Effect of a spherical object in 4 electrode Focused Impedance Method (FIM): measurement and simulation

R Abir¹, F J Pettersen², ³, O G Martinsen², ³ and K S Rabbani¹
¹Department of Biomedical Physics & Technology, University of Dhaka, Dhaka, Bangladesh
²Department of Clinical and Biomedical Engineering, Oslo University Hospital HF, Oslo, Norway
³Department of Physics, University of Oslo, Norway
E-mail: raihan.abir@bmpt.du.ac.bd, rabbani@univdhaka.edu

Abstract: Focused Impedance Method (FIM) gives enhanced localized sensitivity at the centre of a zone defined by a simple system of electrodes, of which a 4-electrode version with electrodes at the corners of a square region has been studied in detail in the present work. The present work studies the effect of a large sphere whose diameter almost equals the dimensions of the central focused zone, or, the Focused Impedance. The sphere is placed at different positions with respect to the centre of the system at the electrode plane. The study has been made using a phantom in which the electrodes are fixed on a side wall while an insulating ball is hung at various positions inside the saline and moved with respect to the electrodes in their vicinity. The same was then simulated by providing appropriate parameters in COMSOL multiphysics, a software package utilizing Finite Element Method, by providing appropriately matching parameters. The measured impedance decreases to the background value as the ball is moved away from the centre in the electrode plane or along the depth, which is expected. The sensitivity also decreases with an increase in electrode spacing. The behaviours agreed very well with that obtained using COMSOL multiphysics package.

1. Introduction

Focused Impedance Method (FIM) is a recent technique, innovated by one of the authors at University of Dhaka, which can localize a zone of interest in a volume conductor and shows quite a promise in providing practical results with a minimum of instrumentation complexity [1]. Three version of FIM were developed, using 8, 6 and 4 electrodes respectively. FIM is attractive because of its ability to localize a small region using a few electrodes and simple instrumentation [2]. Utilising the 3D sensitivity of FIM it is possible to detect objects at shallow depths, typically of the order of the separation of the electrodes [3]. FIM has potential applications in many physiological studies and in the detection and diagnosis of diseases and disorders of the human body [4]. Particularly it may be useful in studying stomach emptying, stomach acid secretion, localized lung ventilation, bladder emptying, etc., where temporal changes occur that may be distinguished through a difference measurement. Again, through changes in the frequency of measurement it may be possible to identify organs or localized tissues that have distinctive frequency spectrum from the surrounding tissues. Thus
it may be possible to characterise breast tumours and to monitor tumour ablation at shallow depths using multiple frequency measurements.

Among the three electrode configurations, 4 electrode FIM (abbreviated as 4-FIM) is simple in electrode configuration and useful in many applications. The concept was initially developed with the help of equipotential lines as shown in Figure 1. Here 4 electrodes, 1,2,3,4 are fixed in a square formation. Firstly, current is driven through electrodes 1 & 2 while potential is measured across electrodes 3 & 4. This gives a transfer impedance $Z_1$ which is essentially due to the impedance of the horizontal shaded region between the equipotential lines passing through electrodes 3 & 4. Then current is driven through electrodes 2 & 3 while potential is measured across electrodes 4 & 1. This gives a transfer impedance $Z_2$ which is essentially due to the impedance of the vertical shaded region. The Focused Impedance $FZ$ is defined as the average of the two impedances, $FZ = (Z_1 + Z_2) / 2$.

Previously Geselowitz’s lead field method and Finite Element method (FEM) were used to assess the point sensitivity in 4-FIMsystem [5, 6] which matched the above prediction well except an increased sensitivity at the four electrodes, which however decreased with depth (into 3D), eventually matching the predicted shape at about one third the electrode spacing.

The effect of five important variables namely electrode spacing, object size, object resistivity, background resistivity and depth of the object were studied in detail to have an understanding of the system [6]. The effect of an object at various positions along the horizontal and vertical axis was also studied. Results of these studies verified the focusing effect of FIM and gave useful insight into the impedance change with depth.

The present work studied the effect of a large sphere whose diameter almost equals the dimensions of the central focused zone, or, the Focused Impedance. The study has been made using a saline phantom with electrodes fixed to a wall. An insulating ball is hung at various positions inside the saline and moved with respect to the electrodes in their vicinity. The same was then simulated by providing appropriate parameters in COMSOL multiphysics, a software package utilizing Finite Element Method, by providing appropriately matching parameters.
2. Methods and measurements

FIM measurements were carried out at 50kHZ using a saline filled 3D phantom, made of transparent acrylic, of dimension 30cm x 30cm x 30cm (related to actual depth of water tank). Electrodes having a diameter of 1cm and a depth of 2mm into the saline were fixed on one side while a spherical insulating object under measurement was hung from the top using a thin thread, guided by calibrated scales. The spacing of the current drive and pick up electrodes was 7cm initially (sides of the square), changed later as indicated. Electrical conductivity of the saline was measured using a conductivity cell of known geometry and was found to be 0.052 S/m. A tennis ball wrapped using black insulating tape was used as the spherical object. It had a diameter of about 6.5 cm, slightly less than the dimension of the square focused zone defined by the electrode spacing. As mentioned before, to get the focused impedance, an alternating current of constant amplitude was driven through two adjacent pairs of electrodes and the potential was measured across the other two. Then the configuration was rotated by $90^\circ$ and again a similar measurement was taken. Because of the constant current, the potentials are proportional to the respective transfer impedances. The average of the two transfer impedances gave the focused Impedance, FZ. Measurements were taken using a Maltron Bodyscan 920 tetra polar impedance measurement equipment.

To perform simulation using COMSOL, the dimensions of the phantom and the object mentioned above were inserted. The conductivity of saline was taken from the measured value at 0.052 S/m. The conductivity of the insulating ball was taken at $10^{-14}$ S/m.

3. Results

The results of the studies are given through the plots in Figures 2 to 4. The measured impedance values are given by the dark lines while the COMSOL simulated values are given by the grey lines. For Figure 2, the object was moved along the horizontal axis parallel to the electrode plane with the centre of the ball at 3.5cm inside the phantom (considered as the depth of the ball, with its surface at 0.25cm depth inside the wall). The electrode separation was fixed at 7cm. For Figure 3, the ball was moved into the 3D having its centre always at the centre of the focused zone, the electrode separation again being 7cm. For Figure 4, the ball was kept at the centre at a depth of 3.5 cm, but the electrode separation was changed.

![Fig.2. Measured and simulated focused impedance FZ when the ball was moved along the horizontal direction, keeping the depth same, at 3.5 cm.](image-url)
4. Discussions

In all the three plots the results of the actual phantom measurements agree well with that obtained using COMSOL simulation. However, there is some discrepancy in Fig.2 which may be due to experimental errors, or other specific reasons yet to be found. The measurements have been repeated several times and therefore, the values can be relied upon. It may be mentioned that not considering the 2mm height of the electrodes, COMSOL gave significantly different results. Therefore one needs to be very careful with the dimensions of the relevant items while working with COMSOL.

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Fig.3. Measured and simulated focused impedance FZ when the ball was moved along the depth with the ball always at the centre of the focused zone.

Fig.4. Measured and simulated focused impedance FZ when the ball was kept fixed at the centre of the focused zone while the electrode spacing was increased.