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A Simulation of Electric Field Distribution in Circular Resonator with Rectangular and Circular Waveguide Applicators

Navapadol Kittiamornkul
School of Biomedical Engineering
Christian University of Thailand
Nakhonpathom, Thailand
navapadol@gmail.com

Kamon Jirasereeamornkul and Kosin Chamnongthai
Department of Electronics and Telecommunication Engineering
King's Mongkut University of Technology Thonburi
Bangkok, Thailand

Supaporn Kittisin
Technology of Information System Management
Mahidol University
Nakhonpathom, Thailand

***Abstract*— This paper presents a simulation of electric field which resonates in circular resonator that has two waveguide applicators. This paper aims to make the electric field covered mostly in the resonator in order to apply in many applications. This simulation resonator is designed to resonate the electric field at 2.45 GHz specifically that can be applied in moisture measurement process. The Computer Simulation Technology (CST) is used to create the 3D simulation of electric field in the designed resonator. The properties of soil which use as sample are loaded to simulated resonator in order to predicate the resonator performance. The simulation results denote contour of electric field with soil sample inside. This result contour can be shown by graphs of Probability Density Function (PDF) that can be used to evaluate the probability of electric field distributions in soil sample that is contained in the proposed resonator. The result shows that this resonator can distribute electric field mostly comparing with conventional resonator which is circular resonator. So, according to the simulation result, this resonator is appropriate to apply to moisture measurement application**

Keywords*— *electric field, simulation, resonator, isosurface, contour

I. Introduction

In agriculture countries, soil has very importance for plant. If soil has high quality, agriculture plant will increase highly. One of the important factors of soil quality is moisture content. The moisture content of plant soil necessary needs to be known in order to make plant efficiently.

The moisture measurement is divided widely into 2 techniques that are destructive technique and nondestructive technique. In destructive technique, the selected sample is dried in order to measure its weight before and after drying proposed by Reeb, James E [1]. Thus, this technique takes very long time, because it cannot use high temperature while drying. Moreover, the selected samples is destroyed by heating.

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For nondestructive moisture measurement, there are many technique which can used to determine granular material like soil sample which proposed in this paper. In resonator technique, the microwave resonator determination of moisture and mass for a soybean seed was presented by W. Kraszewski and O. Nelson [2]. A microwave simulation using cavity resonance in order to measure sample moisture and mass was determined. In cavity design for microwave resonance for a granular characterization of sample mass and moisture, E. Chaix et al. [3] proposed a technique of circular resonant cavity using 11.5 GHz of frequency. The simulation of mass, moisture and density of a granular sample was measured. The transmission technique for moisture determination of wheat using an artificial neural network (ANN) was proposed by Philip G. Bartley et al. [4]. The ANN was used to determine the density-independent moisture content using a coefficient of transmission. For a planar resonator sensor of moisture measurement, Jerzy Skulski and Bogdan A. Galwas [5] proposed the planar ring resonator for a sensitive detector of moisture content in dielectric material. A cylindrical resonating cavity in TM010 Mode for moisture measurement was proposed by Emmanuelle Bourdel et al [6]. This model of cylindrical resonator indicated the moisture content and the specific mass from the complex permittivity. In a microwave attenuation measurement for grain moisture content at 10.5 GHz, the horn antennas was used to measure many kind of granular such as Korean short-grain rough rice, brown rice and barley proposed by Ki-Bok Kim et al. [7]. For the principles of microwave moisture measurement in grain, the techniques of moisture measurement including electric moisture meter were discussed by Stuart O. Nelson et al. [8]. In the instrumentation of measurement characteristics of a wheat grain kernel, the microwave techniques and a gas displacement method used to measure the moisture, mass, volume, and the density of a wheat grain kernel described by Hong S. Chua et al. [9]. In the nondestructive sensing technique of the physical properties of granular materials using microwave permittivity measurement proposed by Samir Trabelsi and Stuart O. Nelson [10], the dielectric of wheat, corn, and soybean were determined by measurement of the transmission coefficient in free space in the frequency range between 2 to 13 GHz. In wireless application using the dielectric resonator antenna (DRA) for proposed by M.S.M. Aras et al. [11], the description of a simple design on dielectric resonator antenna (DRA) using disk shape for wireless application was presented. In the analysis of a continuous fluidized-bed microwave rice kernel drying system presented by C. Sangdao and M. Krairiksh [12], an analysis of a continuous fluidized-bed microwave rice kernel drying system using perpendicular slots of applicator on a concentric cylindrical cavity excited by perpendicular waveguides was proposed. In a system of microwave cylindrical cavity resonator for granular material dielectric measurement using waveguide transmitters proposed by Kittiamornkul N. et al.[13], this paper presented the design of cylindrical cavity, and the electric field distribution was specifically demonstrated by 2.45 GHz. In the effect to the distribution of electric field inside the resonator proposed by Kittiamornkul N. et al. [14], this paper presented the electric field distribution of simulation samples which were solid and grain forms inside the designed resonator, and the computer simulation was used in order to determine the electric field distribution for each form of sample.

This paper proposes simulation of electric field resonated in circular resonator that has waveguide applicators. The properties of soil are loaded as sample in order to predict the electric field inside. The results are comparing with circular resonator which is the conventional resonator. In this paper, the basic theory, simulation, simulation results and conclusion are described in next section respectively.

II. Basic Theory

A resonator [15] is a surrounded region using conducting wall. A resonator technique is one of the technique used the dielectric measurement. This technique has advantage for material highly that changes its shape according to its container in application. In the resonant application, the perturbation theory is used to determine electric field strength in order to apply to moisture measurement. The perturbation theory is expressed shown as follows:

$$\frac{\Delta f}{f} = \frac{-(\varepsilon - 1)\int_{V_s} E_0 E_s dv}{2\int_{V_0} E_0^2 dv} \qquad (1)$$

where Δf is difference of frequency in resonator which is with and without sample inside, f is resonant frequency of empty resonator, E_0 is electric field strength in empty cavity and E_s is electric field strength inside sample.

III. Simulation

According to [14], the circular resonator with waveguide applicators proposed by authors is designed based on electromagnetic theory. The concept of this paper is a combination of ordinary resonator with waveguide applicators in order to gain more electric field distribution. Therefore, this resonator consists of ordinary resonator as main resonator and waveguide applicators. Since, currently, ordinary resonator has two types which are rectangular resonator and circular resonator, in this paper, a circular resonator is selected as main resonator. Because it has no sharp corners, the electric field distributes better than rectangular.

When the main resonator is selected, the waveguide applicators which are used in this paper need to be concerned. According to [14], the rectangular waveguide is used as side applicator, because it can transmit the electromagnetic energy to the main resonator which is circular resonator. Both ends of main resonator use circular waveguides as additional transmitter and receiver to detect the output electric field. The draft of the whole resonator is shown as follows:

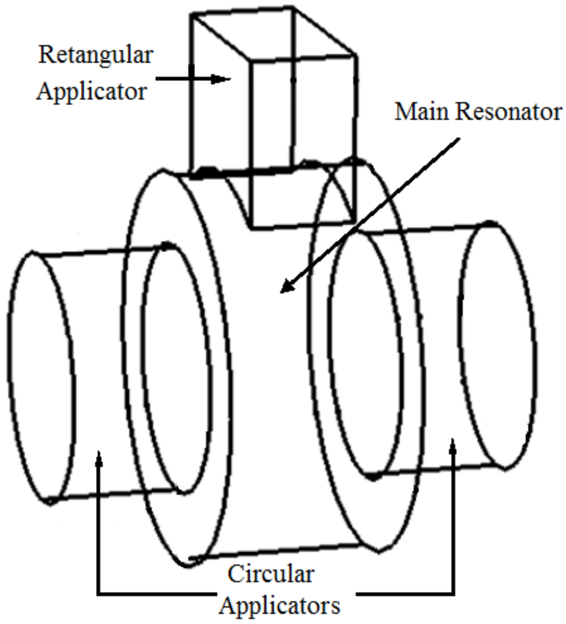

Fig. 1. A draft of circular resonator with waveguide applicators

The dimension of the proposed resonator can be defined by the following subsection.

A. *Main resonator design*

The main resonator which is circular resonator is designed by the mode chart [15] that is a plot of the formula relating resonant frequency to the mode, shape and dimension. The equation is shown by

$$(fD)^2 = A + Bp^2\left(\frac{D}{L}\right) \qquad (2)$$

where A is a constant depending upon the mode, B is 0.34799×10^8 for air at 25°C, p is number of half wavelengths along the resonator, f is resonant frequency, Mc per sec, L is resonator length, inch, D is resonator diameter, inch.

B. Circular waveguide applicator design

The radius of circular waveguide is calculated from the Bessel's function [15]. For TE_{1n} mode, the Bessel's function is shown in the following equation.

$$p'_{mn} = \frac{2\pi a}{\lambda} = 1.84, 5.33, 8.54\ldots \quad (3)$$

where, p'_{mn} is the first derivative of nth root of the approximate curve of the Bessel's function, a is circular waveguide radius, λ is wavelength.

The cutoff frequency of TE mode circular waveguide modes is shown by

$$f_c(TE_{mn}) = \frac{p'_{mn}}{2\pi a\sqrt{\mu\varepsilon}} \quad (4)$$

where, f_c is cutoff frequency of TE mode of circular waveguide, μ is air magnetic constant (1.26×10^{-6} H/m), ε is 8.854×10^{12} F/m.

C. Rectangular waveguide applicator design

The dimension using cutoff frequency of a rectangular waveguide are calculated as follows:

$$(f_c)_{mn} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (5)$$

Where, a is waveguide width, b is waveguide high, m is 0, 1, 2… and n is 0, 1, 2…

Since the dimension of each part is ready, the computer simulation technology (CST) creates the simulation of the proposed resonator shown as follows:

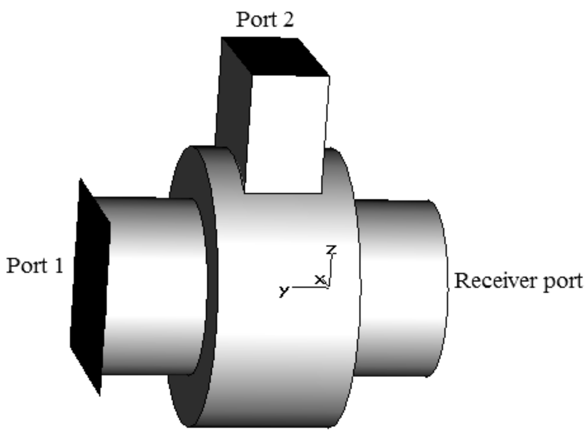

Fig. 2. The completed resonator created by CST

According to Fig. 2, the simulation resonator is set to have three ports which are Port1, Port2 and Receiver port. Port1 and Port2 are set as electromagnetic generator that generates 2.45 GHz of frequency. Receiver port is set to be electromagnetic detector ion order to detect the output electromagnetic signal. All of the resonator walls are set to be conductor in order to reflect the electric field resonantly.

IV. SIMULATION RESULTS

This section will describe the simulation of the electric field distribution inside the resonator. The distribution of electric field from proposed resonator will be compared to the conventional resonator which is circular resonator.

In electric field simulation, the computer specification whish used in this paper is shown in Table I.

TABLE I. COMPUTER SPECIFICATION OF SIMULATION

System	Specification
Central Processing Unit (CPU)	Intel Core i5 CPU M520
Clock Speed	2.40 GHz
Random Access Memory (RAM)	4.00 GB DDR3
Operating System (OS)	Windows 10

According to Table I, the simulation software called Computer Simulation Technology (CST) in the module of Microwave Studio was utilized to observe the electric field simulation inside the resonator.

Moreover, the properties of soil are loaded to main resonator in order to observe the electric field distribution. The properties of soil that are loaded are heat conductivity (k_t), heat capacity (C_m), dielectric constant (ε_r), density (ρ_m) and conductivity (σ). The properties of soil are shown in following table.

TABLE II. ELECTRIC FIELD DISTRIBUTION RESULTS

Properties	Value	Unit
Heat conductivity	0.097	(W/m•K)
Heat capacity	1,800	(KJ/KgºC)
Density	1.347	(g/cc)
Dielectric constant	4.0	-
Conductivity	10^{-3}	S/m

After soil properties shown in Table II are loaded to main resonator, the distribution of electric field inside the resonator in term of contour is generated by simulation software. The cross-section view of electric field distribution of each waveguide applicators in the main resonator was shown in the following figures.

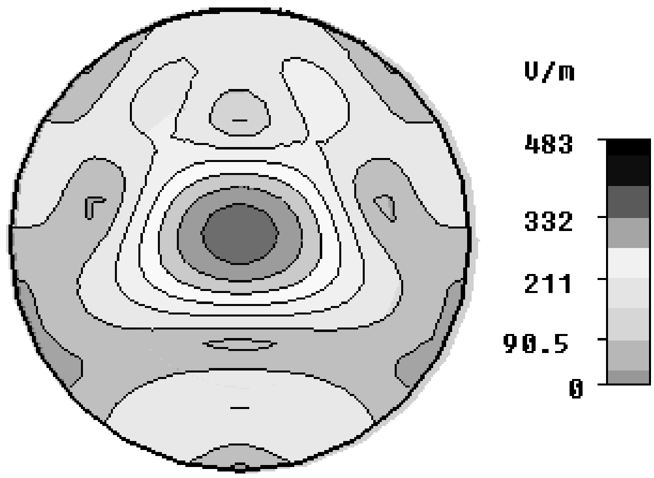

Fig. 3. The electric field distribution of soil sample in the designed resonator which is sent by port 1

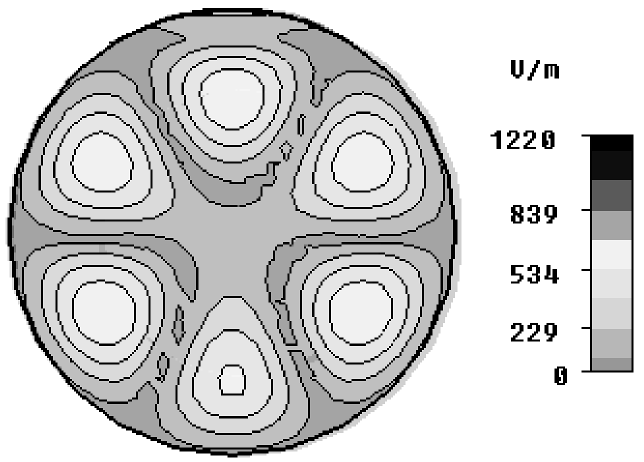

Fig. 4. The electric field distribution of soil sample in the designed resonator which is sent by port 2

According to Fig. 3 and Fig. 4, the distribution of electric field in the part of main resonator which has soil sample inside is simulated. The results will be compared with circular resonator that has soil sample inside also which is conventional resonator in order to evaluate the performance of the proposed resonator.

Therefore, the circular resonator designed to resonate at 2.45 GHz which had soil sample inside was created and illustrated in Fig. 5.

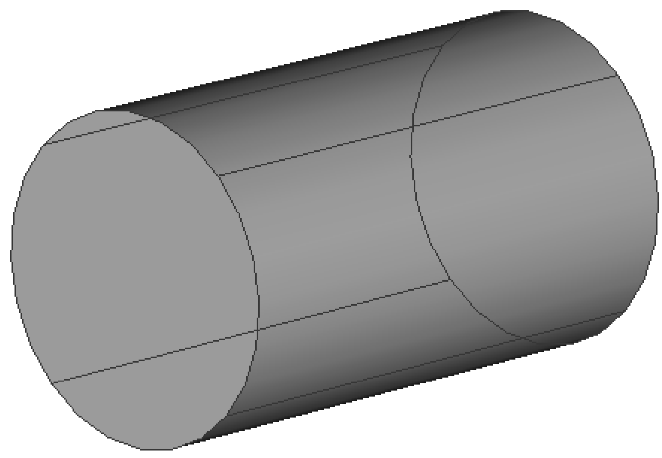

Fig. 5. The circular resonator which is designed to resonate at 2.45 GHz

According to Fig. 5, the circular resonator which is the conventional method is designed to resonate at 2.45 GHz in order to compare the performance of electric field distribution.

The properties of soil sample are also loaded to the circular resonator the same as proposed resonator in order to observe the distribution of electric field and evaluate the performance of electric field of the proposed resonator. The contour of electric field distribution which has soil sample inside of circular resonator is shown in Fig. 6.

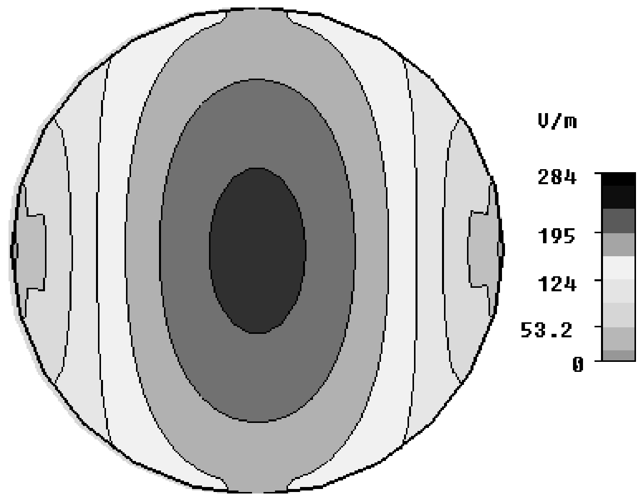

Fig. 6. The electric field distribution of soil sample in conventional resonator

According to Fig. 3, 4 and 6, the electric field distribution detected by receiver port generates the plots of probability density function of electric field distribution in the resonator against the electric field intensity with soil sample in the resonator as shown in Fig. 7.

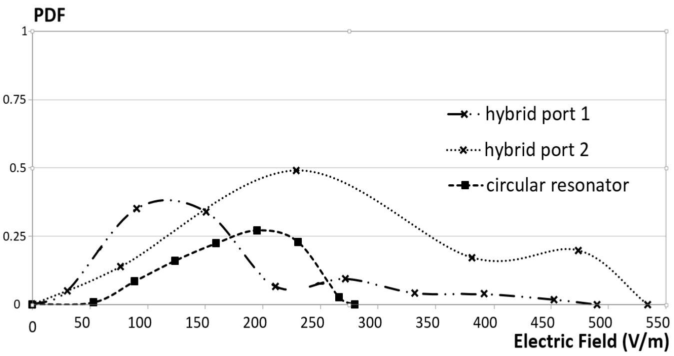

Fig. 7. The plots of PDF against Electric field in the resonator with soil sample inside

According to Fig. 6, the probability density function (PDF) from electric field contour illustrated in Fig. 3, 4 and 6 of proposed resonator is compared with circular resonator which is conventional resonator. The plots show the electric field intensity also. Since higher PDF and higher electric field intensity are the best resonator, the plots of proposed resonator has higher PDF than circular resonator, and the average of electric field intensity has also higher than circular resonator too.

The conclusion of results is shown in following table.

TABLE III. THE HIGHEST PDF OF EACH RESONATOR

Resonator	The highest PDF	Electric field intensity
Circular resonator	0.271	195 V/m
Proposed resonator port 1	0.351	90.5 V/m
Proposed resonator port 2	0.491	229 V/m

According to Table II, the proposed resonator can resonate the electric field higher than circular resonator in each port. At the highest PDF the proposed resonator also resonate higher electric field intensity, too. It means that the proposed resonator can distribute the electric field more covering area than circular resonator, and gain more electric field intensity.

Although, Port 1 of proposed resonator has lower electric field intensity than circular resonator, the average of electric field intensity of Port 1 and Port 2 is still higher than the circular resonator.

Since the electric field intensity should be more than 100 V/m in order to use in moisture measurement application, this paper can distribute more than 100 V/m mostly in the resonator. Therefore, this type of resonator is suitable to use in moisture measurement application.

V. CONCLUSION

This paper presents a simulation of electric field distribution in the circular resonator combined with rectangular and circular waveguide applicator. The simulation of resonator is create by computer simulation technology (CST), and the simulation of electric field is run by CST also.

The results show that the proposed resonator has higher PDF than circular resonator which is conventional resonator. It can indicate that the proposed resonator can distribute the electric field mostly in the resonator, and it has very low nonelectric field area. It is not only the higher PDF, but it is also higher electric field intensity that good resonator should have. From results, one of the proposed resonator ports has lower electric field intensity than circular resonator, but the average of electric field intensity of proposed resonator still higher than the circular resonator.

Moreover the average electric field intensity of proposed resonator has higher than 100 V/m, therefore, this resonator is appropriate to apply in moisture measurement application.

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