# Calculation of Phase Center of Large Geomorphological Object on the Surface


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**ABSTRACT:**

A numerical scattering model for artificial metal structure based on physical optics approximation is developed to identify the height of phase center, and the result is compared with interferometric SAR DEM. The interferometric SAR data were gathered by AIRSAR during PACRIM-Ⅱ campaign on Jeju Island. Power transmission towers on piedmont pasture along the slopes of Mt. Halla look like elliptic risings in TOPSAR DEM. The heights of risings are quantitatively analyzed using a scattering model in the way of achieving the height of phase centers of power transmission towers. A numerical algorithm is developed on the basis of physical optics approximation. The structure of power transmission tower was decomposed into hundreds of rectangular metal plates, of which the scattering matrix is known in analytic form, and the calculated scattering fields were summed coherently. The effect of direct backscattering component, ground-scatterer component and scatterer-ground component are decomposed and computed individually for each rectangular metal plate. The $\Delta$k-radar equivalent was used to calculate height of phase center of the scatterer. The heights of a selected power transmission tower and scattering algorithm results give existence and location of the transmission towers but not actual tower heights.


## 1. INTRODUCTION

The power transmission tower requires systematic management because it degrades landscapes and can be possible source of disasters (Sarabandi et al., 1994). Power transmission tower is one of the most dominant artificial structures found in the study area. Although power transmission towers are not clearly seen in optic sensor images, they stand out in SAR images and produce anomalies on an interferometric SAR DEM.

Observation of forest has been actively studied for decades because only radar observations can assess significant forest parameters such as vegetation biomass or leaf area index, which are vital parameter in the Earth system (Chauhan *et al.* 1991; Kobayashi *et al.*, 2000; Sarabandi, 1997; Lin *et al.*, 1999). Advancements of radar interferometry enabled new application by adding extra parameters; the correlation coefficient and the interferogram phase (Sarabandi *et al.*, 2000) In the study of Kamal and Yi-Cheng, interferometric height was simulated by scattering model of which technique is characterized by coherent sum of scattering field in order to preserve phase information (Lin *et al.*, 1999, Sarabandi *et al.*, 2000). In this paper, the idea is applied to find out height of phase center of power transmission tower.

The purpose of this investigation is to develop an algorithm for power transmission tower capable of predicting the InSAR response. The scattering model suggested by Kamal S. preserves phase information and adopted in this study (Sarabandi, 1997; Lin *et al.*, 1999).

Algorithm and method description in section 2 is composed of descriptions of data acquisition, creation of virtual tower structure, explanation about scattering field computation algorithm and $\Delta$k-radar equivalence relationship with InSAR to extract scattering-phase center. In section 3, input parameters are explained and the results were compared with the real SAR data and conclusion is followed in section 4.

## 2. BACKGROUND AND DESCRIPTION

*A. Data Acquisition*

Two kinds of basic data were used in this study; one is AIRSAR/TOPSAR DEM and the other is *in situ* measurements of a typical power transmission tower. TOPSAR data were acquired by AIRSAR survey during PACRIM-Ⅱ campaign on $30^{th}$ September 2000. Full DEM of Jeju Island was composed from C-band VV polarized single pass SAR data. Recent ground truthing was done on $7^{th}$ May 2004. There are several numbers of power transmission lines running across Jeju Island. One power transmission tower located in an easy to access area was selected and its base width and height are measured by tape measuring and trigonometry using theodorite which measures look up angle. Its position is shown in Fig. 1 and in situ photo of the selected power transmission tower is shown in Fig. 2. Some of the measurements are presented at Table.1.

First, DEM height of selected power transmission tower is extracted. Because we can see some deviations of height even over flat surface in DEM as can be seen in Fig. 1, the mean height of the vicinity around the rise caused by power transmission tower is computed to produce 'vicinity height'. The height distribution of the rise is fitted to two-dimensional Gaussian function and its maximum is considered as 'tower top height'. The subtraction of 'vicinity height' from 'tower top height' is then considered as 'tower height' on DEM. Extracted

DEM height of selected power transmission tower was 8.4m as given in Table 2.

*B. Virtual Power Transmission Tower Structure*

The scattering matrix of rectangular flat conductor respect to given incidence and scattering direction is known in analytic form if physical optics approximation is assumed (Ulaby *et al.*, 1990). In order to apply this result, the power transmission tower was decomposed into 348 rectangular segments with different lengths, orientations and positions (Fig. 3). Orientations are defined in the form of 3 by 3 matrices which rotate coordinate axes to align with each side of rectangular segment to be put parallel to x-axis and y-axis. Then the incidence and scattering wave vectors in global coordinate are transformed by same transform matrix described above so that the scattering field is calculated in the geometry in which the solution is known.

## 3. COHERENT SCATERING SUMMATION

*A. Scattering Calculation algorithm*

Once virtual power transmission tower structure is generated, the scattering field is computed by coherently summing up the scattering field from each rectangle composing the virtual structure. Only the first order scattering is computed from the coherent addition of the individual scattering terms. The total scattering field can be written as

$$\mathbf{E}^s = \frac{e^{ikr}}{r}\sum_{n=1}^{N} e^{i\phi_n}\mathbf{S}_n\mathbf{E}_0^i \quad (1)$$

where $N$ is total number of the scatterers, $\bar{\bar{S}}_n$ is the individual scattering matrix of the $n$th scatterer, which is rectangular segment, and $\phi_n$ is the phase compensation accounting for the shift of the phase dependent on position. This is given by $\phi_n = k_0(k_i - k_s)\cdot\vec{r}_n$, where $\vec{r}_n$ is the position vector of the $n$th scatterer in the global coordinate system.

The scattering matrix of the $n$th rectangular S is composed of three components: direct component $\mathbf{S}_n^t$; ground-scatterer component $\mathbf{S}_n^{tg}$; scatterer-ground component $\mathbf{S}_n^{gt}$. In this study, only direct component is used because in C-band, the ground is thought to be not specular.

*B. Δk-radar equivalence relation*

According to Kamal, phase difference between two slightly different look angles in interferometric SAR configuration can be considered as phase difference between the received signals of two antennae operating slightly different frequencies when the look angle is known (Kamal, 1997). For an InSAR system with known baseline distance( $B$ ) and angle $\alpha$ operating at frequency $f_0$, the frequency shift( $\Delta f$ ) of an equivalent Δk-radar is given by

$$\Delta f = \frac{f_0 B}{mr}\sin(\alpha - \theta) \quad (2)$$

where $\theta$ is the look angle, $m = 1,2$ for repeat-pass and two-antenna InSAR configuration, respectively, and $r$ is distance between the antenna and the scatterer.

TABLE 1
PHYSICAL DIMENSIONS OF THE POWER TRANSMISSION TOWER

| | |
|---|---|
| Location coordinate | 33° 24′ 11.634″ N |
| | 127° 24′ 30.786″ E |
| Base Width | 7.5 m |
| Height | 42.40 m |

Once each electric field is calculated, simple geometry gives phase height of the scatterer determined from

$$z_e = \frac{-\Delta\Phi}{2\Delta k\cos\theta} \quad (3)$$

where $\Delta k = 2\pi\Delta f / c$ and $\Delta\Phi = \angle E_1^* E_2$ represents the phase difference between $E_1$ and $E_2$, which are electric field received by both radars.

## 4. RESULT

Computer algorithm to calculate coherent scattering field is made and executed. Main input parameters are virtual power transmission tower structure and nature of incidence wave. Virtual transmission tower structure is made manually referencing *in situ* measurements.. Incidence wave direction is calculated from incidence angle, which is extracted from the position of power transmission tower in TOPSAR DEM.

Incidence angle varied from 35° to 65° The azimuth angle of incidence wave vector is another factor affecting the scattering behavior. But the dihedral shape of the skeleton produces strong backscatter to almost every incidence angle. So it is assumed that the RCS will show isotropic behavior. In this study, incidence angle was selected to be zero.

There were two lines of power transmit towers in TOPSAR image, Each line was composed of several dozens of power transmit towers showing various incidence angle, Though the angle between the directions of each power transmit towers were about 60°, there was little difference of RCS trand supporting the feasibility of azimuth isotropic assumption.

A. RCS comparison

In the analysis of RCS value of TOPSAR image, the peak of RCS value happens twice in the incidence angle domain. A smaller one is about 40° and a larger one is at 65°. Similar trand was found at the result of simulation. It showd a sharp peak about 49° and and another peak was found at 65°. A peak at smaller incidence angle is though to be related with oblique steel bars. In the simulation result, the angle of oblique bar is fixed to one value, resulting high RCS at that angle. In TOPSAR data, a blured peak is observed. It is because the angles of oblique bar is not same at each oblique bar. So it shows unfocused peak.

RCS values are increasing as the incidence angle increases. It is more intuitive. The higher incidence angle makes the incidence vector goes closer to normal vector of side of power transmit tower if power transmit toer is considered as a squre cone. Such a trend is observed in both TOPSAR data and calculation result.

B. Height of phase center comparison

Interferometric height of power transmit tower as a function of incidence angle and longitudinal distance was compared. (Figure 4) Two significant differences were observed and the interpretation will be followed.

First, longitudinal distance under the influence of power transmit tower is directly affected by incidence angle in the calculation result. It is because the passing time of microwave through power transmit tower is determined by $ct_{pass} = h\cos\theta$. So the longitudinal distance decrease as the incidence angle increases. But in TOPSAR data such trend is not optimal.

Second, the profile of height is a right triangle in the case of calculation result while that of TOPSAR DEM is smooth curve in bell shape. (Figure 5 and 6) It is though that in the interferogram reconstruction process, in order to smooth the fluctuation of interferometric phase, interferometric phase enhancement is involved which smoothes the height resolution.

TOPSAR is working on C-band VV polarization, hence wave length is 0.0567m and polarization is vertical. The results obtained using the algorithm are shown in fiqure .

## 5. CONCLUSION

A coherent scattering algorithm for power transmission tower based on physical optics approximation is developed in this paper. The validity and accuracy of the algorithm was demonstrated by comparing the numerical result with the height of phase center extracted in TOPSAR DEM. The comparison of RCS showed similar trand as a function of incidence angle. And the result of interferometric height calculation was different from observed results. Noise reducing filtering is looking forward to may explain this problem.

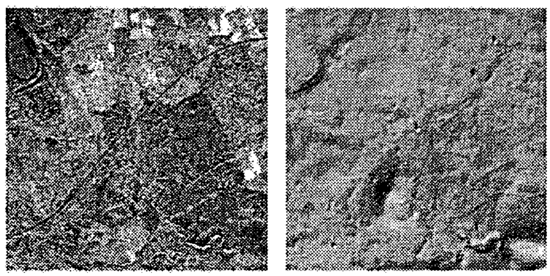
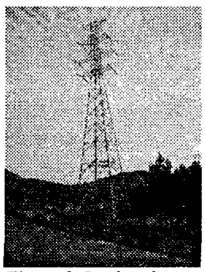


Figure 1. Digital elevation map of Jeju (top) and a portion of a TOPSAR C-band image, indication the power transmission tower (left) and shaded relief map of same region (right). A power transmission line seen in shaded relief map runs along a road seen in TOPSAR image. One power transmission tower is selected and investigated.



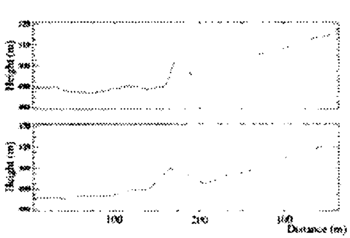


Figure 2. In situ photo of power transmission tower (left) and Figure 3. Height profile along east-west (top) and north-south (bottom) near the power transmission tower The power transmission tower seems to be dispersed.

## REFERENCES


Chauhan, N. S., R. H. Lang, K. J. Ranson, 1991, "Radar Modeling of a Boreal Forest", *IEEE Trans. Geoscience and Remote sensing*, Vol. 29, pp. 627−638

Kobayashi, Y., K. Sarabandi, L. Pierce, M. C. Dobson, 2000, "An Evaluation of the JPL TOPSAR for Extracting Tree Height", *IEEE Trans. Geoscience and Remote sensing*, Vol. 38, pp. 2446−2454

Lin. Y. C., K. Sarabandi, 1999, "A Monte Carlo Coherent Scattering Model For Forest Canopies Using Fractal-Generated Trees", *IEEE Trans. Geoscience and Remote sensing*, Vol. 37, pp. 440−451

Sarabandi, K., L. Pierce, Y. Oh, F. T. Ulaby, 1994, "Power lines: Radar Measurements and Detection Algorithm for Polarimetric SAR Images", *IEEE Trans. Aerospace and Electronic systems*, vol. 30, pp. 632–643

Sarabandi, K., 1997, "Δk-Radar equivalent of Interferometric SAR's: A Theoretical Study for Determinationof Vegetation Height", *IEEE Trans. Geoscience and Remote sensing*, Vol. 35, pp. 1267−1276

Sarabandi, K., Y. C. Lin, 2000, "Simulation of Interferometric SAR Response for Characterizing the Scattering Phase Center Statistics of Forest Canopies" *IEEE Trans. Geoscience and Remote sensing*, Vol. 38, pp. 115−125

Ulaby, F. T., C. Elachi, et al., 1990, *Radar Polarimetry for Geoscience Application*, Norwood, MA : Artech House Inc, pp.61−67

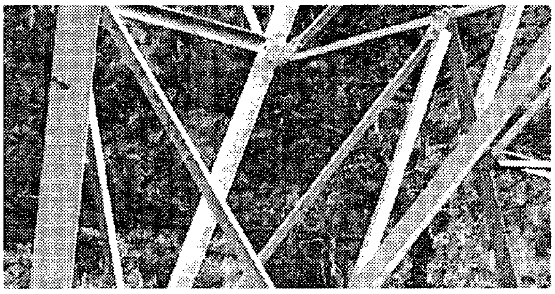



Figure 3. Picture of skeleton of power transmit tower,

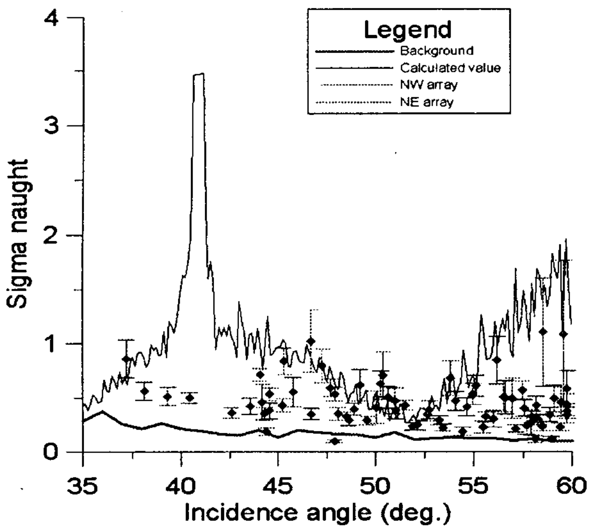


Figure 4. RCS as a function of incidence angle

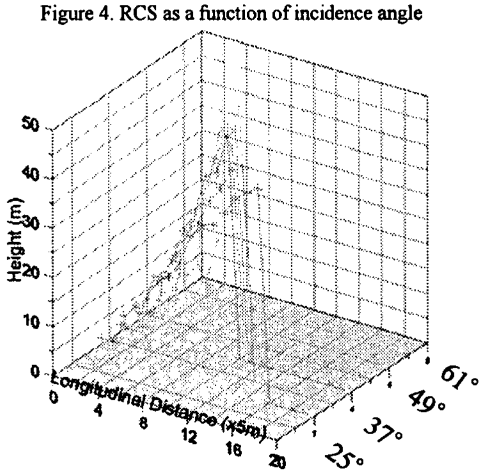


Figure 5. Interferometric height of calculated result

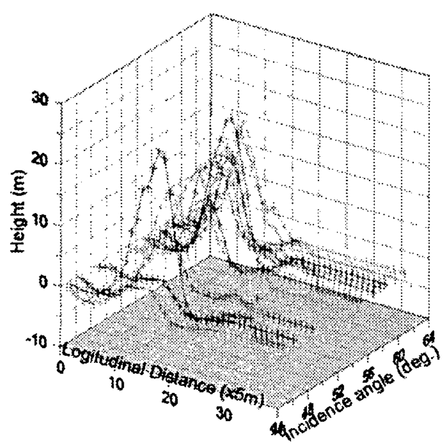


Figure 6. Interferometric height from TOPSAR DEM