CHAPTER - 2

EXPERIMENTAL DETAILS

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2.1 BISTATIC SCATTEROMETER MEASUREMENT

The outdoor test bed size of 4×4 m^2 of bare soil surface and for different type of crops (rice, kidney bean, wheat and chickpea) were specially prepared to carry out bistatic scatterometer measurements at X-band beside the Department of Physics, Indian Institute Technology (B.H.U), Varanasi, India.

Figure 2.1 and Table 2.1 show the geometry and specifications of the bistatic scatterometer system, respectively. In the bistatic configuration, the transmitter and receiver were placed opposite to each other during the measurement of microwave response of the natural terrain (crops/bare soil surface). The transmitter consisted of PSG high power signal generator (E8257D, 10MHz to 20 GHz), pyramidal dual polarized horn antenna and antenna support tower. The receiver consisted of EPM- P series power meter (E4416A), peak and average power sensor (E9327A, 50 MHz – 18 GHz), pyramidal dual polarized horn antenna and antenna support tower. The signal of 20 dBm was transmitted. The polarization of horn antenna was changed by using 90° E-H twister. The portable iron antenna support towers were specially made in the workshop for carrying the transmitting and receiving antennas. The antenna support tower has the facility to adjust the incidence angle and the height of transmitting and receiving antennas. Pointer provided on the circular scale and linear scale respectively can measure the incidence angle and height of transmitting and receiving antennas. The laser pointer was used to match the transmitting and receiving antenna beams at the centre of target for all the angular measurements. The laser pointer helps to overlap the footprint of both (transmitting and receiving) antennas at the centre of the target.

. Attempts were made to receive the coherent component of the scattered waves from the target by adjusting the position of the antenna. The antennas were placed in far field region from the center of the target to minimize the near field interactions. The calibration of system was done regularly during the experiment to ensure the integrity of the system.

All the observations were carried out by changing the incidence (θ_i) and receiving angles (θ_r) in the angular range of 20° to 70° in the elevation direction for azimuthal angle (ϕ= 0).

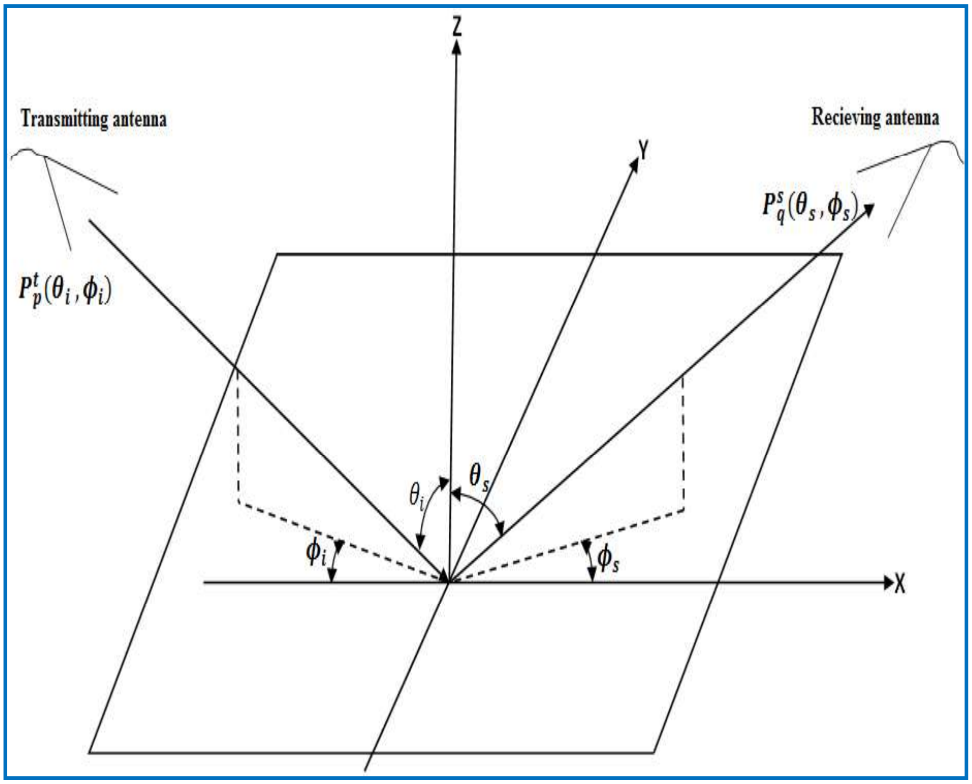

Figure 2.1 Geometry of the bistatic scatterometer system

Figure 2.2 shows the aluminium sheet used for the calibration of the bistatic scatterometer system (Curie 1989). This system has capability to measure the reflected and transmitted power for the angular range of 20° to 70° at HH- and VV-polarizations for X-band (10 GHz). If λ is the wavelength of the transmitted wave, P_t is the transmitted power, G_r and G_t are gain of receiving and the transmitting antennas, R_1 and R_2 are the distance of the transmitting and receiving antenna from the centre of illuminated area, then the power received at the receiver due the perfectly conducting flat aluminum sheet as the reflecting surface is given by

$$P_r^{Al} = \frac{P_t G_r G_t \lambda^2}{(4\pi)^2}(R_1 + R_2)^2 \tag{2.1}$$

If the reflectivity of a reflecting target is $\left|{R_0}^2\right|$ then the received power can be expressed as

$$P_r = \frac{P_t G_r G_t \lambda^2 |R_0|^2}{(4\pi)^2}(R_1 + R_2)^2 \tag{2.2}$$

The reflectivity(r) of the target may be obtained by the equation

$$r = |R_0|^2 = \frac{P_r}{P_r^{Al}} \tag{2.3}$$

For the Fraunhofer zone observation, the range ($R = R_1 = R_2$) can be taken large enough so that the R could be considered constant over A_0 (the surface), the radar equation (Ulaby et al. 1982) reduces to

$$P_r = P_t \lambda^2 \oint_{A_0} \frac{G_r G_t \sigma^0 ds}{(4\pi)^2 R^4} \tag{2.4}$$

For the average measurement of bistatic scattering coefficient of the target such as crop and soil in our case, the bistatic scatterometer system was calibrated for the target of known radar cross section.

The power received from a standard target i.e. perfectly flat and smooth aluminium plate is written as

$$P_r^{std} = \frac{P_t G_{tm} G_{rm} \lambda^2}{(4\pi)^2}(2R)^2 \tag{2.5}$$

Where G_{tm} and G_{rm} represent the maximum gain of the transmitting and receiving antennas, respectively.

From equations (2.4) and (2.5), we get

$$\frac{P_r}{P_r^{std}} = \frac{I}{\pi R^2} \tag{2.6}$$

Where $I = \oint_{A_0} \sigma^0 G_{tn} G_{rn} ds \;\; and \;\; G_{tn} = \frac{G_t}{G_{tm}}, \quad G_{rn} = \frac{G_t}{G_{rm}}$

Figure 2.2 Aluminum sheet used during the calibration of the system

Assuming bistatic scattering coefficient constant over a 3 dB beamwidth of the antenna beam, we have

$$\sigma^0 = \pi R^2 \frac{P_r}{P_r^{Std}} \oint_{A_0} G_{tn} G_{rn} ds \tag{2.7}$$

From equation (2.6) and (2.7), we have

$$\sigma^0 = \pi R^2 \frac{|R_0|^2}{I_0} \tag{2.8}$$

Where I_0 is the illuminated area of the target. An antenna beam falls on the target surface in the form of an ellipse. Figure 2.3 shows the geometry of illuminated area on the target by the incidence and reflected beam of microwave. Its minor axis and major axis are given by

$$Minor\ axis = 2R^2 tan\left(\frac{\phi_{az}}{2}\right) \tag{2.9}$$

$$Major\ axis = R^2 sin\left(\frac{\phi_{el}}{2}\right)\left[sec\left(\theta - \frac{\phi_{el}}{2}\right) + sec\left(\theta + \frac{\phi_{el}}{2}\right)\right], \tag{2.10}$$

where ϕ_{el}, ϕ_{az}, and θ are elevation, azimuth and look angle of antennas respectively. Therefore, the illuminated area is given by

$$I_0 = \frac{\pi}{2} R^2 tan\left(\frac{\phi_{az}}{2}\right) sin\left(\frac{\phi_{el}}{2}\right)\left[sec\left(\theta - \frac{\phi_{el}}{2}\right) + sec\left(\theta + \frac{\phi_{el}}{2}\right)\right] \tag{2.11}$$

Now, substituting the value of I_0 in equation (2.8), the value of bistatic scattering coefficient is obtained as

$$\sigma^0 = \frac{2|R_0|^2 \cot\left(\frac{\phi_{az}}{2}\right) cosec\left(\frac{\phi_{el}}{2}\right)}{sec\left(\theta - \frac{\phi_{el}}{2}\right) + sec\left(\theta + \frac{\phi_{el}}{2}\right)} \tag{2.12}$$

Therefore, the bistatic scattering coefficient in unit dB can be written as

$$\sigma^0(dB) = 10log_{10}\left[\frac{2|R_0|^2 \cot\left(\frac{\phi_{az}}{2}\right) cosec\left(\frac{\phi_{el}}{2}\right)}{sec\left(\theta - \frac{\phi_{el}}{2}\right) + sec\left(\theta + \frac{\phi_{el}}{2}\right)}\right] \tag{2.13}$$

Therefore, knowing the value of the elevation, azimuth, look angle of an antenna and the reflectivity of the target, we can compute the bistatic scattering coefficient of the target by equation (2.13).

2.2 SOIL SURFACE PARAMETERS MEASUREMENT

2.2.1 SOIL MOISTURE CONTENT MEASUREMENT

The gravimetric moisture content of soil is defined as ratio of weight of water present in soil to weight of dry soil. It is expressed as a percentage of soil moisture content. The soil moisture content may also be expressed by volume as a ratio of volume of water to the total volume of the soil sample. To determine gravimetric or volumetric moisture content for a particular soil sample, the water mass must be determined by drying the soil sample.

Area of the ellipse $= \frac{\pi}{4} D_1 D_2$

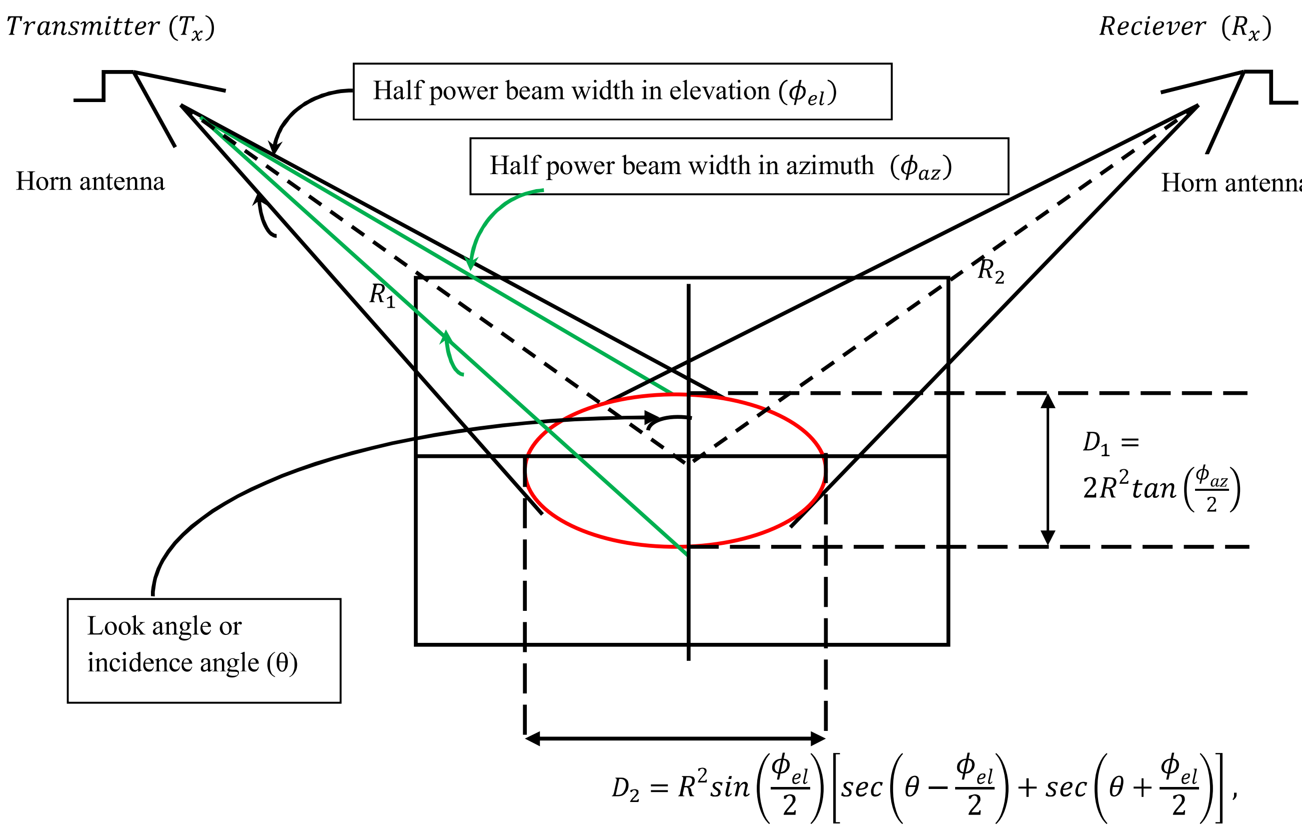

Figure 2.3 Geometry of illuminated area by the beam on the target surface

Table 2.1 Specifications of bistatic Scatterometer system

Parameter		X - Band
Frequency (GHz)		10 ± 0.05
Beam Width	E plane (°)	17.3118
	H plane (°)	19.5982
Band width (GHz)		4
Antenna gain (dB)		20
Cross-polarization isolation(dB)		40
RF generator		E8257D, PSG High Power Signal Generator,10MHz to 20 GHz (Agilent Technologies)
Power meter		E4416A, EPM-P Series Power meter, 10MHz to 20 GHz (Agilent Technologies)
Power sensor		Peak and average power sensor (E9327A, 50 MHz – 18 GHz)
Polarization modes		Horizontal transmit – Horizontal receive (HH) Vertical transmit – Vertical receive (VV)
Antenna type		Dual-polarized pyramidal horn
Calibration accuracy (dB)		1
Platform height (meter)		3
Incidence angle (°)		20° (nadir) – 70°
Measurement interval		20 Minute

Five random soil samples were collected in aluminum soil container up to depth of 5 cm from the soil surface. These soil samples were dried in an oven at 100-110 ^{0}C for 24 hour. The soil samples were weighted before and after drying to compute the gravimetric moisture content. The average of gravimetric moisture content of all the five soil samples were taken to calculate the percentage of soil moisture content of the soil surface. The procedure and requirement to compute the soil moisture content are described point wise as,

2.2.1.1 REQUIREMENTS

- Oven with 100 –110 °C temperature for drying the soil samples.
- A balance of precision of ±0.001 g for weighting the soil samples.
- Aluminium soil container and tube Auger the soil samples from the ground surface.

2.2.1.2 PROCEDURE TO CALCULATE THE SOIL MOISTURE CONTENT

- Taking the soil samples in the soil container from the ground surface depth of 5 cm about a 50 to 200 g. The weight of wet soil sample was measured.
- The soil sample was placed in the oven at 100 °C for 24 hours or overnight after weighting the soil sample and taking the weight of wet soil sample.
- After drying of soil sample, the weight of dry soil sample was measured.

2.2.1.3 SOIL MOISTURE CONTENT COMPUTATION

The gravimetric soil moisture content (M_g) on dry weight basis may be computed using equation (2.15) (Gupta et al (2014), Singh, D (2005), Prasad et al (2009)),

$$M_g = \frac{(weight\ of\ wet\ soil\ sample) - (weight\ of\ dry\ soil\ sample)}{(weight\ of dry\ soil\ sample)} \quad (2.15)$$

2.2.2 SURFACE ROUGHNESS MEASUREMENT

A 1 meter long metallic plate painted with the grid (1cm^2) was used for the measurement of soil surface roughness. The metallic plate was pushed into the surface until the grid line reached at the lowest point on the surface. The surface roughness profile was drawn on the metallic plate using ink marker. The photograph of surface roughness profile was taken and then later digitized from the photograph. The advantage of this approach is that it is easy to make the measurement, and equipment is relatively cheap and easily operated in the field (Elachi and Van Zyl 2006).

2.2.2.1 ROOT MEAN SQUARE HEIGHT (σ) MEASUREMENT

The surface height variation $z(x)$ of a random surface can be considered as the function of horizontal distance (x) across the mean surface. The profile is digitized into discrete values $z_i(x_i)$ at an appropriate spacing Δx**.** The surface height variations across its horizontal distance can be extracted from the digitized photograph of rough surface profile. The detail about the photograph of rough surface profile is presented in the Section 2.2.2. This data contains the vertical surface heights (cm) at the horizontal spacing of 1cm above and below the mean surface height. Such as 100 data points were acquired from the digitized photograph.

The rms height of the discrete one dimensional surface roughness profile can be written as,

$$s = \left[\frac{1}{N-1}\left(\sum_1^N z_i^2 - N\bar{z}^2\right)\right]^{\frac{1}{2}} \qquad (2.16)$$

Where N is the number of samples and

$$\bar{z} = \frac{1}{N}\sum_{i=1}^{N} z_i \qquad (2.17)$$

where $\bar{z}$ id the mean surface of the surface height variation.

2.2.2.2 AUTO CORRELATION FUNCTION AND CORRELATION LENGTH MEASUREMENT

The statistical variation of a random surface is characterized by its rms height σ and its autocorrelation function $\rho(\xi)$. The detailed procedure for the measurement of surface height variation $z(x)$ of typical one dimensional random rough surface profile as a function of horizontal distance (x) is presented above.

The surface autocorrelation function is a measure of the degree of correlation between the surface height variation $z(x)$ at a point x on horizontal scale of the surface profile and the surface height variation $z(x+\ \xi)$ at a point ξ distance from x. The autocorrelation function of discrete one-dimensional surface can be expressed by equation (2.18),

$$\rho(\xi) = \frac{\sum_{i=1}^{N+1-j} z_i z_{j+i-1}}{\sum_{i=1}^{N} z_i^2} \qquad (2.18)$$

Where $\xi = (j-1)\Delta x$ and j is an integer ≥ 1.

The correlation length (l) of a rough surface is defined as the displacement ξ for which $\rho(\xi)$ is equal to e^{-1}

$$\rho(l) = e^{-1} \qquad (2.19)$$

The value of (l) is small for a surface with a rapidly varying height profile, whereas for a perfectly smooth surface for which any point is perfectly correlated with every other point, l is infinite. In general, the rms height (σ) is a measure of the vertical roughness of the surface and correlation length (l) is a measure of the horizontal roughness.

Theoretical surface scattering models are formulated in terms of the autocorrelation function of the surface $\rho(\xi)$. Several mathematical forms have been used in the literature to describe autocorrelation function $\rho(\xi)$ of the natural surfaces. These include;

$$\rho_1(\xi) = \exp\left(-\frac{\xi^2}{l^2}\right) \qquad \text{Gaussion} \qquad (2.20)$$

$$\rho_2(\xi) = \exp\left(-\sqrt{2}\frac{\xi}{l}\right) \qquad exponential \qquad (2.21)$$

These theoretical autocorrelation functions do not provide good match to measure autocorrelation functions of real surface, particularly for displacements exceeding $\xi = l$. This is the limitation of representing the statistical height variations of real surfaces, which are responsible for the relatively poor agreement between the theoretically and experimentally observed radar responses to surface roughness.

2.3 CROP VARIABLES MEASUREMENT

2.3.1 VEGETATION WATER CONTENT (VWC) MEASUREMENT

The vegetation water content (VWC) is defined as the total water content available in the plant constituents. The crop was grown uniformly in the crop bed under study. The sampling strategy for the measurement of VWC depends on the crop type. Two sampling strategy can be adapted to measure the VWC for different types of crop.

If the number of plants or bunches of plants can be calculated in 1 m^2 of the crop bed like rice crop, kidney bean crop and chickpea crop. Then the total number of plants was calculated and divided by 16 (4×4 m^2) for the calculation of number of plants per $meter^2$ (plant density). Five different locations in the crop bed of 1 $meter^2$ area were selected. The total five rice plants were taken from each different locations of 1 $meter^2$ area in the crop bed for computation of VWC.

If the number of plants or bunches of plants cannot be calculated in 1 m^2 of the crop bed like wheat crop. The 10×10 cm^2 area were selected at the five places of the crop bed. The total plants were pulled out from these five small places in the crop bed. The small places (10×10 cm^2) were selected in the crop bed because of the limited area available in our observation crop bed.

In both the cases, total five samples were taken for the computation of VWC from different locations of the crop bed. The leaves and stalks of plants (five samples) were dried in an oven at 100 °C for 24 hours. These five samples were weighted before and after drying separately. The average of these five samples was taken to compute the overall VWC.

In case, the number of the plants can be counted as in the crop bed area 1 meter^2. The following formula was used to compute the VWC

$$(weight\ of\ wet\ plant - weight\ of\ dry\ plant) \times\ plant\ density \tag{2.22}$$

In case, the number of the plants cannot be counted as in the crop bed area 1 meter^2, the following equation (2.23) was used to compute the VWC,

$$(weight\ of\ wet\ plant - weight\ of\ dry\ plant) \times 100 \tag{2.23}$$

2.3.2 LEAF AREA INDEX (LAI) MEASUREMENT

Leaf Area Index (LAI) is defined as the ratio of one sided leaf area to ground surface area. In the present thesis, two instrument were used to measure the LAI of the crop namely ACCUPAR LP-80 Ceptometer and LAI-2200C Plant Canopy Analyzer. These two instruments provide the non destructive method for the measurement of leaf area index.

An instrument ACCUPAR LP-80 Ceptometer (Cohen et al. 1997; Delalieux et al 2008; Kovacs et al. 2009) was used for the measurement of leaf area index of rice and kidney bean crops at its different growth stages. The 20 samples of leaf area index were taken at different locations of crop bed. The average of all 20 LAI samples was taken to compute the overall leaf area index. The sun rays direction, sun light intensity and alignment of the sensors are the important parameters to get accurate measurement of leaf area index by ACCUPAR LP-80 Ceptometer instrument. All the 20 samples of leaf area index were taken in enough sun light intensity along all four directions of crop bed (5 samples in each direction) and maintained the proper alignment by bubble provided at the sensor surface.

The LAI-2200C canopy analyzer was used to measure LAI of wheat and chickpea crops. It computes LAI from measurements made above the canopy and below the canopy. It observes the canopy light interception at 5 angles. The LAI-

2200C has some benefits over other methods such as ceptomtry, which are (i) less assumptions require about canopy structure (ii) the gap fraction measure at 5 zenith angles in single measurement (iii) in contrast to linear sensors, there is no need to wait for the sun angle to change or make multiple measurements to acquire this data (iv) measures up to a 360° azimuthal view for each zenith angle. This provides a large sample area for good spatial averaging (v) filters light below 490 nm to avoid leaf transmission and reflectance errors that occur in some LAI sensors (vi) requires no calibration (vii) can measure small plots and isolated plants (viii) Computes LAI instantly and includes powerful post-processing software.
(https://www.licor.com/env/products/leaf_area/LAI-2200/)

2.3.3 PLANT HEIGHT MEASUREMENT

A linear wooden scale of 1.5 meter length was used to measure the plant height in the crop bed under investigation. The wooden scale is kept vertically in the crop bed. A wooden sheet (5 mm) placed over the plants can move up to top edge of the plants. The thin wooden sheet marks a point on the vertically linear scale and read the height of plants.

2.3.4 SPAD VALUE MEASUREMENT

The SPAD-502 plus was used to measure the SPAD values or chlorophyll contents of leaves of the crop. It also provides the non-destructive method for the measurement of chlorophyll content (Coste et al. 2010; Ling et al. 2011). Ten plants at different locations of the crop bed were selected. The SPAD measurements were taken for all leaves of each plant. The average of SPAD values was taken. This instrument provides a relative index of chlorophyll concentrations.

2.3.5 LEAF LENGTH AND LEAF WIDTH MEASUREMENT

A vernier caliper was used to measure the width and thickness of leafs of the crop. The linear scale was used to measure the leaf length of the plants. The measurement of leaf length is simple however the width and thickness measurements are very tedious due its shape.