

Investigation of Microwave X-band Response on Bricks for Remote Sensing

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Abstract: Microwave X-band spectrum is used to investigate the properties of reflected signal from bricks for remote sensing. The measurements are taken by varying angles of incidence from 30 degree to 60 degree in the intervals of 10 degree for both like polarizations (HH-pol. & VV-pol.) by using an indigenously assembled bistatic scatterometer. The measured values of reflection coefficients are compared with the theoretical Fresnel reflection coefficients using Gaussian rough surface scattering models. The results indicate that the Fresnel reflection coefficients of the bricks for VV-polarization are well bound by the predictions for the smooth and Gaussian rough surface.

Key Words and Phrases: Remote Sensing, Scatterometer, reflection coefficient.

1. Introduction

The studies of the interaction of electromagnetic energy with physical objects provide some important data to develop communication tools. Recently, electromagnetic waves, especially, those in microwave region, are extensively used in the satellites observation and mobile communication. The data obtained by satellite observation is very useful for urban planning and natural resource management. In this contest, the study of microwave response with basic building material like bricks provide valuable database to develop realistic models and analyze the satellite data more fruitfully.

Microwave responses in X-band, (9.5 GHz) on bricks are studied for remote sensing. This band of microwave frequency is mainly used for remote sensing purpose to know the surface characteristics of the target, which is quite beneficial for urban development as well as classification. A considerable amount of work has been done on microwave response on bricks by many instigators (Dillard *et al.*¹, Maierhofer *et al.*², Landraon *et al.*³). Still the detailed study of microwave responses on bricks at 9.5 GHz of X- band is awaited. The present report is an attempt to fulfill this gap. For this purpose, the line of sight (LOS) power, reflected path power and reflection coefficient as well as scattering coefficient of the bricks for both like polarization (HH-pol and VV-pol) at X- band (9.5 GHz) has been estimated experimentally. The polarimetric behavior of the bricks has also been analyzed for the sensor parameter.

2. Approach

A. Reflection and Scattering Models

The Fresnel reflection coefficient describes the field reflection from an infinite dielectric slab are given by in equations

$$(1) \quad \Gamma_{HH} = \frac{\cos \theta - \sqrt{\varepsilon - \sin^2 \theta}}{\cos \theta + \sqrt{\varepsilon - \sin^2 \theta}}$$

$$(2) \quad \Gamma_{VV} = \frac{\varepsilon \cos \theta - \sqrt{\varepsilon - \sin^2 \theta}}{\varepsilon \cos \theta + \sqrt{\varepsilon - \sin^2 \theta}}$$

where θ is the incidence angle and ε is the dielectric constant. Equations (1) and (2) accounts only for specular reflection, which occurs for smooth surfaces. When the surface is rough, some energy will be scattered in angles other than the specular angle of reflection, thereby reducing energy in the specularly reflected component (Bothias⁴). The Rayleigh criterion is commonly used as a test for surface roughness, the condition for the rough surface is

$$(3) \quad h_{rms} > \frac{\lambda}{8 \cos \theta}$$

where λ is wave length of incidence radiation and h_{rms} is standard deviation of surface height about the mean height define by equation

$$(4) \quad h_{\text{rms}} = (\overline{h^2} - \bar{h}^2)^{1/2}$$

where $\bar{h}$ is mean surface height and $\overline{h^2}$ is the second moment height

For the case of rough surface Ament⁵ has derived a scattering loss factor (ρ_s) to account for diminished energy in the specular direction of reflection given by

$$(5) \quad \rho_s = \exp \left[-8 \left(\frac{\pi h_{\text{rms}} \cos \theta}{\lambda} \right)^2 \right]$$

Equations (5) assume that the surface heights are Gaussian distributed with negligible sharp edge and shadowing effects. Using ρ_s to modify the reflection coefficients referred as Gaussian rough surface scattering model, and is written as

$$(6) \quad \left(\Gamma_{HH} \right)_{\text{rough}} = \rho_s \Gamma_{HH}$$

and

$$(7) \quad \left(\Gamma_{VV} \right)_{\text{rough}} = \rho_s \Gamma_{VV}$$

Boithias⁴ reports that the scattering loss factor of equation (5) gives better agreement with measured results when modified as

$$(8) \quad \rho_s = \exp \left[-8 \left(\frac{\pi h_{\text{rms}} \cos \theta}{\lambda} \right)^2 \right] I_0 \left[8 \left(\frac{\pi h_{\text{rms}} \cos \theta}{\lambda} \right)^2 \right]$$

where I_0 is the modified Bessel function of zeroth order. When the Bessel function argument is small, value of equation, (5) and equation (8) are approximately equal, causing I_0 to approach unity.

B. Polarimetric Ratio

The sensitivity of microwave scattering on surface roughness is well known and it gives different characteristics at different polarizations (i.e., HH- and VV-pol) (Ulaby *et al.*⁶, Mattia *et al.*⁷). Therefore, polarization can help to get the individual information of surface, which will be quite useful to develop the retrieval algorithms in remote sensing. For this purpose, we calculate polarimetric ratio (P) and polarimetric discrimination ratio (D)

which is the ratio of scattering coefficients of HH- and VV-pol. (Oh *et al.*⁸, Singh *et al.*⁹) and given as

$$(9) \quad P = \frac{\sigma_{hh}^0}{\sigma_{vv}^0}$$

$$(10) \quad D = \frac{\sigma_{vv}^0 - \sigma_{hh}^0}{\sigma_{vv}^0 + \sigma_{hh}^0}$$

where σ_{hh}^0 and σ_{vv}^0 are the scattering coefficient for HH- and VV-pol respectively.

3. Experimental Procedure

Using an indigenously assembled bistatic scatterometer (Figure-1), we performed the measurements of reflection coefficient. The detail about the scatterometer is discussed in Table-1. The bricks reflectivity observation were taken on four different incidence angle (30° , 40° , 50° , and 60°) at fix frequency 9.5 GHz.

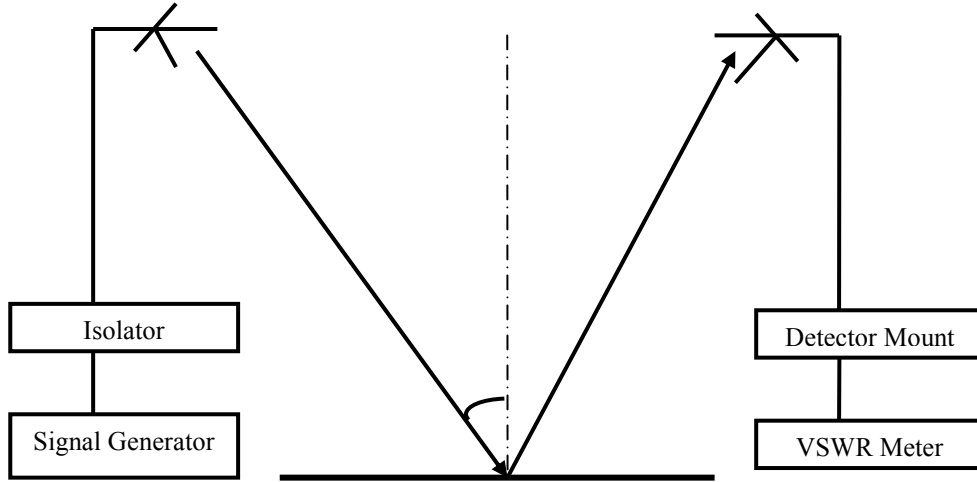


Fig. 1 Scatterometer

A. Scattering Coefficient Measurements

Pyramidal horn antennas are used to take response of the bricks plots. Figure-2, show the foot print geometry of radar antenna illumination. To calibrate the system, the power received by aluminum sheet of known radar

cross section at the receiving antenna, for different angle of incidence, was recorded with power meter.

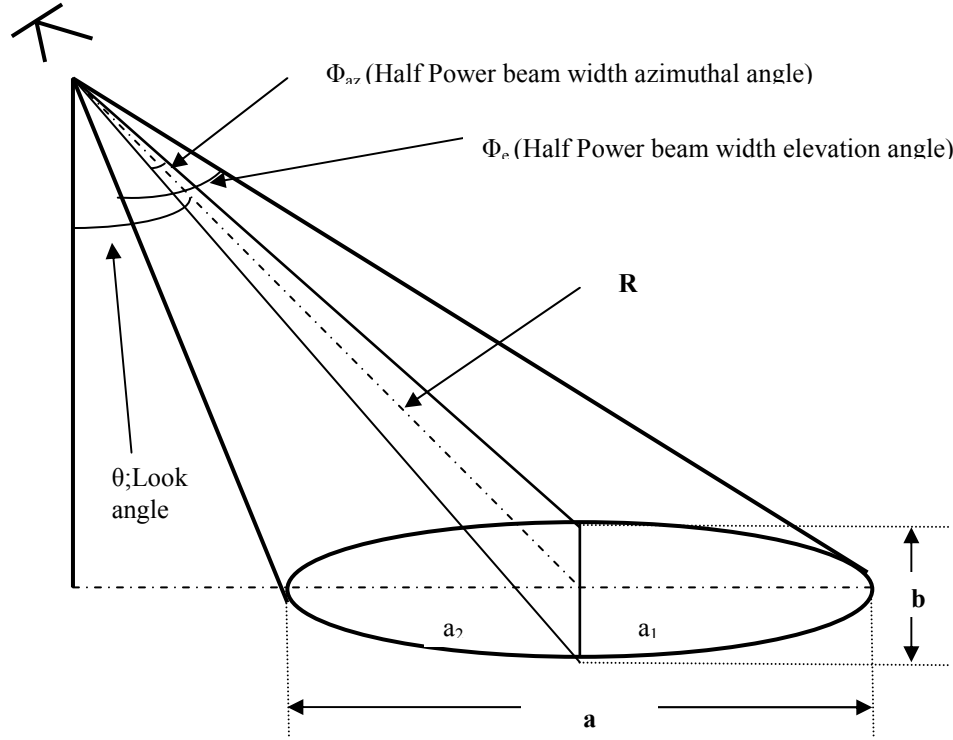


Fig.2 Foot Print geometry of radar antenna illumination

The radar cross section of the aluminum sheet was calculated by using the equation (Curie¹⁰)

$$(11) \quad A_I \sigma_{pp}(\theta) = \frac{4\pi A^2}{\lambda^2} \left[\frac{\sin(kb \sin \theta)}{kb \sin \theta} \right]^2 \cos^2 \theta \quad p=v \text{ or } h$$

where $A_I \sigma_{pp}(\theta)$ radar cross section of aluminum sheet, A is area of sheet, λ is wave length of operation, θ is angle of Incidence, b is the dimension of square sheet, and $k = \frac{2\pi}{\lambda}$. The radar cross section of aluminum sheet expressed in dB as equation;

$$(12) \quad A_I \sigma_{pp}(\theta)(dB) = 10 \log_{10} A_I \sigma_{pp}(\theta), \quad p = v \text{ or } h$$

Firstly, the observations were carried out for aluminum sheet and scattered power ($_{Al}P_{pp}$) from aluminum sheet were noted after that scattered power was observed for bricks ($_bP_{pp}$) at various incidence angles and like polarization (HH- and VV-pol), and the scattering coefficient of bricks ($_b\sigma^0_{pp}$) was computed with the help of equation

$$(13) \quad _b\sigma^0_{pp}(\theta) = \frac{_bP_{pp}}{_{Al}P_{pp}} \times _{Al}\sigma_{pp}(\theta) \quad p = v \text{ or } h.$$

In decibels, the scattering coefficient can be written as equation:

$$(14) \quad _b\sigma^0_{pp}(\theta)_{dB} = 10 \log_{10} (_b\sigma^0_{pp}(\theta)) \quad p = v \text{ or } h.$$

B. Reflection Coefficient Measurements

The reflection coefficients were measured using a two-step technique (Landron³). First line of sight (LOS) power measurements were made with the two antennas facing each other. Then, the antennas were aimed at the reflection point on the test surface and then received reflected power was measured.

The LOS measurements provided a reference for comparison with the received power values from the reflection measurements. Performing the LOS and reflected path measurements sequentially ensured that variances due to the measurement equipment (e.g., temperature variations, cable losses, connector losses, etc.) were minimized. This two-step method was repeated for each desired incident angle.

The LOS power was taken to be the free space value i.e.

$$(15) \quad (P_R)_{LOS} = \frac{P_T G_T G_R \lambda^2}{(4\pi d_{LOS})^2},$$

where P_T is the transmitted power, G_T is the gain of the transmitting antenna, G_R is the gain of the receiving antenna, λ is the wave length of radiation and d_{LOS} is line of sight distance.

The reflected power was taken to be the free space value for the unfolded path length multiplied by the square of the voltage reflection coefficient (Γ), or

$$(16) \quad (P_R)_{\text{reft}} = \frac{P_T G_T G_R \lambda^2 |\Gamma|^2}{(4\pi)^2 (d_1 + d_2)^2}$$

where d_1 is distance between transmitting antenna and center of illumination area of bricks site and d_2 is distance between receiving antenna and center of the illumination area of bricks site. Taking the ratio of equations (15) and (16) and solving for the reflection coefficient gives:

$$(17) \quad |\Gamma| = \frac{d_1 + d_2}{d_{\text{LOS}}} \sqrt{\frac{(P_R)_{\text{reft}}}{(P_R)_{\text{LOS}}}}$$

The dielectric constant of the bricks measured by using free space transmission measurement and found 4.42 at 9.5 GHz. whereas the h_{rms} of the bricks site is 0.6 cm

4. Result and Discussion

A. Line of Sight (LOS) Power and Reflected Path Power Measurement

Figure-3 shows the variation of line of sight power (LOS) with line of sight distance. This measurement has been performed with the two antennas of scatterometer facing each other.

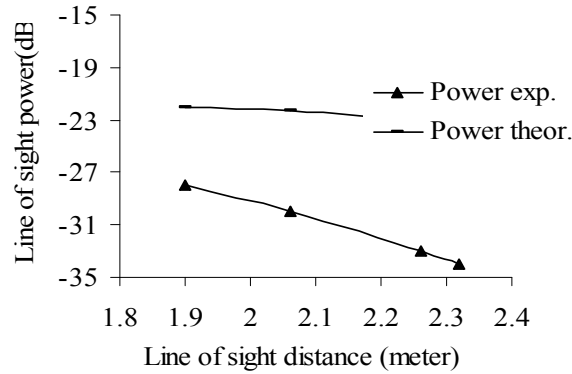


Fig.3 Variation of line of sight power(LOS) with line of sight distance

The LOS is decreasing as the line of sight distance is increasing. The maximum power received in case of LOS is -28 dB at 1.9-meter distance. Theoretically calculated power by using equation (15) is also shown in the

figure (3), its maximum value is -22 dB at 1.9-meter distance. Theoretical value is decreasing with increasing distance, but very slowly.

The antennas were aimed at the bricks site to measure the received reflected power from the bricks site at 20° incidence angle. The distance measurement for the LOS and reflected path perform sequentially to minimize the variances due to measurement equipments. Figure (4) shows the variation of received power of bricks and aluminum sheet with distance for VV-pol.

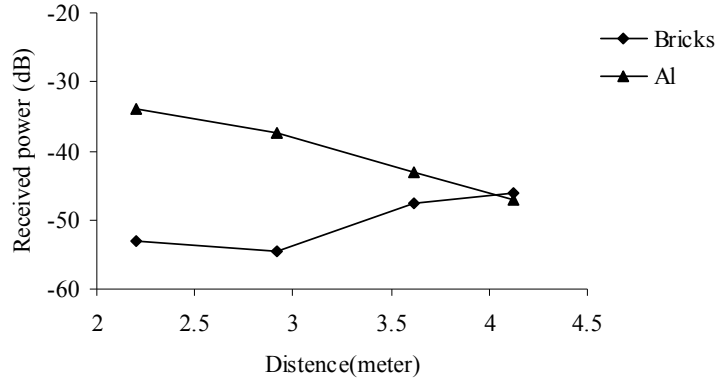


Fig. 4: Variation of received power with distance (VV-pol) at 20 degree incidence angle

The received power is decreasing with increasing distance, for aluminum. In case of bricks, the power decreases as we increase distance up to 2.9 m, then it increase with increasing distance. The maximum value of power for VV-pol is -46 dB at 4.2 m. The average power received by aluminum sheet is high in HH- pol (figure 5). Received power shows decreasing trend for bricks in HH- pol, it starts from maximum value -34 dB at 2.3 m and minimum value -45 dB at 4.2 meter distance.

B. Analysis of Reflection Coefficient

Figure-6 show the angular variation of the measured reflection coefficients of bricks site for VV-pol. & HH-pol. In VV-pol, the value of reflection coefficient increases from 30° to 40° incidence angle. However, at 50° of incidence angle its value decreases sharply, shows the Brewster angle effect. For HH-pol the reflection coefficient of the bricks shows very different result. Initially its value increasing with increasing incidence angle from 30° to 40° and then it become constant. The average valve of reflection

coefficient for bricks in HH pol is higher than the reflection coefficient of VV-pol for bricks.

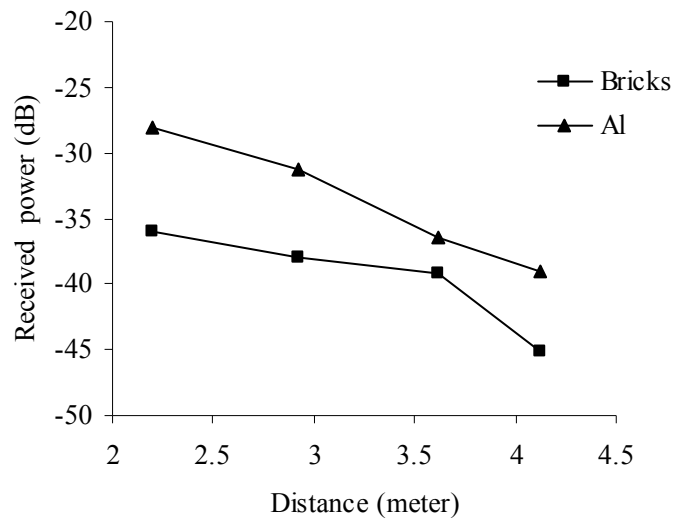


Fig. 5: Variation of received power with distance (HH - pol) at 20 degree incidence angle

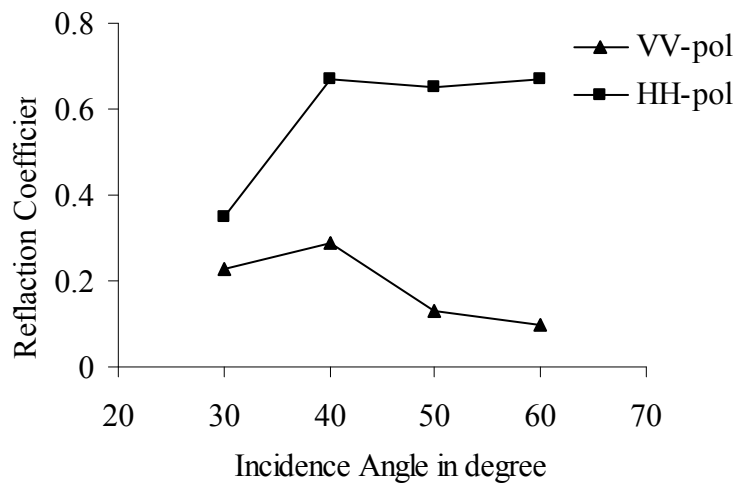


Fig.6 Angular variation of Reflection Coefficient of Bricks

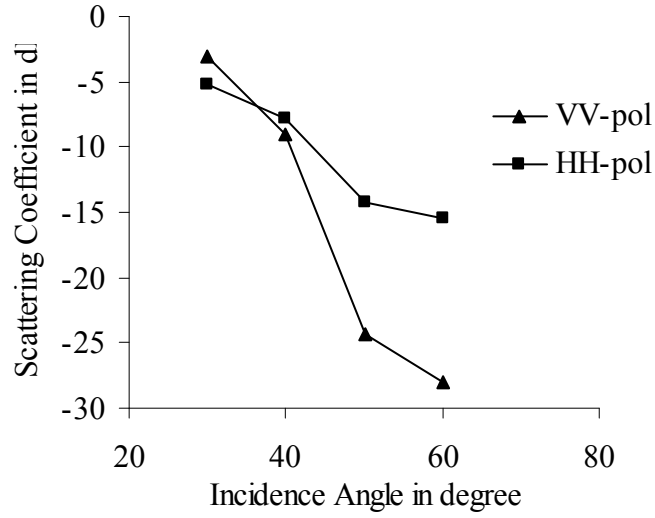


Fig. 7 Angular variation of Scattering Coefficient of Bricks

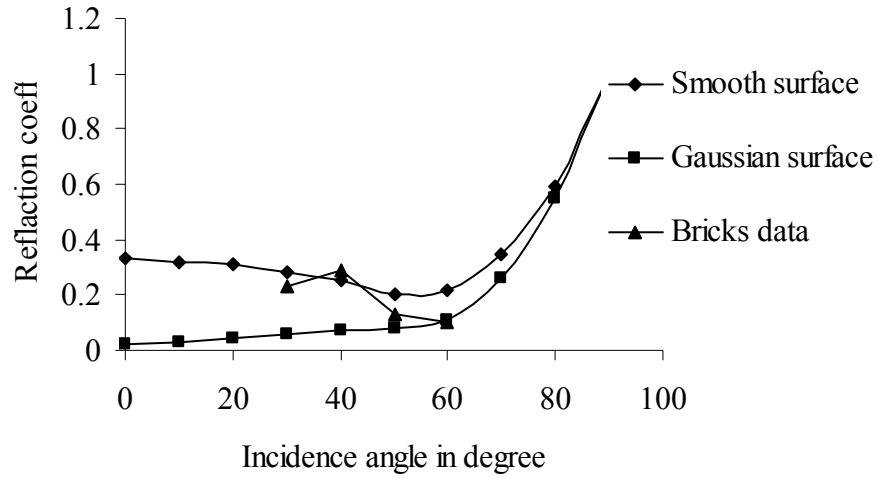


Fig.8: Comparison of observed and theoretical reflection coefficient (VV-pol)

Figures (8) and (9) show the angular variation of the reflection coefficient for bricks by using equation (17) and the theoretically calculated reflection coefficient by equations (1),(2),(6) & (7) (for smooth surface and Gaussian rough surface). The measure value of reflection coefficients lies

between the predicted value of reflection coefficient for smooth surface and Gaussian rough surface for VV-polarization, but in the case of HH-polarization, the measured value of the reflection coefficients is much higher than predicted reflection coefficient.

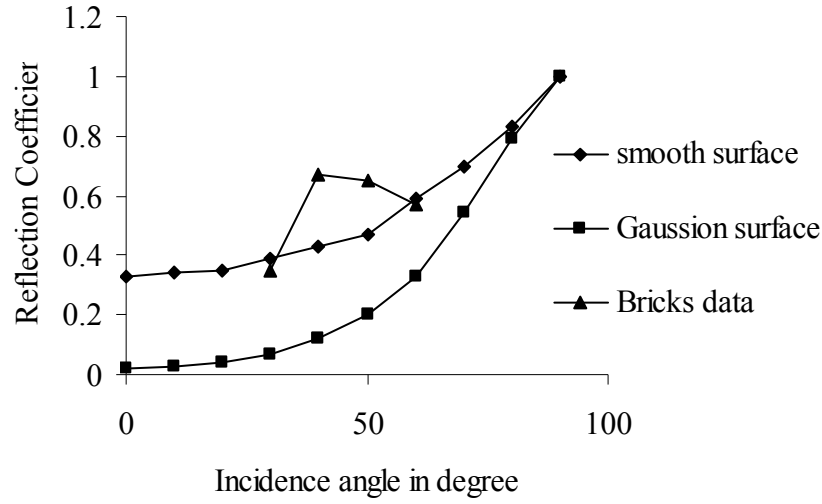


Fig. 9: Comparison of observed and theoretical Ref. Coefficient (HH-pol.)

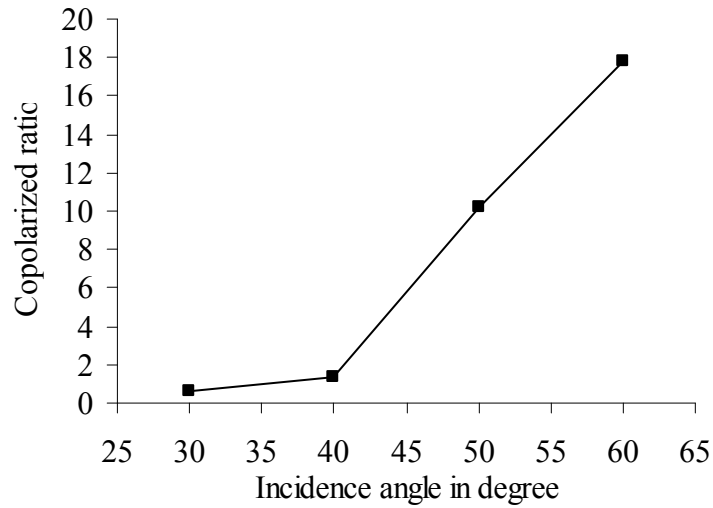


Fig.10 Angular variation of copolarized ratio (Bricks)

C. Analysis of scattering coefficient

The scattering coefficient for the both like polarization at X-band (9.5 GHz) for the bricks site has been observed. Figure-7 display the angular variation results of the scattering coefficient for VV-pol and HH-pol. For both like polarization the value of scattering coefficient is decreasing with increasing incidence angle. At 60° incidence angle the value of scattering coefficient is -32 dB for VV-pol (show the Brewster angle effect), in case of HH-pol the value is much higher, -15 dB.

D. Analysis of Polarimetric Ratio

Effect of polarization and its interaction with surface parameters has been observed with the measurement of copolarized ratio and discrimination ratio. The copolarized ratio and discrimination ratio have been calculated with scattering coefficients of both like polarization (VV-pol, HH-pol). Figure(10) show the angular variation of the copolarized ratio, up to 40° of incidence angle its value is very low (~ 0.8) and then sharply increasing with increasing incidence angle. The similar trend is observed for discrimination ratio as shown in figure (11). At 60° incidence angle the co polarization ratio and discrimination ratio both are maximum. This indicates clearly the high separation between σ_{hh} and σ_{vv} at high incidence angle.

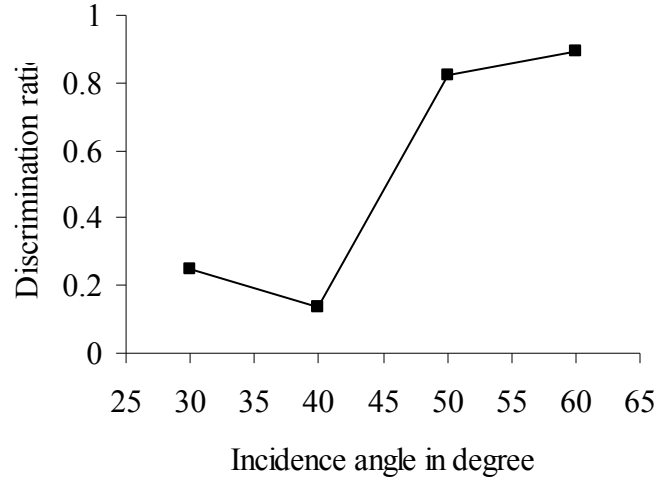


Fig. 11: Angular variation of Discrimination ratio (Bricks)

Table 1: Scatterometer Characteristics

Central frequency	9.5 GHz
Frequency Band Width	0.8 Hz
Antenna Type	Dual Polarized Pyramidal Horn
Antenna band Width	8.5 Degree
Antenna Gain	20dB
Plate form Height	03 m
Cross – Poll Isolation	40dB
Calibration Accuracy	1dB

5. Conclusion

Measurements, prediction as well as comparisons were performed for both like polarizations at bricks surface for X-band microwave frequency. The line of sight (LOS) power is very high in comparison to antenna site path received power. At 2.2-meter distance, about 65% power absorption is recorded for VV-pol; in case of HH-pol the power absorption is less (12.5%). It is observed that over 90% of the measured reflection coefficients are bounded by the Fresnel formula for smooth and rough surfaces. The scattering coefficients of bricks for VV-pol and HH-pol have been measured and its angular variation is studied. Quite strong angular variation of scattering coefficient has been noticed at X-band that may be used to select the optimum incidence angle to characterize the bricks behavior at X-band.

References

1. C. L. Dillard, M. G. Timothy and W. B. Charles, Rough Surface Scattering From Exterior Walls at 28 GHz, *IEEE Trans. Antennas and Propagt.*, **52-12** (2004) 3173-3179.
2. Ch. Maierhofer and J. Wostmann, Investigation of dielectric properties of brick materials as a function of moisture and salt content using a microwave impulse technique at very frequency, *NDT&E International*, **31-4** (1998) 259-263.

3. O. Landron, M. J. Feuerstein and T. S. Rappaport, In situ microwave reflection coefficient measurements for smooth and rough exterior wall surfaces, IEEE Veh. Technol. Conf., Secaucus, NJ, May 18-20, 1993.
4. L. Boithias, *Radio wave propagation*, McGraw-Hill Inc., New York, 1987.
5. W. S. Ament, Toward a theory of reflection by a rough surface, *Proceeding of the IRE*, **41-1** (1953) 142-146.
6. F. T. Ulaby, R. K. Moore and A. K. Fung, *Microwave Remote Sensing (Active and Passive)*, Vol-I, II and III, Addison wesely Publishing company, Reading, MA, 1982.
7. F. Mattia, T. L. Toan, J. C. Souyris, N. Grolis, F. Floury and G. Pasquariello, The effect of surface roughness on multi frequency polarizationarimetric SAR data, *IEEE Trans. Geosci. and Rem. Sens.*, **35** (1997) 954-966.
8. Y. Oh, K. Sarabandi and F. T. Ulaby, An empirical model an inversion technique for Radar scattering from bare soil surfaces, *IEEE Trans. on Geo. and Rem. Sens.*, **30** (1992) 370-381.
9. D. Singh, Polarization discrimination ratio approach to retrieve bare soil moisture t X-band, *Proce. of IEEE, IGARSS*, (2005) 408-411.
10. N. C. Curie, *Radar reflectivity measurement: Techniques and Applications* Artech House, 1989.