



## Conditioning Electrical Impedance Mammography System



Ali Zarafshani<sup>a,c,d,\*</sup>, Thomas Bach<sup>b</sup>, Chris R. Chatwin<sup>a</sup>, Shanshan Tang<sup>c</sup>, Liangzhong Xiang<sup>c</sup>, Bin Zheng<sup>d</sup>

<sup>a</sup> Biomedical Research Group, Department of Eng. and Design, School of Eng. and Informatics, University of Sussex, BN19QT, UK

<sup>b</sup> Sensatech Research Ltd, Brighton BN2 0GP, UK

<sup>c</sup> TRUE Lab, School of Electrical and Computer Eng., University of Oklahoma, Norman, OK 15213, USA

<sup>d</sup> CAD Lab, Stephenson Cancer Research Center, School of Electrical and Computer Eng., University of Oklahoma, Norman, OK 15213, USA

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### ABSTRACT

A multi-frequency Electrical Impedance Mammography (EIM) system has been developed to evaluate the conductivity and permittivity spectrums of breast tissues, which aims to improve early detection of breast cancer as a non-invasive, relatively low cost and label-free screening (or pre-screening) method. Multi-frequency EIM systems typically employ current excitations and measure differential potentials from the subject under test. Both the output impedance and system performance (SNR and accuracy) depend on the total output resistance, stray and output capacitances, capacitance at the electrode level, crosstalk at the chip and PCB levels. This makes the system design highly complex due to the impact of the unwanted capacitive effects, which substantially reduce the output impedance of stable current sources and bandwidth of the data that can be acquired. To overcome these difficulties, we present new methods to design a high performance, wide bandwidth EIM system using novel second generation current conveyor operational amplifiers based on a gyrator (OCCII-GIC) combination with different current excitation systems to cancel unwanted capacitive effects from the whole system. We reconstructed tomography images using a planar E-phantom consisting of an RSC circuit model with different set of values, which represents the resistance of extra-cellular (R), intra-cellular (S) and membrane capacitance (C) of the breast tissues to validate the performance of the system. The experimental results demonstrated that an EIM system with the new design achieved a high output impedance of 10 MΩ at 1 MHz to at least 3 MΩ at 3 MHz frequency, with an average SNR and modelling accuracy of over 80 dB and 99%, respectively.

### 1. Introduction

Electrical Impedance Spectroscopy (EIS) [1–3] or multi-frequency Electrical Impedance Tomography (EIT) [4–6] systems were designed and used to measure extensive electrical properties based on the conductivity and permittivity of the biological tissues, which are quite different from other conventional medical imaging modalities that mostly used to detect or describe tissue density, stiffness, and other physical features. Multi-frequency EIT provides a new alternative or supplementary approach to help improve diagnosis of breast cancer based on the differentiation of dielectric properties of biological tissues [7], as there is a significant difference in dielectric properties between the normal and malignant tissues [8,9]. The EIT technique has unique several advantages such as: non-invasive, relatively inexpensive, non-hazardous attachments, non-ionizing radiation, label-free, possibility of repeated use without any side effects, and capability of quantitative measurement of electrical characteristics [10,11]. Therefore, it is

proposed as a new potential breast cancer screening or pre-screening method to detect malignant tumors at early stage [12,13]. In this regard, it is suggested to call it “Electrical Impedance Mammography (EIM)” [14–17].

An EIM system includes a number of software and hardware subsystems consisting of analogue and digital elements that are usually developed together [18–20]. Specifically, an EIM system consists of a signal generator, voltage-to-current (V/I) converters, drive and receive multiplexers (MUXs) in case of single source topology, channel switching control with calibration circuits, differential voltage amplifiers, and DSP components to demodulate and find “in-phase” and “quadrature” of the transfer voltage measurements at different frequency points leading to a breast impedivity image reconstruction (IR), the EIM structure is shown in Fig. 1.

For reconstructing the impedivity image of a breast under test, it is required to employ a current excitation and the data acquisition system (DAS) to measure different potentials at multi-frequency points [21].

\* Corresponding author at: 101 David L Boren Blvd. Suite 1001, School of Electrical and Computer Engineering, University of Oklahoma, Norman, OK 73019, USA.  
E-mail address: [A.Zarafshani@ou.edu](mailto:A.Zarafshani@ou.edu) (A. Zarafshani).

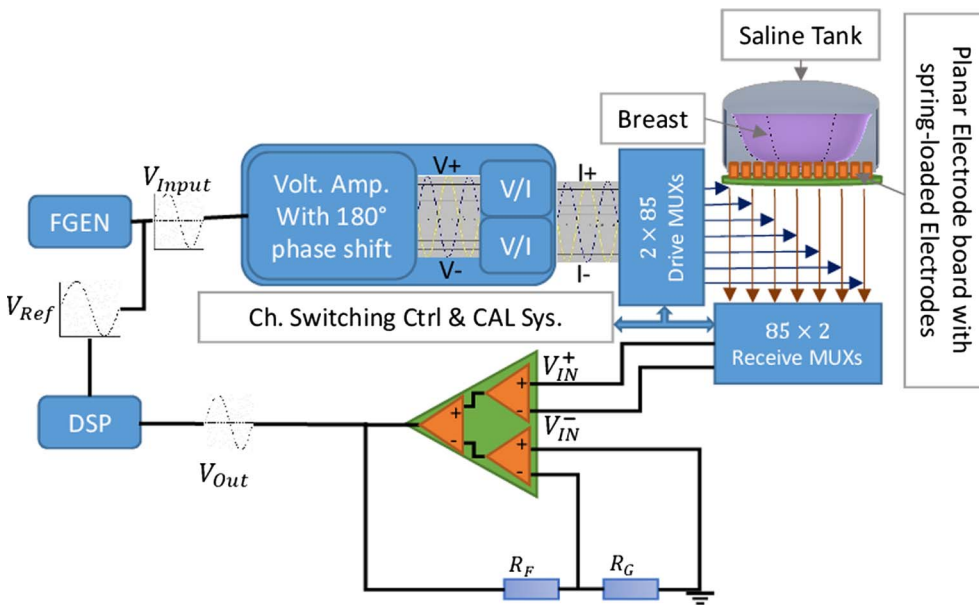


Fig. 1. Overview of the single source Sussex EIM system regarding the Sussex 85 planar electrode structure.

Indeed, on the subject of injecting current, in order to achieve high measurement precision, it is important that the current injection circuits have a high output impedance over the required frequency bandwidth [22]. This will deliver a high-performance system with improved spatial resolution to measure electrical impedance properties of biological tissues [23]. The change in electrical properties of a small region of tissue can be observed over a frequency range of interest [24]. These changes can provide significant information about the structure and composition of the tissue [25–27]. Since tissue electrical properties are determined by their resistive and capacitive characteristics, the measured values depend upon the conductivity  $\sigma$  and permittivity  $\epsilon$ , which quantifies the tissue's ability to permit storage of electric energy [28]. Therefore, these high-frequency measurements are vital for intracellular impedance imaging because membranes of cells block the current flowing to inside the cells at low frequency [29].

Multi-frequency EIM systems typically employ current excitations and measure differential potentials from the subject under test. Both the output impedance and system performance (SNR and accuracy) depend on the total output resistance, stray and output capacitances, capacitance at the electrode level, crosstalk at the chip and PCB levels. This makes the design of system highly complex due to the impact of the unwanted capacitance, which substantially reduces the output impedance of stable current sources and bandwidth of the required data. In order to overcome this difficulty, the objective of this study is to apply a new EIM system design method and test whether the new system can produce significantly higher contrast in generating EIM images. To report our study methods and results, this article is organized as follows. We first provide a theoretical description of the voltage and current-mode source topologies as the main part of the hardware subsystem. Next, we propose a current conveyor structure by application of a gyrator to eliminate the current excitation limitations, and its development is followed by experimental tests to show the potential enhancement of the detected signals. We also build an Electric phantom (E-phantom) with an RSC circuit model to simulate breast tissue electrical properties. Then, we conducted experiments to test the potential enhancement of the detected or measured EIM signals from the breast phantom. The results are presented and discussed in the last section of this article.

## 2. Materials and methods

### 2.1. Current excitation system

The most recent technique for developing clinical and physiological applications of EIT systems is based on applying a known value of low amplitude current between 0.1–2 mA. It is injected into the subject at different frequencies. Consequently, measuring the resulting multi-frequency potentials around 10 kHz up to a few MHz in order to produce an impedance based image of the biological tissue sample. This design meets standard IEC 60601-1 for biomedical systems in which the maximum amount of current injection must be limited to 10 mA above 100 kHz. The current source topologies are commonly employed instead of voltage sources, due to advantages including predictability of constant current, high output impedance and low noise advantages. For example, current sources were utilized by Kyung Hee (IIRC); Oxford Brookes (OXBACT5); Rensselaer (ACT4); Sheffield (Mk3.5); UCL (Mk2.5 & 1b), and also the Leicester group (Mk3) [11,22,30–35] in developing their EIT or EIS systems.

The key factor or evaluation index in assessing performance and reliability of multi-frequency systems is signal-to-noise ratio (SNR) and its accuracy [36–39], which are directly affected by the output impedance of the current excitation system when measuring the voltage between two points of the sample tissue. In reality, the output impedance of the current source is not infinite. Since the current excitation system is affected by output capacitance  $C_O$ , and output resistance  $R_O$ . The output capacitance effects generated by the current source circuitry and extra capacitance that exists in electrical components in the output signal path such as MUXs, capacitances on the PCB copper tracks, which carry the output signal to other copper areas. These capacitances represented by output capacitance of the source  $C_O$ , stray capacitance  $C_{Stray}$  are in parallel with the load impedance  $Z_{load}$  and output resistance  $R_O$ , as shown in Fig. 2. These unwanted capacitances can significantly reduce the output impedance amplitude of the current excitation system and introduce additional phase shifts at high frequencies.

The most popular current source topologies that are employed in bio-impedance excitation systems are Howland based current source, mirror current source, Wien Bridge circuit, V/I sources and current conveyor source, however, each has advantages and disadvantages [40–44]. In order to improve system performance a new Sussex EIM system was developed. In this study, the improved Howland current

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