Simulation of Microwave Non Destructive Testing Environment (MNDT) To Determine Dielectric Constant of Concrete Using Waveguide Port Approximation at 8-12GHz (X-Band) in CST MICROWAVE STUDIO

Mohd Hanafi bin Mohd Nasir
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
E-mail: mrhanafinasir@yahoo.com

Abstract- **The main objective of this research is to determine the dielectric constant of a concrete block using the CST Microwave Studio at frequency 8-12GHz(X-Band) and thus compare the result from the real environment measurement setup. MNDT is a method used to determine the characteristic of a material without changing its natural properties. Concrete block has an ideal characteristic of dielectric constant which is in between 2.1 – 2.3. Therefore, this value will be the benchmark in this project. Besides the dielectric constant, the behaviour of wave propagating through a Gaussian Optic Lens antenna is also studied and how the wave penetrates the concrete block is also focussed on. The simulations are done using the CST Microwave Studio software and MNDT environment is modelled accordingly to get the results. There are 10 concrete blocks which are simulated in this research. The most flexible solver is chosen which is the transient solver and with this solver we can obtain the broadband frequency behaviour of the simulated device from only one calculation run. All results from simulation are observed and discussions are made from the result. From the simulation, the average value of dielectric constant is 2.5874 and the average percentage error between simulation and real measurement is 0.24754%**

Keywords - Computer Simulation Technology (CST), Microwave Non Destructive Testing (MNDT), 8-12GHz (X-Band), Concrete Block, Dielectric Constant and Transient Solver.

I. INTRODUCTION

Microwave non Destructive Testing is a contactless technique which can be implemented by measuring electrical parameters such as complex permittivity and complex permeability as a function of frequency and temperature. Some of the advantages of applying this method are saving both money and time in product evaluation, troubleshooting, and research. In this research, the environment of the MNDT techniques were simulated using CST Microwave and S-parameter results were observed. From the results, dielectric constant of the simulated concrete block can be determined. This simulation is basically done to show that the value from real measurement setup and value from simulation are the same or almost the same. Therefore, an appropriate design was taken into consideration and in this simulation, waveguide port approximation is used. From the simulation, the wave propagation can also be observed.

A. MNDT

Microwave non Destructive Testing can be performed in many ways such as free space and rectangular or coaxial waveguide. This method is widely used for geometrical sized and quality control of different material such as liquids, polymers, fibreglass, ceramics, water etc. This quality control process may be performed either during the fabrication of product which target to change some technological parameters or after the fabrication to determine the quality of a product. Microwave radiations are highly directive and because any of the short wavelengths involved, the devices used often are very compact. [1]

B. Free Space Measurement Method (FSMM)

In the real environment, free space method is applied in order to determine the electromagnetic properties of any material. Free Space Microwave Measurement (FSMM) consists of a pair of spot-focusing horn lens antennas GOA antennas, coaxial cables and WILTRON 37269B Vector Network Analyzer (VNA). The transmitting and receiving antennas are spot focusing horn lens antennas which are laid on a large table (1.83m by 1.83m). The spot-focusing antennas are connected to the two ports of S-parameter test set by using circular-to rectangular waveguide adapters, rectangular waveguide to coaxial line adapters (Agilent K281C Coaxial Waveguide Adapter) and precision coaxial cables. The S-parameter measurements in free space were measured by WILTRON 37269B Vector Network Analyzer.

C. *CST Microwave Studio*

This project will concentrate on the simulation of the environment of a Microwave non Destructive Testing setup where all parameters are taken into consideration and any losses are eliminated. Simulations are done to study the wave behaviour of a Gaussian Optic Lens antenna when propagating through a concrete block. From the transmission coefficient, dielectric constant of the materials can be extracted. All simulations of the environment are done using CST Microwave Studio.

CST Microwave Studio is the most efficient program to deal with electromagnetic problems in the high frequency range. The program is especially suited to the fast, efficient analysis and design of components like antennae (including arrays), filters, transmission lines, couplers, connectors (single and multiple pin), printed circuit boards, resonators and many more. Since the underlying method is a general 3D approach, CST MICROWAVE STUDIO® can solve virtually any high frequency field problem. [2]

With the simulation, all inaccuracies in dielectric measurements using free space method can be reduced. Normally inaccuracies are due to 1) diffraction effects at the edges of the sample and 2) multiple reflections between the two horns via the surface of the sample [3]

D. *Concrete Blocks*

In this project, concrete blocks were chosen to be the research specimens. Concrete is a heterogeneous mixture composed of water, cement powder, sand (fine aggregate), rocks of various size or grade (coarse aggregate), and air (porosity). Water and cement powder chemically combine into a cement paste binder which, in due curing time (28 days), produces concrete with its specified compressive strength. Compressive strength of concrete is strongly influenced by its water-to-cement (w/c) ratio as well as its coarse aggregate-to-cement (ca/c) ratio. [4] It is well known that concrete block has its own strength depending on the mixture of the concrete. Besides classifying the concrete block strength by its compressive strength, another efficient way to classify the strength of concrete is by its dielectric constant. For a typical concrete block, the value of the dielectric constant is between 2.1 to 2.3 and this value will be the benchmark for the analysis of this project. [5] The dimension of concrete block used in the simulation is 10cm x 10cm x 10cm.

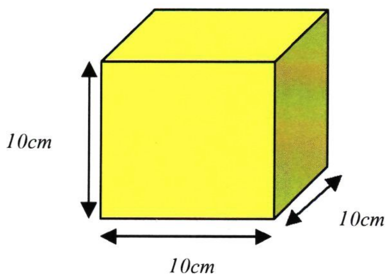


Figure 1: Concrete Block Dimension

III. THEORY

Simulation of the FSMM must consist of the basic mechanism of the antenna itself. Only the Gaussian Optic Lens antenna has to be modelled in the CST Microwave Studio and also the sample.

A. *Lens Antenna*

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape. [6]

B. *Gaussian Optic Lens Antenna*

Gaussian optic lens antennas are usually designed for radio astronomic purposes; they combine a conical corrugated horn and a dielectric lens. Such antennas are now used in the telecommunication domain for either terrestrial or spatial applications. This is due to the need of higher frequencies from 40 GHz to the millimetre waves. They are also studied for personal vehicle security radar. [7] A basic Gaussian lens antenna consists of two main parts which is the horn antenna and dielectric lens.

C. *Waveguide port approximation*

This research is concentrating on the plane wave which travels through the concrete block. Therefore, an approximation in the simulation design is taken into consideration where waveguide ports were applied. This method is closely similar to the second method of MNDT testing which is the rectangular waveguide method. Waveguide ports represent a special kind of boundary condition of the calculation domain, enabling the stimulation as well as the absorption of energy. This kind of port simulates an infinitely long waveguide connected to the structure. The waveguide modes travel out of the structure toward the boundary planes thus leaving the computation domain with very low levels of reflections. [8] Therefore, in this study, waveguide port approximation is chosen since it provides very low reflections and behaves almost exactly the same as a plane wave.

D. *Model Setup*

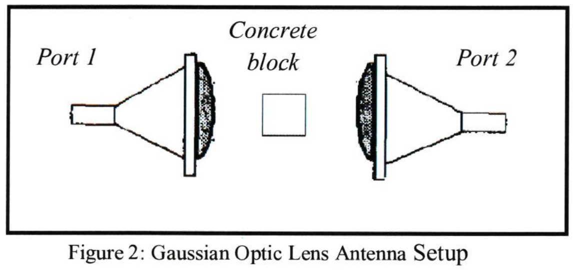


Figure 2: Gaussian Optic Lens Antenna Setup

In the simulation, only the main parts of the environment are taken into consideration of the design. Main mechanism of MNDT environment includes the Gaussian optic lens antenna and the concrete block. The main mechanisms are dimensioned using the actual measurement of the antenna and concrete blocks. Other parameters are set in the CST Microwave studio itself. For the concrete strength determination, only the concrete blocks are taken into consideration in order to avoid multiple reflections. Waveguide ports are placed at both end of the concrete block to get the S21 parameters for the travelling wave.

E. Dielectric Constant

Dielectric constant is also known as the relative permittivity, ε_r, is defined as the ratio of the permittivity of the electric to that of free space. ε_r, has no dimension. [9]

The electric constant was one of the characteristics of board material, or laminates that determine how efficiently the energy passes via the board. The term electric constant comes from the fact that the material used for microwave must be uniform in construction. Uniform construction means that the dielectric construction and thus its effect must remain constant. It also indicates how close the material being discussed comes to free space conditions. The tolerance on the dielectric constant tells how close these conditions are held throughout the material. The dielectric constant is the real part of the relative complex permittivity and is denoted by ε_r'. The real dielectric constant reflects the amount of polarization of the material. [10]

F. Transient Solver

The time domain solver calculates the development of fields through time at discrete locations and at discrete time samples. It calculates the transmission of energy between various ports and/or open space of the investigated structure.

The fields are calculated step by step through time by the "Leap Frog" updating scheme. It is proven that this method remains stable if the step width for the integration does not overcome a known limit. This value of the maximum usable time step is directly related to the minimum mesh step width used in the discretization of the structure. Therefore, the denser the chosen grid, the smaller the usable time step width. [11]

III. SCOPE OF WORK

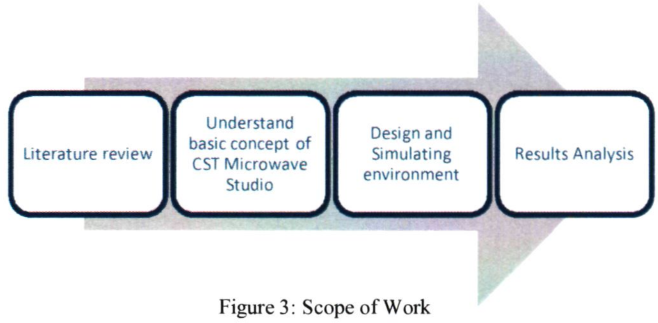
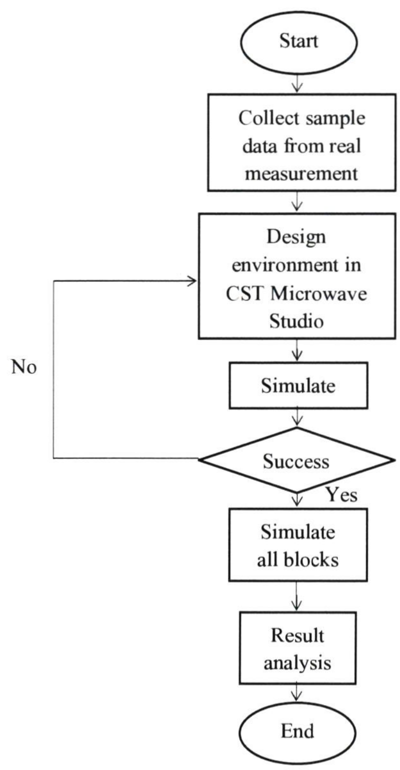


Figure 3: Scope of Work

Upon the completion of this research, four main stages are gone through. The first stage is literature review where all information about the measurement are gathered and studied. Once all basic design requirements are understood, the next stage will be the stage where the function of CST Microwave Studio is discovered. Basic parameters setup need be fully understand in order to get the best results of the simulation. At the design and simulating stage, all design measurements are taken into considerations. The environment must behave exactly as the real environment. After going through all the simulation for the concrete blocks, the result is analyzed and comparisons are made between the real measurement and the simulation.

IV. METHODOLOGY

The flowchart below can summarize the flow of this research.



V. SIMULATION SETUP

The simulations of this research are divided into two types. First setup is to study the behaviour of the travelling wave through the Gaussian optic lens antenna and the next setup is to study the strength of the concrete blocks.

A. Gaussian optic lens antenna setup

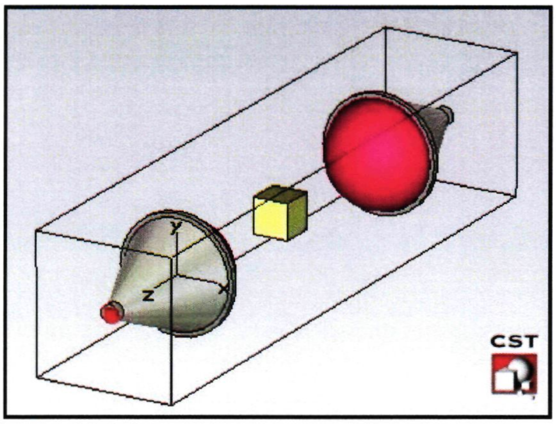


Figure 4: GOLA Setup in CST Microwave Studio

The setup as shown above in the figure is for the purpose to study the electromagnetic wave travelling from the port through the lens. All measurements are according to the specification taken from the datasheet. Lenses are position 304.8mm away from the sample where sample has the dimension of 100mm x 100mm x100mm. The material used for the lens is Rexolite which has a dielectric constant value of 2.53. The simulation was done at frequency range of 8-12GHz(X-Band).

B. Dielectric constant for concrete block setup

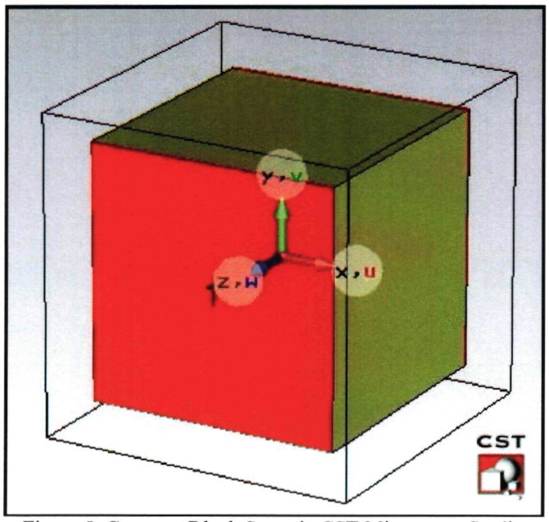


Figure 5: Concrete Block Setup in CST Microwave Studio

From the figure above, it is shown that port one and port two are placed back to back at the surface of the concrete block. The dimensions for the concrete blocks are the same as the dimension in the previous setup. In this simulation, the concrete dielectric constant can be observed from the S-parameter value. Dielectric constants of concrete blocks are extracted using the program in FORTRAN.

VI. RESULTS AND DISCUSSION

From the simulation, two results can be observed which is first the electromagnetic wave travelling in the environment and secondly the dielectric constants of each concrete blocks. Below are the results for the travelling wave in the MNDT environment simulation.

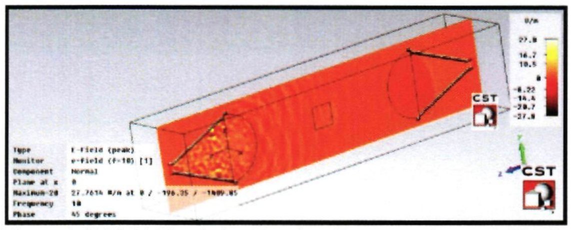


Figure 6: E-Field Simulation Result at Frequency Range 8-12GHz

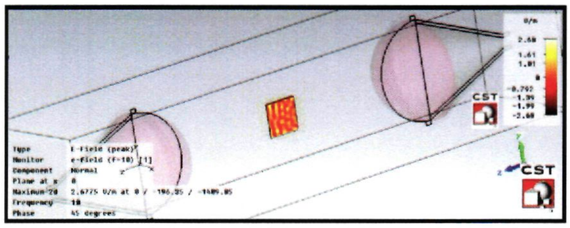


Figure 7: E-Field Simulation Result at Concrete Block at Frequency Range 8-12GHz

From Figure 6 and Figure 7, the wave propagation through a lens antenna is shown. From the simulation, it is proven that the theory of lens antenna which converts various forms of divergent energy into plane waves.

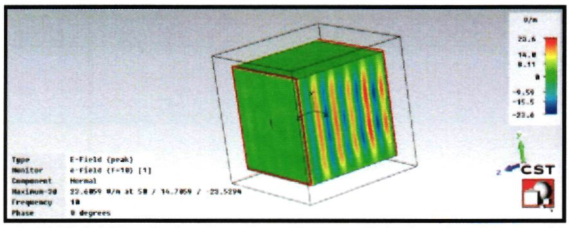


Figure 8: E-Field Simulation Result at Concrete Block using Waveguide port Approximation at Frequency Range 8-12GHz

From Figure 8, the value of S-parameter will be taken to calculate the dielectric constant of the simulated concrete block. Only the forward transmission coefficient (S21) is taken which consist of magnitude in dB and phase in degree.

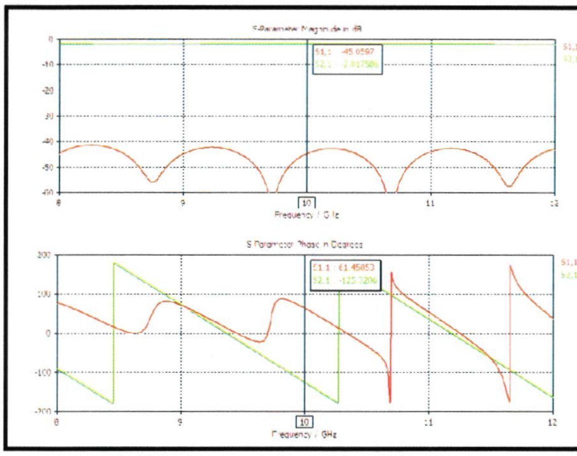


Figure 9: S-parameters results from CST simulation for block 8

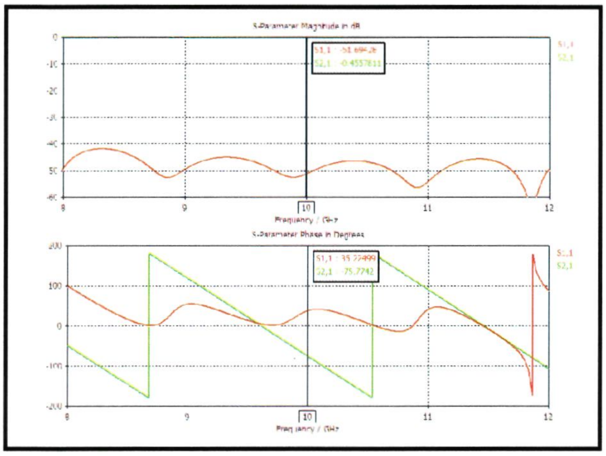


Figure 10: S-parameters results from CST simulation for block 5

From the results shown in Figure 9 and Figure 10, the values from S21 which includes magnitude in dB and phase in degrees are taken for the calculation of the dielectric constant of the concrete block. Only results at 10GHz which is the midband frequency are taken for the calculation of dielectric constant. These values are inserted in the FORTRAN program and the values of dielectric constant from CST simulation are determined at the end of the simulation run in FORTRAN.

TABLE I: Real measurement results and CST simulation results for concrete block at frequency 10GHz

lock 'ame	*Real Measurement*			*CST Simulation*		
	S21 [dB]	***S21 [deg]***	***Dielectric Constant***	***S21 [dB]***	***S21 [deg]***	***Dielectric Constant***
1	*-30.852*	*-152.55*	*2.619904*	*-1.8516830*	*-140.5643*	*2.617594*
2	*-13.547*	*-163.34*	*2.669861*	*-0.3397222*	*-159.6199*	*2.668443*
3	*-13.199*	*-112.50*	*2.533532*	*-0.3340426*	*-107.9409*	*2.529781*
4	*-13.134*	*-128.51*	*2.576344*	*-0.4143807*	*-129.6359*	*2.590714*
5	*-12.98*	*-75.91*	*2.436990*	*-0.4557811*	*-75.7742*	*2.436093*
6	*-13.764*	*-139.58*	*2.605568*	*-0.3745404*	*-135.4428*	*2.606366*
7	*-35.149*	*-140.46*	*2.579303*	*-2.0175860*	*-125.3206*	*2.576451*
8	*-34.004*	*-164.43*	*2.646564*	*-0.3985748*	*-156.2119*	*2.659844*
9	*-37.11*	*-147.22*	*2.593675*	*-10.839740*	*-130.8657*	*2.584285*
10	*-37.919*	*-146.24*	*2.589244*	*-0.2989654*	*-134.6609*	*2.604428*

From table I, although there are difference in the value of S21 between real measurement setup and CST simulation, it will not affect too much on the value of the dielectric constant of the concrete blocks.

Figure 11: Comparison for dielectric constant of Concrete Blocks between real measurement and CST simulation

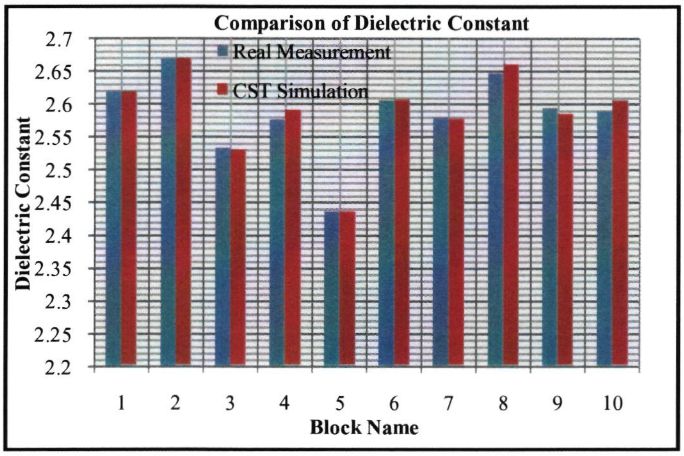


TABLE II: Percentage error between real measurement and simulation at frequency 10GHz

Block Name	***Dielectric Constant From real measurement Setup***	***Dielectric Constant From CST Simulation***	***% error [±]***
1	*2.619904*	*2.617594*	*0.08817*
2	*2.669861*	*2.668443*	*0.05311*
3	*2.533532*	*2.529781*	*0.14805*
4	*2.576344*	*2.590714*	*0.55777*
5	*2.436990*	*2.436093*	*0.03681*
6	*2.605568*	*2.606366*	*0.03063*
7	*2.579303*	*2.576451*	*0.11057*
8	*2.646564*	*2.659844*	*0.50178*
9	*2.593675*	*2.584285*	*0.36203*
10	*2.589244*	*2.604428*	*0.58643*

It is shown in Figure 11 that all dielectric constant for simulated blocks is greater than the ideal dielectric constant which has the value of 2.2. From Table II, it is observed that all percentage error has the value smaller than 1%. The maximum difference occurs at block 10 which has the percentage error of 0.58643% and the minimum difference occurs at block 6 which has the percentage error of 0.03063%. The average percentage error is 0.24754% and is smaller than 1%. Therefore, we can say that the result from simulation and real measurement does satisfy each other. The differences are mainly caused by the value of dielectric constant itself and have no effect caused by the design of the concrete block since all surface and block dimension are the same in the simulation. Another factor that affects the difference between simulation and real measurement is the surface of the concrete blocks during the real measurement. Since not all concrete block has a smooth surface; it may result to difference in the dielectric constant.

VII. CONCLUSION

From the research, it is proven that, MNDT setup can be simulated in the CST Microwave Studio and results from the simulation can be observed. Although there are slight differences from the actual measurement, all results are still in the range where it satisfies each other. It is not possible to get the value of dielectric constant at the first setup which consist both antennas and lenses because design must be at the most accurate. One other reason why this research only concentrated on the waveguide approximation is; to avoid multiple reflections of the propagating wave in the simulation. From the results, it is shown that once an electromagnetic wave passes through a Gaussian optic lens antenna, it will behave as a plane wave and this indirectly proves the theory of a lens antenna. The theory of lens antenna states that, they can transform various forms of divergent energy into plane waves. Values for the dielectric constant calculation are done at 10GHz since it is the most stable frequency in either the real measurement or simulation setup. From the simulation, it is shown that there is an average of 0.24754% for percentage error between the real measurement and the simulation. The simulation can be continued to study the imaginary part of the dielectric constant or complex permittivity of the concrete blocks. It is suggested that for any future research to use other approximation method rather than the waveguide port approximation.

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