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Microwave measurements on oilshale rocks

M. S. AHMAD, M. K. ABDELAZEEZ*, A. M. ZIHLIF
*Physics Department, and *Electrical Engineering Department, University of Jordan, Amman, Jordan*

Characterization of some structural and electrical properties of oilshale deposit are studied in the X-band (8 to 12 GHz) through measuring the insertion loss (IL), return loss (RL), and the material equivalent input impedance, Z_m. X-ray diffraction and scanning electron microscopy show that the deposit contains a number of minerals and oil pores. Measurements at microwave frequency show that the IL for the rock specimen of 5.1 mm thickness ranges between 2 and 4.5 dB; and the value of the RL for the same specimen ranges between 2 and 5.8 dB over the whole X-band. A particular surface deposit specimen of thickness 7.15 mm shows a high value of RL of about 38 dB at around 11.2 GHz, which seems almost transparent at this frequency. The overall behaviour of the measured impedance as a function of frequency shows a relatively strong dependence on the specimen thickness and weak dependence on both deposit depth and composition. Analysis of the obtained data of impedance indicates that the deposit has an inductive behaviour.

1. Introduction

The electrical characteristics of materials are extremely important because they are used in different applications especially in the field of remote sensing of the earth in search of various types of deposits. The oilshale deposit (or rock) distributed in some locations around the world is nowadays of great importance because of its possible utilization as a source of energy. Some countries such as China have succeeded in obtaining great amounts of oil through certain technologies. Recently, the scientific community has paid attention to some physical properites of inhomogeneous porous materials such as sedimentary rocks, which have important electrical and dieletric behaviour [1-4]. In this paper, research activities [5-7] are extended to determine some of the structural and electrical properties of the oilshale deposit existing in great amounts in Jordan, with an average yield of crude oil of 5% to 15% by weight [8].

2. Experimental work

2.1. Material

Samples were obtained from El-Lajjun oilshale deposit located in the southern part of Jordan near Karak city. The deposit area is 10 km long and 2.5 km wide, the deposit existing at a depth of about 32 m under sedimentary rock structures consisting of limestone, marls, cherts, shales and phosphate. The average thickness of the oilshale deposit is relatively homogeneous as indicated from the uniformity of lithology with several constituents as moisture, oil, sulphur, complexes and organic matter. From bottom to top, the oil content varies from 12.6 % to 4.3 %, the moisture from 1.8 % to 3.6 %, sulphur from 3.5 % to 1.9 %, and the organic carbon matter from 14.5 to 6.3 wt % as reported by the Natural Resource Authority of Jordan [8]. Test plate-shaped specimens, 3 to 7.15 mm thick, were cut randomly from the oilshale deposit with dimensions suitable for the various measurements reported in this work.

2.2. X-ray diffraction and scanning electron microscopy (SEM)

Two samples from the oilshale deposit were investigated by X-ray diffraction and SEM techniques. One was obtained from the top deposit structure unit and the other from the bottom unit. A Phillips X-ray diffractometer with nickel-filtered Cu$K\alpha$ radiation is used. The diffractometer was operated to scan over the 2θ range from 2° to 60° when a powder-thin layer was mounted on the goniometer. A Leitz SEM is used to examine the texture of different samples of the deposit taken from different depths. The test specimens are mounted on stubs and coated with gold for SEM observations.

2.3. Microwave measurements

The waveguide components used operate in the frequency range 8 to 12 GHz. The measurements are carried out using a conventional swept frequency technique [6]. Each test specimen was placed normal to the waveguide axis. Special care was taken to reduce the reflections and mismatch in the apparatus. The measurements cover the insertion loss (IL), return loss (RL), and the equivalent impedance, Z_m, of the specimen. The reproducibility of the results are within ± 5 %.

The values of IL and RL are given by

$$\mathrm{IL} = 10 \log (P_i/P_t) \quad \mathrm{dB} \tag{1}$$

$$\mathrm{RL} = 10 \log (P_i/P_r) \quad \mathrm{dB} \tag{2}$$

where P_i is the incident signal level (W), P_t is the transmitted signal level after introducing the specimen (W),

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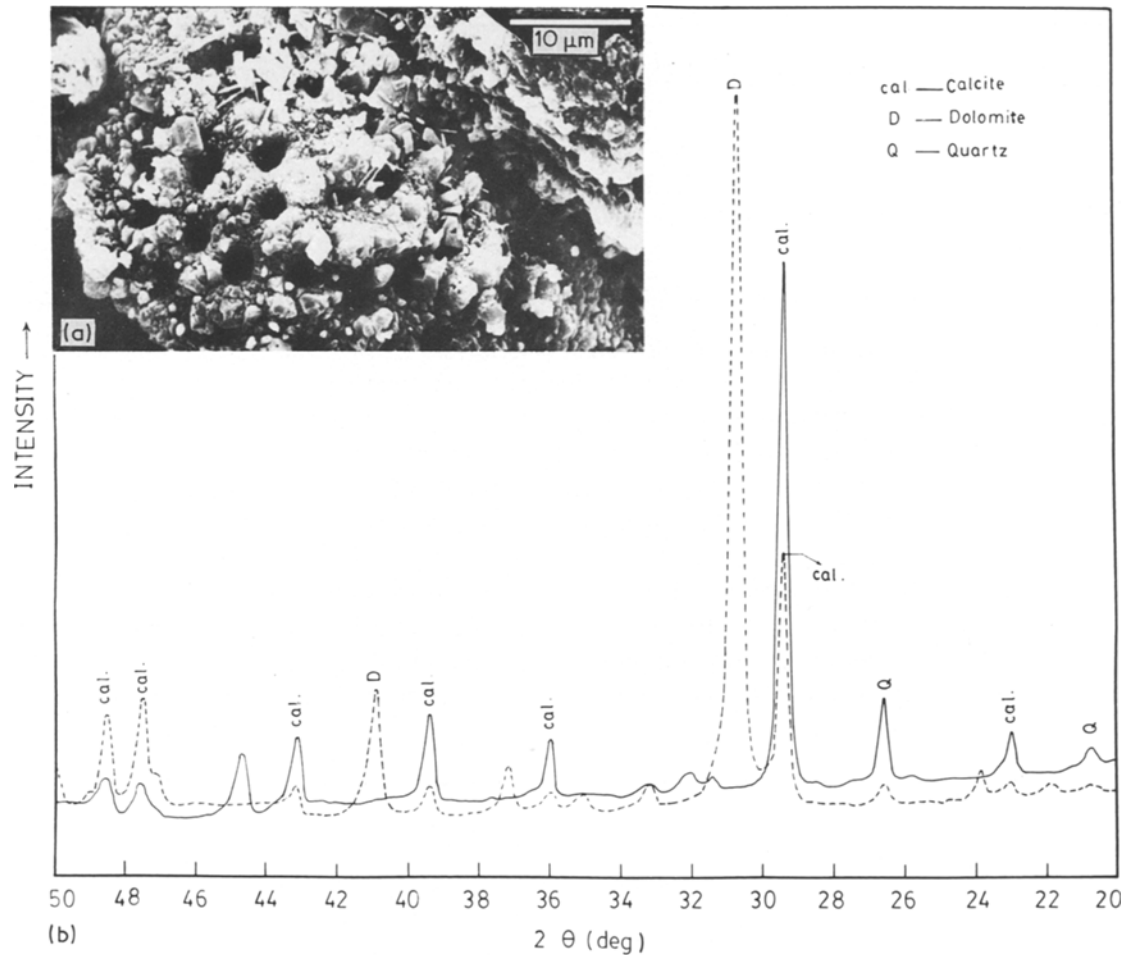

Figure 1 (a) Scanning electron micrographs, (b) X-ray diffracted reflections.

and P_r is the reflected signal level from the specimen (W).

It is worthwhile to note that the incident signal will split into three components, i.e.

$$P_i = P_t + P_r + P_L \tag{3}$$

where P_L is the lost power inside the specimen. Its value can be ignored for thin specimens and small equivalent material conductivity; consequently Equation 3 can be written as

$$P_i \approx P_t + P_r \tag{4}$$

The above relationships are used to determine the IL, RL and other parameters for the oilshale rock.

3. Results and discussion

3.1. Structural aspects

The scanning electron micrograph shown in Fig. 1a reveals the texture of a test sample taken from an oilshale unit at about 20 m depth. The sample microstructure consists of a mixture of minerals, such as calcite, quartz, kaolinite, apatite and dolomite crystallite and a small percentage of complex organic carbon matter. Black pores of average diameter 3 μm, containing some traces of oil, are clearly seen in the micrograph which reveals an inhomogeneous pore-structure. The X-ray patterns for two specimens are shown in Fig. 1b. One specimen is taken from the top deposit layer ($\approx$ 3 m deep), and the other from the bottom deposit layer ($\approx$ 25 m deep). Analysis of the X-ray diffraction patterns (reflections) shows that top and bottom layers have different mineralogical compositions. The top deposit layer is rich in dolomite and a small percentage of calcite; while the bottom layer does not contain dolomite but contains a high percentage of calcite. The results of the present SEM and X-ray diffraction studies are consistent with those reported elsewhere [8].

3.2. Insertion and return losses

Measured values of IL and RL in the X-band are shown in Fig. 2 for a specimen 5.1 mm thick taken randomly from the upper part of the oilshale unit. The IL decreases with increasing frequency from about 4.5 to 2 dB. On the other hand, RL increases with frequency from about 2 to 5.8 dB. The variations of IL and RL as a function of frequency are shown in Fig. 3 for a specimen 5.1 mm thick taken from a deep part of the deposit. It shows that the value of IL decreases with increasing frequency from about 6.5 dB to around 1.2 dB, and the value of RL increases with increasing frequency from about 1.5 dB to about 8.2 dB. This similarity in IL and RL behaviour for both test specimens from the different locations (upper and lower deposit) indicates that the overall structure units of oilshale contain equal amounts of complexes and conductive elements which could be considered as a source of electrical conductivity and hence control the loss values [9]. If the specimen thickness is smaller, the measured values of IL and RL

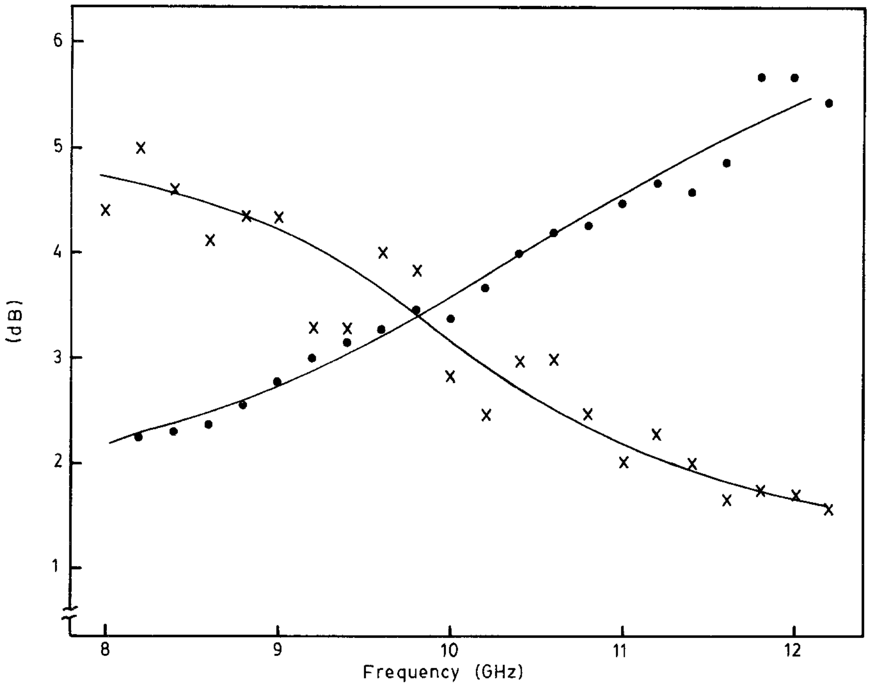

Figure 2 Variation of (x) insertion and (●) return losses with frequency for a specimen 5.1 mm thick taken from the upper rock unit.

become lower and their variations with frequency become less pronounced as shown in Fig. 4 which is plotted for a 3 mm specimen taken from the upper deposit. The measured values of RL presented in Fig. 5 for a thicker specimen (7.15 mm) are interesting because the RL frequency dependence exhibits a sharp maximum around 11.2 GHz. The observed RL value at this peak is around 38 dB and the IL value is less than 1 dB.

For all of these specimens, it can be observed that the IL decreases and the RL increases with increasing frequency over the whole X-band, irrespective of the specimen thickness and location. The peculiar behaviour of the 7.15 mm specimen at around 11.2 GHz seems to suggest that the specimen is almost transparent around this frequency, because this thickness is roughly one-quarter of the waveguide wavelength. Also, it is worthwhile to point out that the shielding effectiveness (SE) of these oilshale units can be estimated for these different specimens from Equation 4, i.e.

$$SE = 10 \log (P_i/P_t) = 10 \log [1 + (P_r/P_t)] \text{ dB} \quad (5)$$

Using Equations 1 and 2 in Equation 5, the SE value can be obtained

$$SE = 10 \log [1 + 10^{(IL-RL)/10}] \text{ dB} \quad (6)$$

where both IL and RL contribute to the SE value.

Table I includes some parameters calculated [9, 10] in the microwave frequency range, such as the electrical conductivity, σ, and the SE for oilshale specimens of different thicknesses. It can be seen that these parameters vary with the rock-unit location, geometry, and composition of the test specimen. The values of σ obtained indicate that oilshale deposit contains some

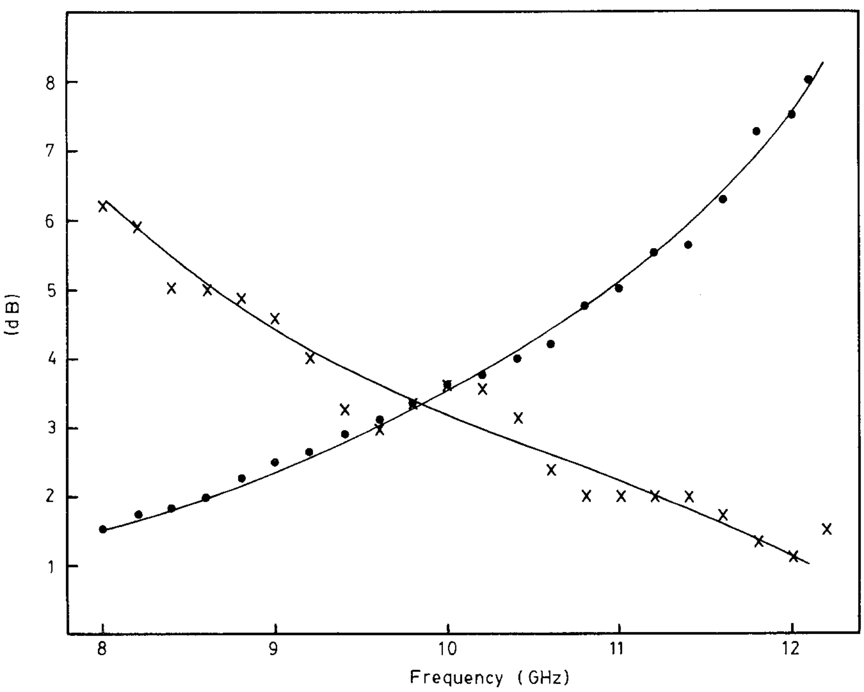

Figure 3 Variation of (x) insertion and (●) return losses with frequency for a specimen 5.1 mm thick taken from the bottom unit.

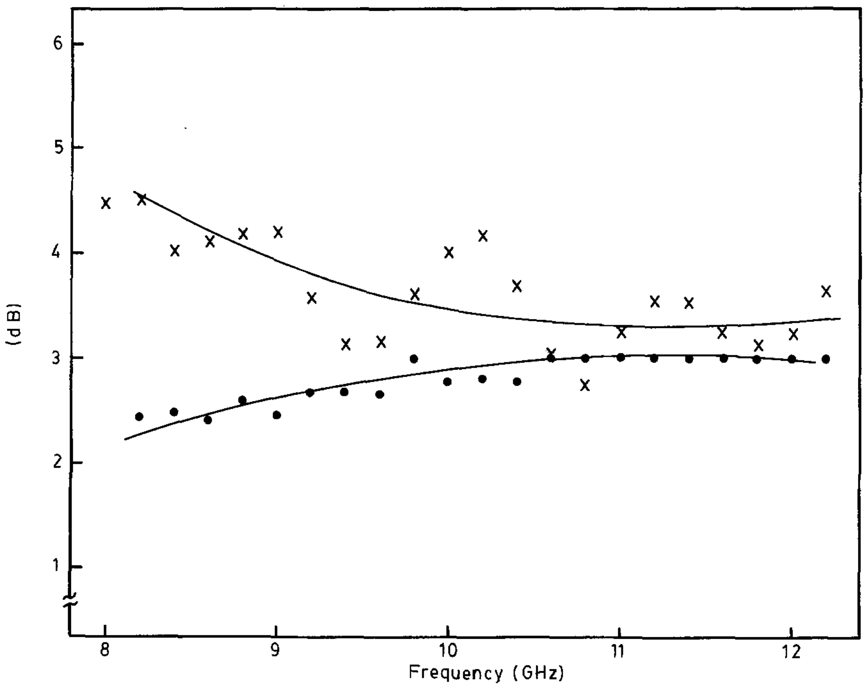

Figure 4 Variation of (x) insertion and (●) return losses with frequency for a specimen 3 mm thick taken from the bottom unit.

conductive materials, such as the metallic complexes, inclusions and the organic carbon content.

3.3. Equivalent input impedence

The variation of the magnitude of the normalized equivalent input impedance $|z|$ with frequency is shown in Fig. 6, where $|z| = |Z_m/Z_w|$, Z_w is the waveguide characteristic impedance (Ω) and Z_m is the material equivalent input impedance (Ω). The phase of the equivalent input impedance, ϕ (deg), as a function of frequency is shown in Fig. 7 for different specimens. The data obtained for z show that there is no difference between the 5.1 mm specimen taken from the upper deposit and the 5.1 mm specimen taken from the lower deposit. These curves indicate that the normalized equivalent impedance, $|z|$, depends on thickness. Both the measured impedance and phase angle of the specimen 3 mm thick show a weak variation with frequency. But these observations are much more pronounced in the case of surface and deep specimens of the same thickness (5.1 mm), where $|z|$ increases from 0.5 to 2.5 and the phase, ϕ, decreases from around 75° to 2° over the whole frequency band. This observed frequency dependence of $|z|$ for a porous oil reservoir rock is different from that observed in the case of partially (oil–water) saturated rocks where the measured dielectric constant decreases with increasing frequency [3, 4]. The dependence of the impedance on frequency for a surface specimen 7.15 mm thick shows also a peculiar behaviour, as observed in the case of IL and RL. The magnitude of the normalized impedance $|z|$, in this case, reaches its maximum value at 9 GHz and decreases with increasing frequency to reach approximately 1; and the phase angle, ϕ, decreases from 75° at 8 GHz to a minimum value at 10.5 GHz, and increases to about 16° at 12 GHz. This specimen (at around 11 GHz) has a normalized equivalent input impedance, $|z| \approx 1 \underline{|0°}$ which confirms the fact that the specimen is transparent to the electromagnetic energy around this frequency due to its thickness and its composition.

Finally, the overall behaviour of the impedance of the oilshale deposit at microwave frequencies is found to have an inductive behaviour. Moreover, the present study was encouraging to extend the measurements in the low-frequency range. The results of this proposed study will be reported later.

4. Conclusion

Some structural and microwave properties of oilshale rocks existing in Jordan are studied. It was found through X-ray diffraction and SEM techniques that the deposit has a microstructure consisting of a number of minerals such as calcite, quartz, kaolinite, apatite and dolomite. The top and the bottom units of the deposit have different mineralogical compositions which weakly affect the values of the insertion and return losses and the equivalent input impedance. A

TABLE I Some calculated parameters of oilshale: the frequency is given in GHz, SE is the shielding effectiveness given in dB, and σ is the conductivity which is given in (moho/m) × 10^{-4}

Frequency (GHz)	Sample thickness							
	3 mm (deep)		5.1 mm (surface)		5.1 mm (deep)		7.15 mm (surface)	
	SE (dB)	σ (10^{-4} moho m^{-1})	SE (dB)	σ (10^{-4} moho m^{-1})	SE (dB)	σ (10^{-4} moho m^{-1})	SE (dB)	σ (10^{-4} moho m^{-1})
8	4.4	3.7	4.3	2.1	6	2.5	4.4	0.11
10	3.3	3.3	3.3	1.8	2.8	1.8	1	0.5
11.2	3.2	2.9	1.6	1.3	1.6	1.3	≈0	0.18
12	3.2	2.7	1.5	1.2	0.9	0.9	0.2	0.14

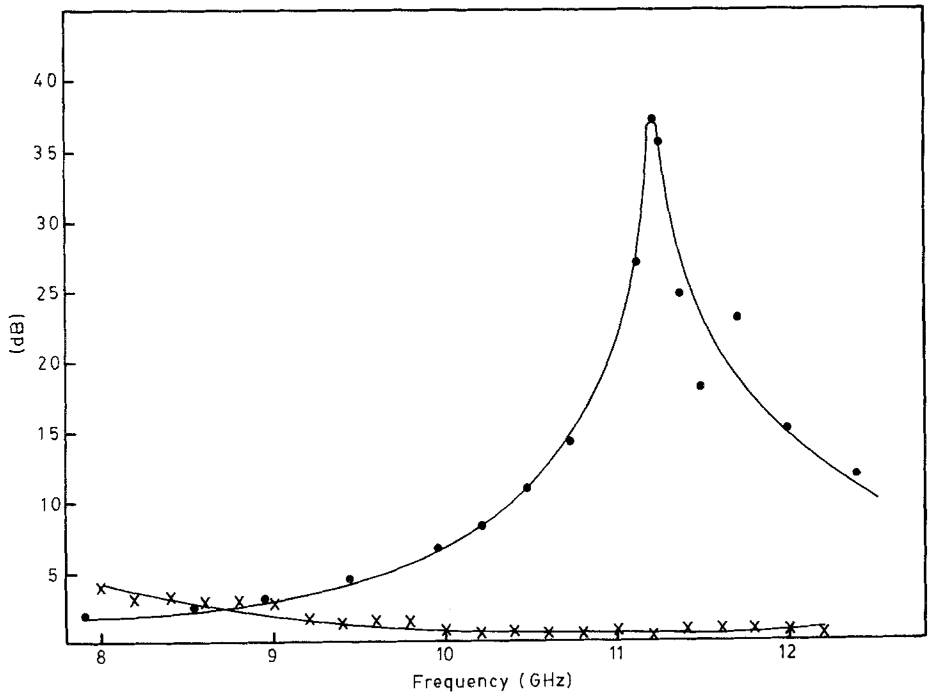

Figure 5 Variation of (x) insertion and (●) return losses with frequency for a specimen 7.15 mm thick taken from the upper rock unit.

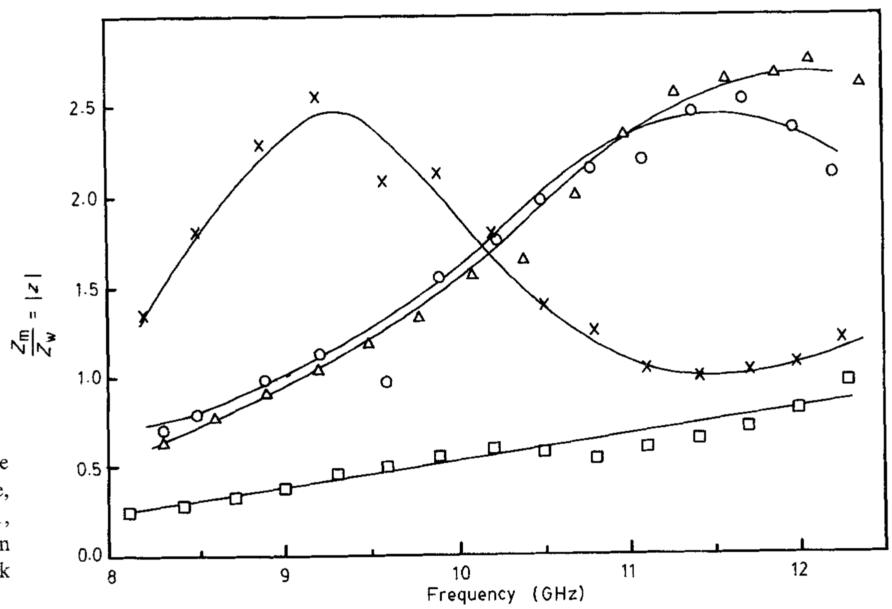

Figure 6 Variation of magnitude of the normalized equivalent input impedance, $|z|$, with frequency for (□) 3, (○, △) 5.1, and (x) 7.15 mm thick specimens taken from the upper and bottom oilshale rock deposits.

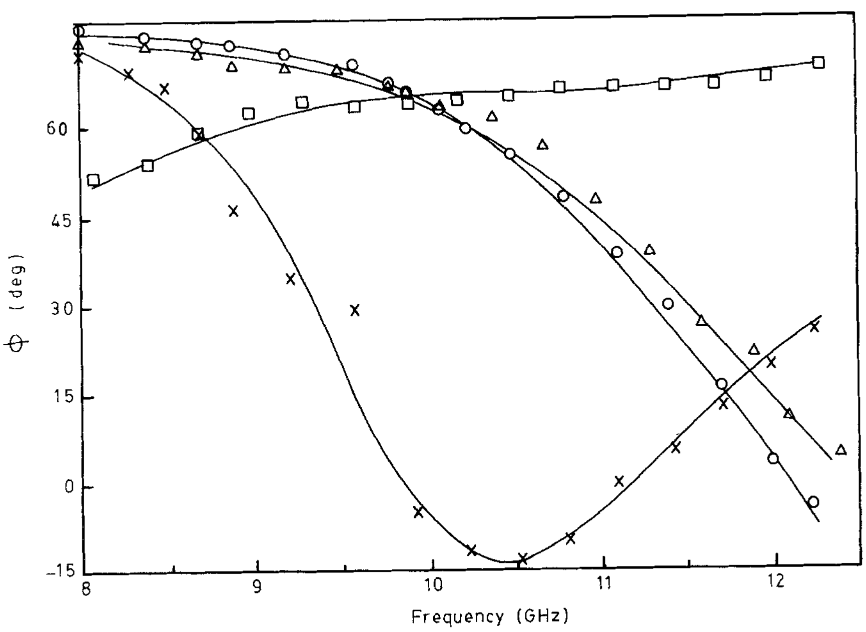

Figure 7 Variation of the phase angle, ϕ, with frequency for (□) 3, (△, ○) 5.1, and (x) 7.15 mm thick specimens taken from the upper and bottom oilshale rock deposits.

surface deposit specimen of thickness 7.15 mm showed an interesting behaviour around 11.2 GHz which yields a value of RL of about 38 dB seeming to suggest that the specimen is almost transparent around this frequency. The observed behaviour of the phase angle, ϕ, and the magnitude of the normalized equivalent input impedance, $|z|$, of the given deposit as a function of microwave frequency depends strongly on the specimen thickness, and weakly on the rock unit depth and composition. The overall behaviour of the deposit impedance is found to be inductive. Furthermore, the values of the shielding effectiveness and the conductivity for this material are evaluated for various given specimens.

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