EVALUATION OF SOIL DIELECTRIC PROPERTIES USING MICROWAVE NON-DESTRUCTIVE TECHNIQUE (MNDT) AT X-BAND FREQUENCY

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ABSTRACT

This study explores the dielectric properties of soil samples applied with AB mix nutrients across varying electrical conductivity levels using microwave non-destructive technique, MNDT. By employing vector network analyzer, VNA within the X-band frequency, 8 to 12 GHz this research evaluates the dielectric constant, ϵ' and scattering parameters, S-parameters of the soil samples. Results reveal notable difference in dielectric constant, ϵ' between the top and bottom soil layers, with the bottom layer showed higher dielectric constant, ϵ' of 2.3184 due to differences in nutrient and water content. Pearson Correlation analysis showed strong negative correlations at the 99 % significance level between the real and imaginary components of S_{11} and S_{21}, with correlation coefficients as low as -0.899 for the S_{11} phase and -0.836 for the S_{21} phase. These findings highlight the effectiveness of MNDT system in soil analysis, providing a robust, non-destructive method for evaluating soil properties, particularly in agriculture and environmental settings by highlighting the impact of water content and soil compaction on dielectric characteristics.

Keywords: Dielectric properties; Scattering parameters (S-parameters); Microwave Non-Destructive Technique (MNDT); Electrical conductivity (EC)

Evaluation of Soil Dielectric Properties using Microwave Non-Destructive Technique at X-Band Frequency

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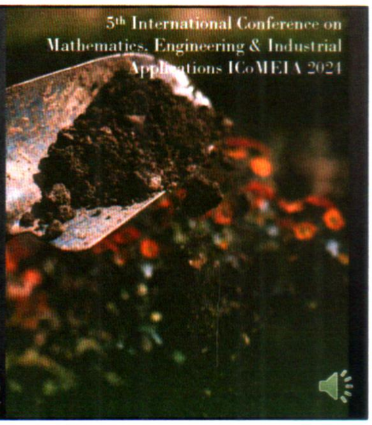

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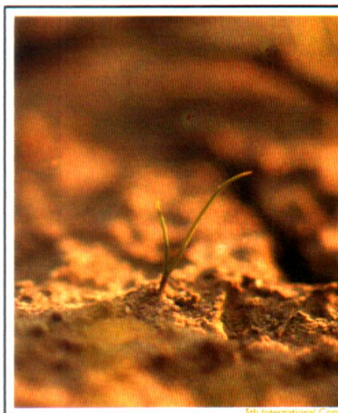
presentation outline

introduction

1. Microwave remote sensing has emerged as crucial field for studying natural resources, emphasizing the interaction of electromagnetic waves with materials.
2. Research on dielectric properties of soil at microwave frequencies are particularly significant for interpreting remote sensing data and planning ground-penetrating radar surveys.
3. Dielectric properties of soil primarily influenced by the frequency, water saturation, porosity, soil texture, component geometry and electrochemical interactions.
3. Low-frequency dielectric dispersion helps to understand induced polarization behaviors, whilst the high-frequency measurement is essential for practical applications like remote sensing and radar surveys.
4. This work focused on the dielectric properties of different soil textures using waveguide cell method, particularly in the X-band microwave frequency range of 8-12 GHz.
5. The soil samples were initially treated with inorganic fertilizers (AB mix nutrients) at different electrical conductivity, EC levels and volumes to observe the effect of over fertilization towards the soils.



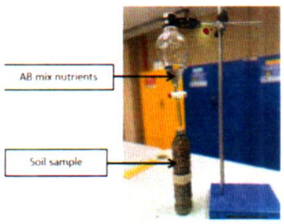
research objectives

1. To study the effect of excessive fertilizers of different concentration / electrical conductivity (EC) level and amount (mL) of fertilizers towards treated soils at X-band frequencies.
2. To study the S-parameters of MNDT data (S_{11}) and (S_{21}) in order to determine the reflective and transmissive properties of the treated soils.

methodology: soil preparation

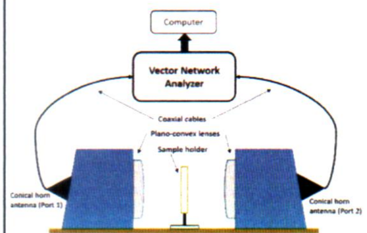
1. Soils in 3:2:1 ratio of black soil, red soil sand were thoroughly blended and placed into 450 mL water bottles of dimension 20 cm in height and 7 cm in diameter.
2. AB mix nutrients of different concentration levels (EC) and volumes were applied to the soil samples using dripping method over a period of 28 days, sequentially.
3. The EC level were set at 1.8 mS/cm and 2.6 mS/cm, and the volume applied were 3, 6 and 9 mL.

No. of Samples	EC Levels (mS/cm)	Amount of AB Mix Nutrients Applied (mL)
1	1.8	3
2	1.8	6
3	1.8	9
4	2.6	3
5	2.6	6
6	2.6	9



Dripping process of AB mix nutrients into soil sample placed in modified 450 mL bottle

methodology: vna characterisation



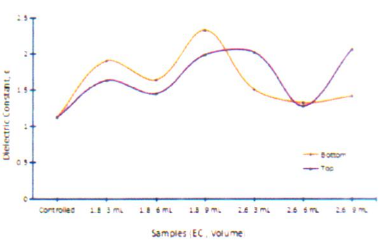
Schematic diagram of Vector Network Analyzer (VNA) via Microwave Non-Destructive Testing, MNDT

1. The soil samples were characterised using VNA via MNDT technique at the Microwave Research Institute Lab, Faculty of Electrical Engineering, UiTM Shah Alam.
2. The lens's focal distance to antenna diameter (F/D) ratio is one (1), with D approximately 30.5 cm.
3. The frequency, f range of the measurement from 8 GHz to 12 GHz.
4. The S-parameters were analysed using Pearson Correlation Analysis of SPSS software.

results and discussion

dielectric constant, ε' of soil samples

1. The dielectric constant, ε' data increased with the application of AB mix nutrients.
2. The bottom section depicts higher dielectric constant, ε' compared to top section due to the accumulation of nutrients at the bottom of the container.
3. The highest dielectric constant, ε' recorded at 9 mL application with 1.8 mS/cm condition.
4. Inconsistencies of data is observed that certain 3 mL applications yielded higher dielectric constant, ε' than that of 6 mL and 9 mL applications.



Dielectric constant, ε' data between the top and bottom soil samples at different EC levels and volumes of AB mix nutrients measured at 10 GHz

results and discussion

dielectric constant, ε' of soil samples

4. Irregularity data may be due to nutrient distribution, soil structure and the complex interactions between soil particles and nutrients may play significant role in determining the soil's dielectric properties.
5. Factors that may contributes to the increase of dielectric constant, ε' data in bottom section due to
   - Accumulation of nutrients in the lower layers due to gravitational pull and water movement.
   - Soil compaction in the bottom layers where air gaps reduces and density increased which likely contributes to the higher dielectric constant, ε' at the bottom section.
   - Moisture content of the soil. Compacted soil tends to retain moisture more effectively and since water has a significantly higher dielectric constant, ε' than soil with minerals and air, the increased moisture content in the bottom sections further elevates the dielectric constant, ε' value [28].

results and discussion

s-parameter, S_{11} top soil sample

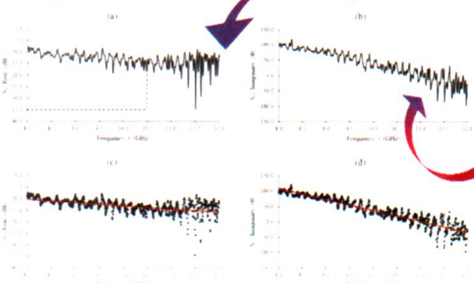


Figure (a) shows the results of the real S_{11} top soil sample with 2.6 mS/cm of EC level at 6 mL application

1. Real S_{11} component predominantly exhibited negative values, with the amplitude ranging from -5 dB to -35 dB.
2. Imaginary S_{11} component illustrated significant variation across the same frequency spectrum, with values oscillating between +150° and -150°.

results and discussion

s-parameter, S_{11} top soil sample

Correlations

		Frequency, *f*	S_{11} Real
Frequency, *f*	Pearson Correlation	1	-0.553**
	Sig. (2-tailed)		< 0.001
	N	800	800
S_{11} Real	Pearson Correlation	-0.553*	1
	Sig. (2-tailed)	< 0.001	
	N	800	800

** Correlation is significant at 0.01 level (2-tailed)

Pearson Correlation analysis between frequency and real S_{11} signal for bottom soil sample at 2.6 mS/cm of 6 mL AB mix nutrients application

Correlations

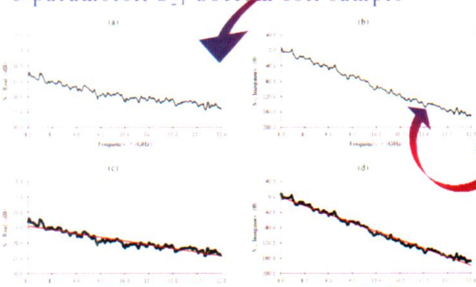
		Frequency, *f*	S_{11} Imaginary
Frequency, *f*	Pearson Correlation	1	-0.935**
	Sig. (2-tailed)		< 0.001
	N	800	800
S_{11} Imaginary	Pearson Correlation	-0.935**	1
	Sig. (2-tailed)	< 0.001	
	N	800	800

** Correlation is significant at 0.01 level (2-tailed)

Pearson Correlation analysis between frequency and imaginary S_{11} signal for bottom soil sample at 2.6 mS/cm of 6 mL AB mix nutrients application

results and discussion

s-parameter, S_{21} bottom soil sample



Bottom soil sample at 2.6 mS/cm of 6 mL AB mix nutrients (a) graph for S_{21} real, (b) graph for S_{21} imaginary, (c) scattering plot for S_{21} real and (d) scattering plot for S_{21} imaginary

1. The real part of S_{21} display a steady decline as the frequency increased. The real S_{21} values gradually decreased from -5 dB at 8 GHz to -25 dB near 12 GHz
2. The imaginary part of S_{21} illustrates a clear negative trend as the frequency increased from 20° to -180° at 8 and 12 GHz, respectively

results and discussion

s-parameter, S_{21} bottom soil sample

Correlations

		Frequency, *f*	S_{21} Real
Frequency, *f*	Pearson Correlation	1	-0.951**
	Sig. (2-tailed)		< 0.001
	N	800	800
S_{21} Real	Pearson Correlation	-0.951**	1
	Sig. (2-tailed)	< 0.001	
	N	800	800

** Correlation is significant at the 0.01 level (2-tailed)

Pearson Correlation analysis between frequency and the real S_{21} signal for bottom soil sample at 2.6 mS/cm of 6 mL AB mix nutrients application

Correlations

		Frequency, *f*	S_{21} Imaginary
Frequency, *f*	Pearson Correlation	1	-0.994**
	Sig. (2-tailed)		< 0.001
	N	800	800
S_{21} Imaginary	Pearson Correlation	-0.994**	1
	Sig. (2-tailed)	< 0.001	
	N	800	800

** Correlation is significant at the 0.01 level (2-tailed)

Pearson Correlation analysis between frequency and the imaginary S_{21} signal for bottom soil sample 2.6 mS/cm of 6 mL AB mix nutrients application

conclusion

1. The dielectric constant, ε' of soil samples are significantly affected by the EC levels and volume of AB mix nutrients application.
2. The highest dielectric constant, ε' observed was at 9 mL and 1.8 mS/cm condition.
3. Bottom soil layers exhibited consistently possessed higher dielectric constants, ε' compared to top layers, which may be attributed to the increment of nutrient accumulation, moisture retention and soil compaction.
4. Moisture content was found to have substantial impact on the dielectric constant, ε' i.e. higher moisture levels correlating with the increasing dielectric constant, ε' values. This underscores the importance of moisture management for optimizing soil dielectric properties in applications such as remote sensing and agricultural monitoring.
5. Analysis of S-parameters revealed that the soil's reflective and transmissive properties are frequency-dependent, with notable variations in the real and imaginary components of S_{11} and S_{21}.
6. Strong negative correlations between frequency and both the real and imaginary parts of S_{11} and S_{21} parameters were observed, highlighting the intricate interactions between soil composition, electromagnetic waves and applied nutrients.
7. Overall, this study demonstrates the efficacy of VNA analysis within the X-band for evaluating soil dielectric properties and S-parameters. The findings emphasize the critical roles of moisture content and soil compaction in shaping these properties.
8. The strong correlations between S-parameters and frequency validate the effectiveness of the MNDT system, providing a robust, non-destructive method for precise soil analysis.

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Thank You

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