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Design of C band antenna downlink system for monitoring Sentinel 1A signals on ground surface

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Abstract. The C band microwave signals are widely used for Earth observation in the field of remote sensing by using synthetic aperture radar sensor. The coverage of Indian regions by Sentinel 1A SAR sensor in interoferometric wide swath mode, provide an opportunity to research and conduct studies in remote sensing areas from urban planning to disaster management applications. The sensor acquired images undergo calibration test to confirm the quality requirements. The foremost significant step to ensure the availability of the signal of Sentinel 1A on the ground surface is by designing a antenna system which tracks and monitor the signal strength. In this context, the following stages are significant in signal monitoring system: satellite downlink budget calculation to ensure minimum signal strength, designing and configuring antenna system to receive the signals and measurement system such as spectrum analyser to monitor the signal strength. The paper presents the mathematical analysis of designing a down link for receiving Sentinel-1A SAR signals. An antenna subsystem is implemented which includes the design of the parabola antenna with horn feed and the simulation of the same using Matlab platform to confirm antenna parameters such as gain, directivity, VSWR and beam-width which meets the practical requirements

Keywords: Sentinel 1A, Matlab, dish antenna, horn feed, spectrum analyser, signal strength

1. Introduction

With the advancements in satellite and sensor technology, the range and diversity of applications has extended to various fields, predominantly in remote sensing areas, from meteorological and ocean studies, the Earth observation and glacier monitoring to disaster management applications. The satellite operating in microwave region is much like terrestrial link in Line of sight (LOS) communication with a large coverage area. An Antenna system is designed and implemented to monitor Sentinel 1A synthetic aperture radar (SAR) signals.

The Satellite downlink budget [1] is a method to ensure the signal power on the ground surface is greater than or equal to receiver sensitivity by accounting all types of losses during the course of signal propagation from the transmitter to receiver as shown in the figure 1

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Let Pt be the power transmitted by the satellite. Due to spread of electromagnetic energy in the course of propagation, an antenna is used to focus the energy in the desired direction or in the direction of the receiver. The effective radiated power (EIRP) is the power radiated by the satellite transmitter constituting a source and an antenna with gain Gt and is equal to product of Pt and Gt



Figure 1. Schematic of satellite down link [13]

The power flux density (φ_m) at a distance R in the direction of maximum radiation is given by

$$\varphi_m = \frac{p_t G_t}{4\pi R^2} \quad \text{watts/m}^2 \tag{1}$$

The receiving antenna with effective aperture A_e intercepts a fraction of the total power and the received signal power P_R is given by

$$P_{R} = \varphi_{m} * A_{e} \tag{2}$$

 A_e is the effective aperture area of the receiving antenna as given by

$$A_e = \frac{G_R \lambda^2}{4\pi} \tag{3}$$

and is related to the gain of the receiving antenna gain G_R as

$$G_R = \frac{4\pi}{\lambda^2} A_e \tag{4}$$

Therefore the received signal power by the antenna is given by

$$P_{R} = \frac{p_{t}G_{t}}{4\pi R^{2}} * \frac{G_{R}\lambda^{2}}{4\pi} = \frac{P_{t}G_{t}G_{r}}{\left(\frac{4\pi R}{\lambda}\right)^{2}}$$
(5)

Where $\left(\frac{4\pi R}{\lambda}\right)^2$ is the free space path loss (FSPL) In decibels, the received power

$$P_{R} = EIRP + G_{R} - FSPL - AL - L_{txa} - L_{Rxa}$$
(6)

In addition to FSPL, the other miscellaneous power losses include atmospheric losses (AL) and antenna misalignment losses, transmitter and receiver antenna losses Ltxa and Lrxa respectively which are taken into account by appropriate design margin typically 5-10dB.

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The article aims to provide a detailed presentation on the design of satellite down link for remote sensing satellite Sentinel 1A. It highlights on design efficiency of Parabola and horn antenna. The simulation results using Matlab is presented to validate the requirements of antenna receiver.

2. Methodology

2.1. Analysis and design of satellite down link for Sentinel -1A at frequency f=5.405GHz

The table.1 lists the specifications of Sentinel 1A in order to compute power budget for down link and estimate the received power on the ground surface

Parameters	Specifications
Centre frequency	5.405 GHz)
Bandwidth	0-100 MHz
Polarisation	HH+HV, VV+VH, VV, HH
Altitude	653Km
Elevation angle	55 ⁰
Incidence angle range	20°- 46°
Look direction	right
Antenna type	Slotted waveguide radiators
Azimuth beam width	0.23°
Elevation beam width	3.43°
RE Peak nower	- 4.368 kW, - 4.075 kW (IW, dual
Ki i cak power	polarisations)
Pulse width	5-100 μs (programmable)
Transmit duty cycle	IW 9%,
Receiver noise figure at	3 dB
module input	
Maximum range	100 MHz
bandwidth	
PRF (Pulse Repetition	1 000 - 3 000 Hz (programmable)
Frequency)	

Table.1 : Specifications of Sentinel-1A (2)
--------------------------------------------------	----

2.2. Free space path Loss

In order to compute free space path loss (FSPL), the slant range (R) [1] between the transmitter and receiver is determined from the knowledge of Earth's station elevation angle (θ), altitude (h) of the Satellite as given by equation (7)

$$R = R_E \sqrt{\frac{h + R_e}{R_e} + \cos(\theta)^2} - \sin(\theta)^2$$
(7)

Where h is the altitude, R_e the radius of the Earth, θ is the elevation angle for Sentinel -1A altitude of 653 km, and elevation angle of 55⁰, slant range obtained is equal to 785.676km and FSPL=165dB

From the specifications of S-1A satellite signal as given in table 1, the received signal power on the ground surface is calculated as given by equation. (6) Based on power budget calculation as shown in the table.2, the signal power computed at the antenna input is - 59.38dBm. The signal

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power is enhanced with a antenna gain of 30dB to -29.38dBm which is well within the receiver sensitivity. The receiver used for this application is a measurement system: spectrum analyser with the dynamic range of -160dBm to +20dBm [3].

S1.	Parameters	Specifications
no		
1.	Peak input power at antenna input (dBW)	36.17 dB
2.	Satellite antenna gain	43.5 dB
3.	Path loss	165dB
4.	Atmospheric loss	3dB
5.	Antenna loss (Ltxa & Lrxa)	0.7dB
6.	Received power at the antenna input	-59.38dBm
7.	Receiving antenna gain	+30dB
8.	Received signal at the spectrum analyser input	-29.38dBm

Table.2:	Link	budget	computation
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2.3. Design consideration of dish antenna

The main objective is to design the receiving antenna with a gain of 30dB. This large gain is achievable with parabola antenna which has primary feed and secondary reflector. Commonly, dish antenna is chosen for high gain (30- 40dB) which is obtained by large aperture area and large capturing capability. They are characterized to have high directivity and wide bandwidth. i.e., they produce narrow beam. Typically the dimension of paraboloid is chosen larger than the wavelength (λ) of the signal used.

In order to increase aperture efficiency [4] [5] [6], the dish is illuminated such that energy illuminates uniformly upto the edge of the dish and drops off quickly beyond the edge. The energy at the edges is 10dB lower than at the centre. Further, most of the noise received by an antenna pointed at the sky is the Earth's noise at 300K temperature rather than the noise from the sky. The pickup of background noise can be reduced by reducing spill over efficiency. The dish and associated feed is designed such that energy illumination covers only dish area and doesn't spill over the edges as shown in the figure 2.

To achieve this, the dish is illuminated for 80% portion with drop of energy at the edges. This will reduce taper efficiency and gain, but at the cost of improvement in SNR of the signal.



Figure 2. Dish illumination with taper efficiency [12]

The parabola is defined by F/D ratio and typically varies from 0.25 to 0.65. For focal length (f) equal to 60cm, F/D ratio obtained is 0.5. As F/D ratio becomes smaller, the feed pattern to illuminate the dish becomes broader and is harder to illuminate efficiently. Further F/D ratio is the fundamental factor governing the design of the feed for a dish. The ratio is directly related to beam width of the feed necessary to illuminate the dish effectively. The smaller the ratio, lower the beam width and smaller the side lobes.

SI.	Antenna Parameters	Expression
No		
1.	Focal length	$f = \frac{D^2}{16 d}$
2.	Aperture angle	$\theta_0 = 2 \tan^{-1}(\frac{1}{4\frac{f}{D}})$
3.	Antenna gain	$G=\eta(\frac{\pi d}{\lambda})^2$
4.	Beam width	Bw= $70\lambda/D$

 Table. 3: The Parabola antenna parameters

Table. 4 : Design	specifications	of dish antenna	for Gain=30dB
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Parameter	Specifications
Diameter(D)	120cm
Depth (d)	15cm
Focal length (f)	60cm
F/D ratio	0.5
Aperture angle θ_0	53.1 ⁰
Beam width	3.2°

2.4. Design of horn feed for dish antenna

Sentinel-1A signals are vertical (V) and horizontal (H) polarized signals, to receive different combinations of polarized signals (HH+HV, VV+VH, VV, HH), pyramidal horn antenna is chosen as a feed for parabola antenna, as it is sensitive to V and H Polarization.



Figure 3. Schematic of Pyramid horn antenna

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A horn antenna is basically a waveguide (WG) with flaring at open ends as shown in the figure 3. The function of the flare in the horn is to produce uniform phase front with larger aperture than that of the WG and hence greater directivity. A WG excited at one end and open at other end radiates, however due to mismatch between WG and free space impedance, the radiation is poor and results in non directive radiation pattern. The open ends are flared out to improve radiation efficiency and directivity. The type, direction and amount of flare have significant effect on the radiation characteristics.

The gain of 20 to 30 dB is achievable with Horns. The larger the aperture, larger is the directivity. Hence the gain is directly proportional to length and area of horn. Horns are characterized to have little loss and therefore widely used as standard gain antennas.

To receive C band signals at a frequency of 5.405GHz signals, we chose standard waveguide WR157 [7] [8] with dimensions: breadth (a) and width (b) as 4.038cm and 2.0193cm respectively. The Cut- off wavelength $\lambda_c = 8.076cm$ and corresponding cutoff frequency fc= 3.7147GHz

2.4.1. Algorithm [9][10] to design pyramid horn antenna for gain of 15dB at frequency f=5.405GHz For the desired gain G0, and basic dimension of the waveguide ('a' and 'b') of the rectangular waveguide, the objective of the design is to determine the remaining dimensions A, B, ρ_e , ρ_h , RE and RH of the horn as shown in the figure 4 and figure 5 by combining E and H plane that will lead to optimum gain.



1: Find the initial value of zeta (χ) for the desired gain G₀ given by

$$\chi = \frac{G_0}{2\pi\sqrt{2\pi}} \tag{8}$$

2: For a pyramid horn antenna to be physically realizable R_E and R_H of E and H plane must be equal. To achieve this, by trial and error method, χ is updated to satisfy the equation (9)

$$(\sqrt{2\chi} - \frac{b}{\lambda})^2 (2\chi - 1) = (\frac{G_0}{2\pi} \sqrt{\frac{3}{2\pi}} \frac{1}{\sqrt{\chi}} - \frac{a}{\lambda})^2 (\frac{G_0^2}{6\pi^3} \frac{1}{\chi} - 1)$$
(9)

3: After a few iteration a more accurate value of χ is determined for which the equation 13 is satisfied 4: Using equations 10 and 11 determine ρ_e and ρ_h

$$\frac{\rho_e}{\lambda} = \chi \tag{10}$$

$$\frac{\rho_h}{\lambda} = \frac{G_0^2}{8\pi^3} \left(\frac{1}{\chi}\right) \tag{11}$$

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5: The corresponding values of A and B are given by equations

$$A = \sqrt{3\lambda\rho_h} \tag{12}$$

$$B = \sqrt{2\lambda\rho_e} \tag{13}$$

6: The values of R_E and R_H are determined using equations

$$R_{E} = (B - b) \left[\left(\frac{\rho_{e}}{B} \right)^{2} - \frac{1}{4} \right]^{2}$$
(14)

$$R_{\rm H} = (A - a) \left[\left(\frac{\rho_h}{A}\right)^2 - \frac{1}{4} \right]^2 \tag{15}$$

The algorithm is simulated using Matlab platform. The simulated pyramid horn antenna parameters are given in the table. 5.

$ ho_e$	0.1021m
$ ho_h$	0.1216m
А	0.1423m
В	0.1065m
RE	0.706m
RH	0.706m

Table. 5: Designed pyramid horn antenna dimensions

3. Results and Discussion

The pyramid horn antenna is simulated using Matlab simulation platform. The beamwidth and directivity in the azimuth and elevation direction is shown in the figure 6, 7, 8 and 9 respectively and the beamwidth is equal to $\sim 32^{\circ}$

3.1. Matlab simulation results of pyramid horn antenna



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The radiation pattern and VSWR plot is shown in the figure 10 and 11 respectively. From the plot it is evident the VSWR is desirably low at the operating frequency.

3.2. Matlab simulation results of Dish antenna with horn feed

The pyramid horn antenna is integrated with dish antenna to obtain dish antenna with horn feed. The Matlab simulated dish antenna with horn feed is shown in the figure 12 and figure 13. The directivity or gain is equal to ~22.8dB. From the plots of VSWR and return loss shown in the figure 14 and 15 respectively, it is evident the VSWR and return loss is appreciably low





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3.3. Experimental setup/Hardware implementation

The hardware antenna system setup deployed for monitoring Sentinel 1A SAR signals is shown in the figure 16 and figure 17. It includes dish antenna with horn feed whose output is monitored on spectrum analyser



Conclusions

An antenna system is designed to monitor Sentinel 1A SAR signals on the ground surface. Link budget calculation is vital to determine theoretically the minimum signal strength availability on the ground surface by taking accountability of all possible losses during the course of propagation. The antenna based system is designed to receive signals and monitor the strength, frequency, power and its variability. Dish antenna with pyramid horn is designed for required specification and simulated in Matlab and meets the gain requirement of 22dB, a low VSWR and return loss. Based on the design, dish antenna hardware system is implemented to test the design.

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