

# SIMULATION STUDY ON NON-HOMOGENOUS SYSTEM OF NON-INVASIVE ERT USING COMSOL MULTIPHYSICS

## Article history

Received

28 June 2015

Received in revised form

1 September 2015

Accepted

15 October 2015

Yasmin Abdul Wahab<sup>a</sup>, Ruzairi Abdul Rahim<sup>b\*</sup>, Mohd Hafiz Fazalul Rahiman<sup>c</sup>, Leow Pei Ling<sup>b</sup>, Suzzana Ridzuan Aw<sup>d</sup>, Fazlul Rahman Mohd Yunus<sup>b</sup>, Herlina Abdul Rahim<sup>b</sup>, Naizatul Shima Fadzil<sup>b</sup>, Mohd Zikrillah Zawahir<sup>b</sup>, Juliza Jamaludin<sup>b</sup>, Muhammad Saiful Badri Mansor<sup>b</sup>, Mohd Fadzli Abdul Sahib<sup>b</sup>, Ling En Hong<sup>b</sup>

\*Corresponding author  
ruzairi@utm.my

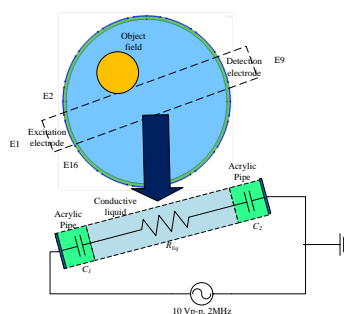
<sup>a</sup>Department of Instrumentation & Control Engineering (ICE), Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang, 26600, Pekan, Pahang, Malaysia

<sup>b</sup>Process Tomography and Instrumentation Engineering Research Group (PROTOM-i), Infocomm Research Alliance, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

<sup>c</sup>Tomography Imaging Research Group, School of Mechatronic Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia

<sup>d</sup>Faculty of Electrical & Automation Engineering Technology, Terengganu Advance Technical Institute University College (TATIUC), Jalan Panchor, Telok Kalong, 24000 Kemaman, Terengganu, Malaysia

## Graphical abstract



## Abstract

The non-invasive sensing technique is one of the favourite sensing techniques applied in the process tomography because it has not a direct contact with the medium of interest. The objective of this paper is to analyse the simulation of the non-homogenous system of the non-invasive ERT using finite element software; COMSOL Multiphysics. In this simulation, the liquid-air medium is chosen as the non-homogenous system. A different analysis of the non-homogenous system in term of the different position of the single air, different size of the single air and the multiple air inside the vessel were investigated in this paper. As a result, the location, size and multiple air inside the pipe will influence the output of the non-invasive ERT system. A liquid-gas medium of non-homogenous ERT system will have a good response if the air is located near the source, the size of the air is large enough and it has multiple air locations inside the pipe.

Keywords: Non-invasive, ERT, COMSOL, non-homogenous

© 2015 Penerbit UTM Press. All rights reserved

### 1.0 INTRODUCTION

Process tomography is used to reconstruct the cross-sectional image of the medium of interest [1]. Process tomography has been applied widely in monitoring and visualizing the industrial applications such as in multiphase flow. The multiphase flow can be either three-phase flow or two-phase flow. The liquid/liquid, liquid/gas, and liquid/solid are the examples of two-phase flow used in the process tomography.

Electrical resistance tomography (ERT) is one the types of process tomography applied in industrial applications such as for liquid/gas flow regime as in Ref. [2–8]. It works based on the conductivity distribution to getting the tomogram of the medium of interest [9]. The common practice of ERT system is by using invasive but non-intrusive sensing technique. The reason of applied this sensing technique is to allow the continuous current flow from excitation electrode through the conductive medium and detected by the detection electrode [10].

Conversely, the metal electrodes of the conventional ERT had a direct contact with the conductive liquid that may result of electrode rust due to the electrochemical erosion and polarization effects. As a result, it may consist of unpredictable measurement error and limits the application of ERT system [11]. As reviewed by Ref. [12], the non-invasive ERT system is believed to overcome the conventional ERT system. The arrangement of the electrodes mounted on the periphery of the pipe wall could help to overcome the invasive sensing technique of ERT system. Thus, the purpose of this paper is to analyse the simulation of the non-homogenous system of the non-invasive ERT system using finite element software; COMSOL Multiphysics.

### 2.0 A SIMULATION MODEL OF NON-INVASIVE ERT SYSTEM

The important of the non-invasive ERT simulation model is how the electrical signal penetrates from excitation electrode through the conductive medium and received by the detection electrode. Figure 1 shows the basic principle setting of non-invasive ERT.

The mathematical model of non-invasive ERT system is obtained by Maxwell's equation. Since the system consists of insulating the pipe and conductive liquid as a major medium in the vessel, the system can be classified as electro quasi-static (EQS). In EQS, the magnetic induction is neglected, and results in the system are influenced by the capacitive effect [13]. In this paper, the simulation of the system is in two-dimensional and thus, the fringe effect caused by the height of the electrodes was neglected. The 2D EQS equation of the sensing field in the non-invasive ERT system can be shown in (1). Where  $\Gamma_i$  and  $\Gamma_j$  represent the spatial locations of  $n$  electrodes;  $i$  and  $j$  are the indexes of excitation and detection

electrodes respectively, and  $V_0$  is the applied voltage to the system.

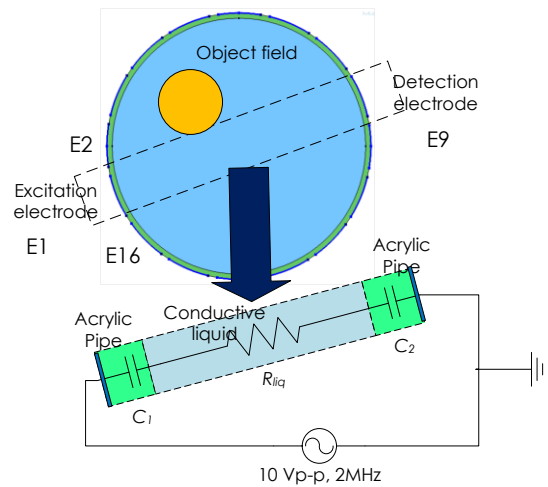


Figure 1 The excitation and detection electrodes of non-invasive ERT

$$\begin{cases} \nabla \cdot (\sigma(x, y) + j\omega\epsilon(x, y))\nabla V(x, y) = 0 & (x, y) \subseteq \Omega \\ V_i(x, y) = V_0 & (x, y) \subseteq \Gamma_i \\ V_j(x, y) = 0 & (x, y) \subseteq \Gamma_j \\ \frac{dV(x, y)}{dn} = 0 & (x, y) \subseteq \Gamma_k, (k \neq i, j) \end{cases} \quad (1)$$

In addition, the current measured based on Ampere's law. If considering the integral form, we can get the total current equation on the surface of the sensing field [14] as (2). The  $I$  is a total current on the surface,  $I_c$  is a conduction current, and  $I_d$  is a displacement current. The  $s$  is the surface of the electrode, and  $ds$  is the discrete element of the electrode.

$$\oint_c \mathbf{H} dl = \oint_s \mathbf{J} ds + \oint_s \frac{d}{dt} \mathbf{D} ds = I_c + I_d = I \quad (2)$$

Based on Figure 1, the system consists of coupling capacitances affected by the insulating pipe used. Alternatively, the coupling capacitance refers to the capacitance between the electrode mounted on the periphery of the insulating pipe wall and the conductive liquid. It is very different if compared to the conventional ERT system, which only considers the resistance between each pair of the measurement electrodes. In that case, the non-invasive ERT system will have total impedance,  $Z_{total}$  of resistance in series with the coupling capacitances as in (3).

$$Z_{total} = R_{liq} - j \frac{1}{2\pi f \left( \frac{C_1 C_2}{C_1 + C_2} \right)} \quad (3)$$

By implementing a certain frequency to the non-invasive ERT system that is high enough to optimise the reactance part of the impedance, Ohm's law can determine the resistance between any pairs of electrodes. The  $R_{ij}$ ,  $V_o$  and  $I_{ij}$  in (4) refer to the value of the resistance, voltage and current for every pair of the electrodes, respectively. The value of the resistance will be used later for the image reconstruction part to determine the conductivity distribution of the medium of interest.

$$R_{i,j} = real \frac{V_o}{I_{i,j}} \quad (4)$$

In this paper, we adopt the finite element model software, COMSOL Multiphysics to model the two-dimensional non-invasive ERT system. The simulation set-up of the non-invasive ERT model can be divided into the following approach:

1. The electric current (ec) module under AC/DC physic is chosen. Also, the frequency domain of equation form was selected as presenting the electro-quasi static electric field. The frequency of the system was set up to 2 MHz.
2. The geometry model of the system drew according to the specific parameters.
3. The material for each domain of the geometry model was defined.
4. The boundary condition of the electrical properties of excitation and detection electrodes was set-up. The excitation electrode, E1 was connected to the voltage source, 10 V and the detection electrodes, E2-E16 were connected to the ground.
5. The extra fine mesh was generated.
6. The sensitivity of the sensor was observed and analysed in terms of current value.

The detail of the parameters used for modelling the non-invasive ERT system can be found in Table 1.

**Table 1** Parameters of simulation model

No	Item	Dimension
1	Electrode width	16 mm
2	Electrode length	200 mm
3	Thickness of pipe	2 mm
4	Outer diameter of pipe	100 mm
5	Electrical Permittivity	$\epsilon_r = 3.45$ (acrylic) $\epsilon_r = 80$ (water) $\epsilon_r = 1$ (air)
6	Electrical Conductivity	$\sigma = 3e-14$ S/m (acrylic) $\sigma = 7e-3$ S/m (water) $\sigma = 0$ (air)

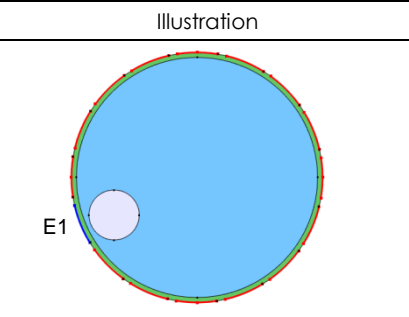
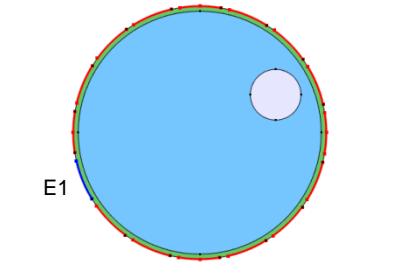
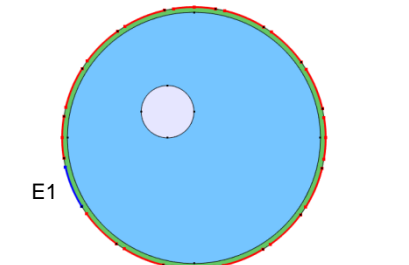
### 3.0 ANALYSIS OF SIMULATION RESULTS OF NON-HOMOGENOUS SYSTEM

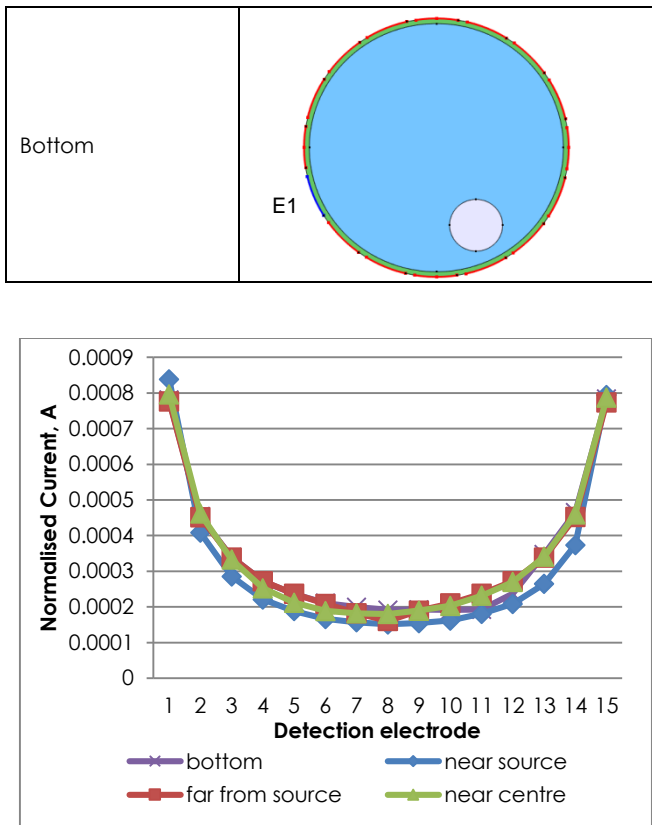
The non-homogenous system that consists of water as a main conductive medium and air as the object field was analysed. The comparative analysis of different position, different sizes and different numbers of air are carried out and the simulation results are described as follow.

#### 3.1 Different Position of Single Air in the Pipe

The different position of air placed in the pipe is illustrated in Table 2. The Figure 2 shows the normalized current distribution for different location of air the pipe. Generally, the normalised current value for the air near source was small if compared to the air placed at the farthest electrode. Simultaneously, the different position of the air will influence the current value at the detection electrode near to that air. It can be seen in Figure 2 for the air located at the bottom of the pipe which is the detection electrode E11 and E12, it gave the small value of normalized current compared to others detection electrodes. Overall, the sensor of non-invasive ERT become more sensitive for the area of non-homogenous near to the source due to the large reflection of current signal before it can travelled and detected by the detection electrodes.

**Table 2** Illustration of single air (20 mm) placed in the pipe

Position	Illustration
Near source	
Far from source	
Near Centre	



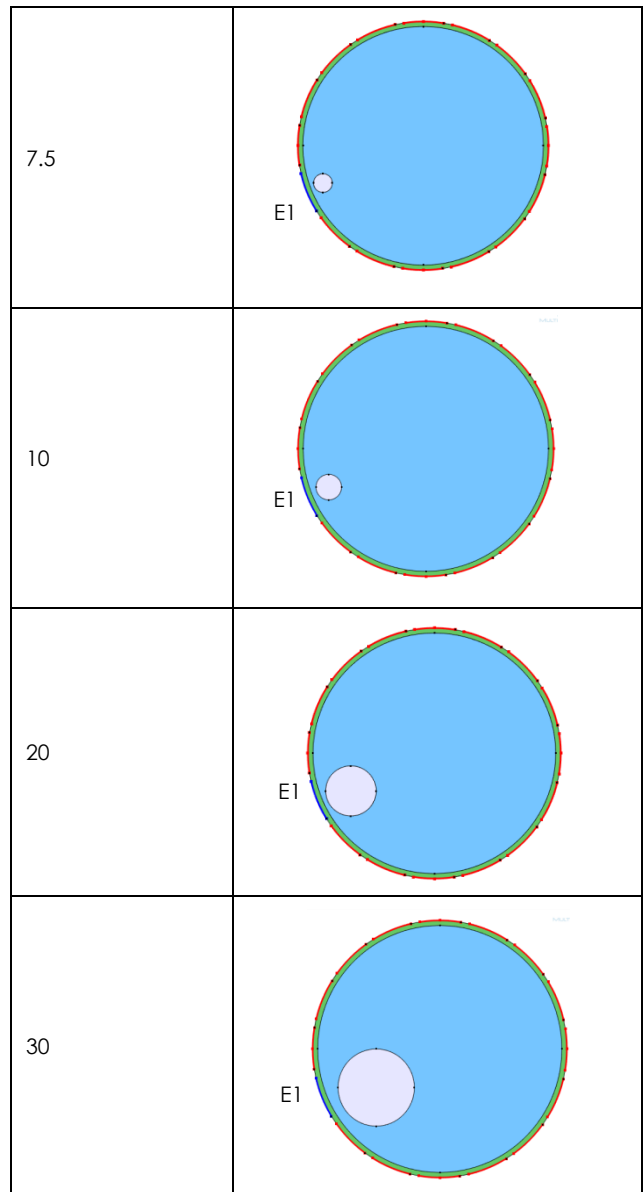
**Figure 2** Normalised current distribution for one air in different position

### 3.2 Increment Size of Single Air

The analysis of the increment size of air located near the source was also investigated as shown in Table 3. The size of air in term of diameter chose randomly starting from 2.5 mm in diameter till 30 mm in diameter.

**Table 3** Illustration of the increment size of single air placed in the pipe

Size of air (Diameter, mm)	Illustration
2.5	



Based on Figure 3, the normalized current distribution of air fell with the rise of the diameter of air. However, when the size of air is too small, the change of normalized current was not significant. Consequently, there is better quality of tomography when the size of air in the non-homogenous system becomes large enough.

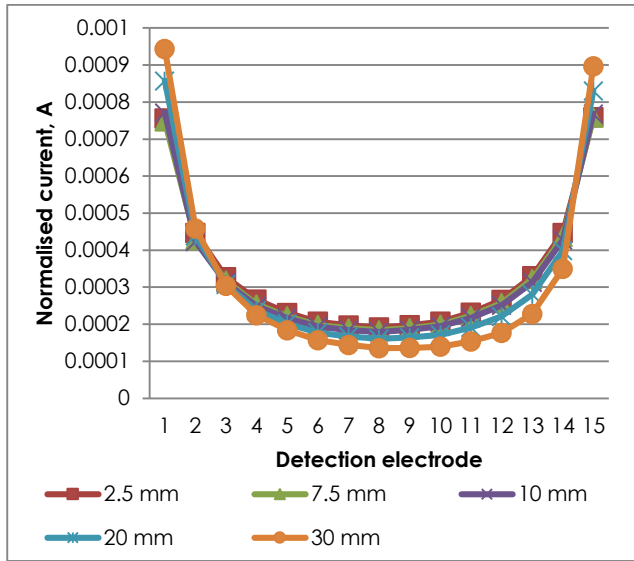


Figure 3 Normalised current distribution for one air in different size

3.3 Different Number of Air inside the Pipe

In the same way, the homogenous system (full liquid) was compared with the two and four numbers of airs located in the pipeline. The reason of doing this analysis is to do the further investigation of the changes of the non-invasive ERT system. The illustration of the homogenous (full liquid) and non-homogenous in term of surface current line and electric field is shown in Table 4. Noted that, the size of the air used is 20 mm in diameter.

As seen in Table 4, the trend of the surface current line and electric field of the non-invasive ERT system changed with the different numbers of air inside the pipe. Furthermore, as shown in Figure 4; the normalized current value also fell if compared to the homogenous system with the increasing of the numbers of air. It was also depending on the position of the air inside the vessel. Additionally, if the air placed near to the source electrode, the normalized current value becomes higher at the adjacent detection electrodes near the source if compared to the homogenous system, while it becomes small at other detection electrodes. Again it is due to the reflection of the electricity becomes higher when it was placed near to the source before it can be received by the detection electrode.

Table 4 Illustration of surface current line and electric field of the non-invasive ert system

Surface Current line	Electric field

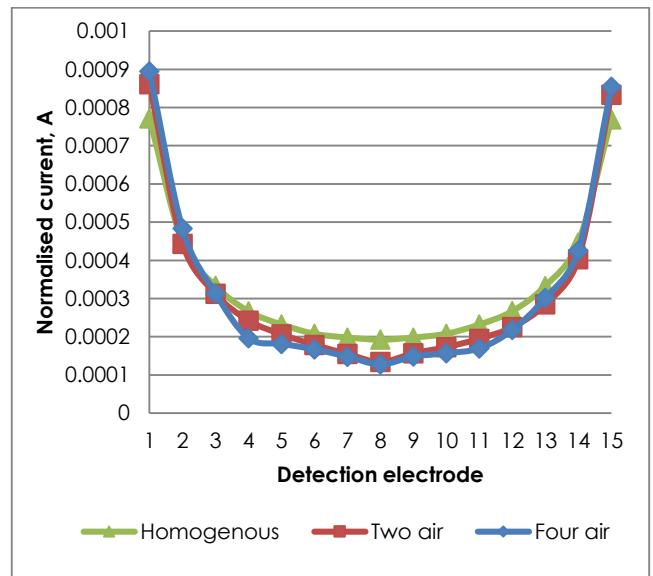


Figure 4 Normalised current distribution for different numbers of air



## 4.0 CONCLUSION

To conclude, the objective of this paper had been achieved. The simulation of non-homogenous of non-invasive ERT system which is the water-air regime inside the insulating pipe had been investigated and analysed. It is proven that the location of air as obstacle inside the vessel will influence the value of the normalised current. If the air near the source, the sensor will have a better response compared to the farthest air from the source. A large value of the normalised current will appeared at the adjacent detection electrodes near the source compared to the other detection electrodes. Moreover, the non-invasive ERT will have a better quality when the size of obstacle is a large enough. Furthermore, if the system consists of a multiple air, the value of the normalised current becomes small compared to the homogenous system. A different medium of the non-homogenous system will have a different performance of the non-invasive ERT system. Simultaneously, it is believed that the simulation result could be applied for the chemical application such as for monitoring and visualization of the performance of the bubble column.

## Acknowledgement

The authors would like to thank the Ministry of Higher Education and University Malaysia Pahang for funding the study. Very special thanks go to the Universiti Teknologi Malaysia (research university grant 08h31, PY/2015/04458, and PY/2015/04567) and PROTOM research group for their generous support and cooperation

## References

- [1] S. Ridzuan Aw, H. Arshad Amari, J. Pusppanathan, M.H. Fazalul Rahiman, Y. Abd Wahab. 2011. Initial Study on Ultrasonic Tomography for Multiphase Flow Application. *Jurnal Teknologi*. 54 (Sains & Kej.): 267–288.
- [2] W. Yenjaichon, J.R. Grace, C. Jim Lim, C.P.J. Bennington. 2013. Characterisation of gas mixing in water and pulp-suspension flow based on electrical resistance tomography. *Chemical Engineering Journal*. 214: 285–297. doi:10.1016/j.cej.2012.10.057.
- [3] M. Sobri, A. Ahmad, M. Irwan, S. Jantan. 2013. ERT Visualization of Gas Dispersion Performance of Aerofoil and Radial Impellers in an Agitated Vessel. *Jurnal Teknologi*. 64(5): 75–78.
- [4] A.D. Okonkwo, M. Wang, B. Azzopardi. 2013. Characterisation of a high concentration ionic bubble column using electrical resistance tomography. *Flow Measurement Instrumentation*. 31: 69–76. doi:10.1016/j.flowmeasinst.2012.10.005.
- [5] X. Deng, G. Li, Z. Wei, Z. Yan, W. Yang. 2011. Theoretical study of vertical slug flow measurement by data fusion from electromagnetic flowmeter and electrical resistance tomography. *Flow Measurement Instrumentation*. 22 : 272–278. doi:10.1016/j.flowmeasinst.2011.03.007.
- [6] C. Yang, H. Wang, Z. Cui. 2012. Application of Electrical Resistance Tomography in Bubble Columns for Volume Fraction Measurement. *IEEE International Instrumentation and Measurement Technology Conference (I2MTC 2012)*.Graz. 13-16 May 2012. 1199 – 1203.
- [7] J. Kourunen, T. Niifti, L.M. Heikkinen. 2011. Application of three-dimensional electrical resistance tomography to characterize gas holdup distribution in laboratory flotation cell. *Mineral Engineering*. 24: 1677–1686. doi:10.1016/j.mineng.2011.09.004.
- [8] H. Jin, S. Yang, G. He, M. Wang, R.A. Williams. 2010. The effect of gas-liquid counter-current operation on gas hold-up in bubble columns using electrical resistance tomography. *Journal of Chemical Technology & Biotechnology*. 85: 1278–1283. doi:10.1002/jctb.2428.
- [9] G.P. Lucas, J. Cory, R.C. Waterfall, W.W. Loh, F.J. Dickin. 1999. Measurement of the solids volume fraction and velocity distributions in solids-liquid flows using dual-plane electrical resistance tomography. *Flow Measurement Instrumentation*. 10: 249–258. doi:10.1016/S0955-5986(99)00010-2.
- [10] M. Sharifi, B. Young. 2013. Electrical Resistance Tomography (ERT) applications to Chemical Engineering. *Chemical Engineering Research and Design*. 91: 1625–1645. doi:10.1016/j.cherd.2013.05.026.
- [11] B. Wang, Y. Hu, H. Ji, Z. Huang, H. Li. 2012. A novel electrical resistance tomography system based on C4D technique. *IEEE International Instrumentation and Measurement Technology Conference (I2MTC 2012)*. Graz. 13-16 May 2012. 1929–1932. doi:10.1109/I2MTC.2012.6229290.
- [12] Y. Abdul Wahab, R. Abdul Rahim, M.H. Fazalul Rahiman, S. Ridzuan Aw, F.R. Mohd Yunus, C.L. Goh, et al. .2015. Non-invasive process tomography in chemical mixtures – A review. *Sensors Actuators B Chemical*. 210: 602–617. doi:10.1016/j.snb.2014.12.103.
- [13] D.K. Kalluri. 2013. *Principles of electromagnetic waves and materials*. New York: CRC Press.
- [14] F.T. Ulaby, E. Michielssen, U. Ravaioli. 2010. *Fundamentals of applied electromagnetics, 6th ed.* . Boston: Prentice Hall.