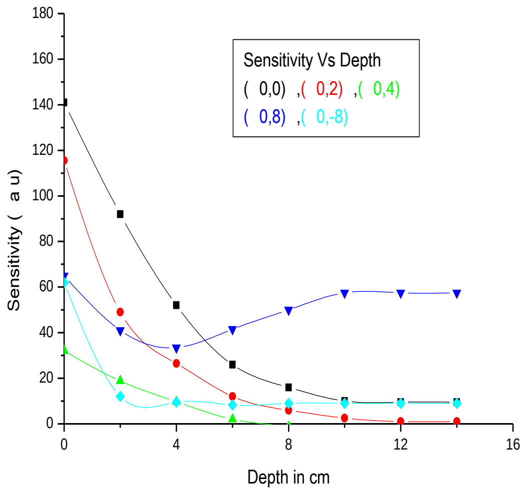


Figure 11

From the figure 11, we can see that the FIM output decreases with depth quite rapidly when they are very near to the electrode plane. As the depth increases the rate of change becomes less, while the sensitivity decreases too. Therefore, slight uncertainty in the depth may increase the uncertainty in the volume measured. We, therefore, conclude that it is better to have the object at some distances in the $3^{rd}$ dimension. On the other hand, this will reduce the sensitivity. Hence, we may have to optimize for each organ by adjusting the separation of the driving and measuring electrodes. Both these separations will have effect on the volume sensitivity.

**Conclusion:** The present work on sensitivity measurement of insulator has increased the confidence with which the FIM system may be applied for real life measurements on human subjects for physiological studies and for diagnosis of disorders such as cancer cell – identification, post heart attack, kidney, skin disease identification etc. In this respect, our work has passed the way for future application of FIM for useful medical purposes.

**Acknowledgement:** I am extremely delighted to express my deepest sense of gratitude and indebtedness to my respected teachers, Golam Dastegir Al-Quaderi, Associate professor, Department of Physics and Dr. Khondkar Siddique-e-Rabbani, Professor and Chairman of Department of Biomedical Physics & Technology, University of Dhaka. Their consistent encouragement, continuous guidance, numerous suggestions and ideas throughout the experimental process as well as in the preparation of the manuscript were absolutely essential.

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