Design of Satellite antenna for high-speed image transfer application

Antenna use case:

We are designing an antenna/mast for a geostationary satellite. It takes images of India's borders, seas, and ocean areas. Then send them to the base station located in India.

We need to consider several factors for designing an antenna and successfully deploying it in space. The factors include frequency band selection, launch vehicle selection, antenna selection, and material selection.

Frequency band selection:

For frequency band selection, we need to consider the following factors.

Beam Width:

Beam width is a measure of the angular width of a main lobe of a directional antenna pattern. It is defined as the angle between the two points on either side of the main lobe where the power radiated by the antenna has dropped to half (-3dB) of the maximum power of the lobe.

Data rate or Bit rate:

The data rate measures the amount of data transmitted over a communication channel in a given time period. In other words, the rate at which digital data can be transferred between the satellite and the ground station or between two satellites.

Attenuation:

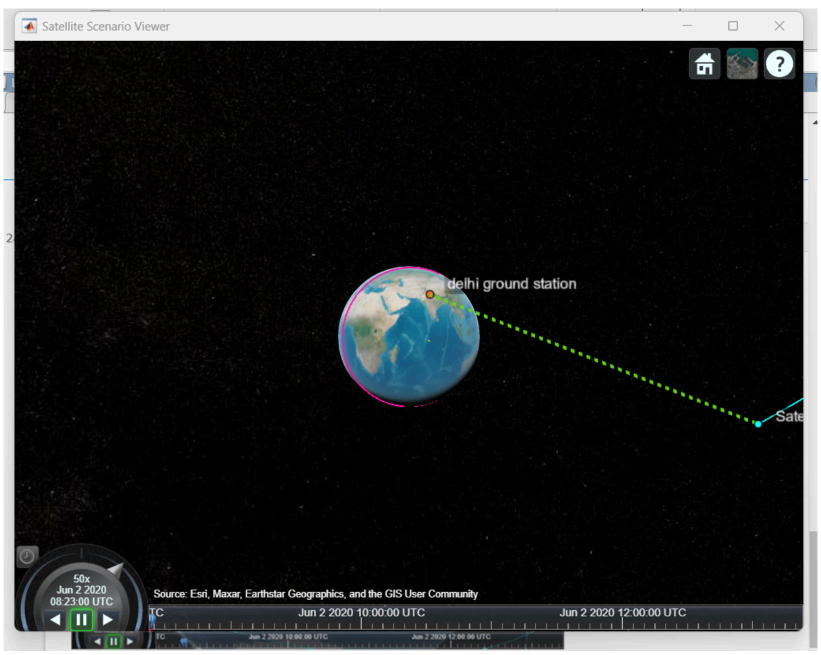
Attenuation refers to the loss of signal strength or power that occurs as the electromagnetic waves travel through the transmission medium, such as atmosphere or space.

Some of the most suitable Radio Frequency bands (RF) are:

1. UHF band
2. S-band
3. X band
4. Ka-band

BAND	FREQUENCY	BIT RATE	BEAM WIDTH	ATTENUATION
UHF	300 to 1000 MHz	80-100 Kbps	60-120 degrees	0.4dB/Km
S	2 to 4 GHz	1-10 Mbps	20-40 degrees	3.5dB/Km
X	8 to 12 Ghz	10-100 Mbps	10-20 degrees	11db/Km
Ka	27 to 40 GHZ	100Mbps -1Gbps	1-5 degrees	39dB/Km

As the satellite is in a geostationary orbit and we need to send the high-resolution images taken by the satellite to the ground station, we need a frequency band that gives us a high bit rate. Because it is in a geostationary orbit, the low beam width is sufficient because we don't need a large coverage area.



This is the scenario simulation where we can see a link between the satellite and the ground station. And the field of view of the satellite is shown in the image.
As we can see, the field of view includes a vast area.

The satellite takes ten high-resolution images per second, each with 10Mb of data, so the data rate needed is 100Mbps. So the most suitable band for communication is the X band for the given specifications.

Launch Vehicle specifications:

There are four available variants of PSLV they are:

1. PSLV-G:

Height: 44.4 meters
Diameter: 2.8 meters
Number of stages: 4
Total lift-off mass: 320 tonnes
Payload capacity to SSO: 1,750 Kg
Strap-on boosters: 4

2. PSLV-XL:

Height: 44.4 meters
Diameter: 2.8 meters
Number of stages: 5
Total lift-off mass: 320 tonnes
Payload capacity to SSO: 2,200 Kg
Strap-on boosters: 6

3. PSLV-CA:

Height: 44.4 meters
Diameter: 2.8 meters
Number of stages: 4
Total lift-off mass: 230 tonnes
Payload capacity to SSO: 1,100 Kg
Strap-on boosters: None

4. PSLV-DL:

Height: 44.4 meters
Diameter: 2.8 meters
Number of stages: 5
Total lift-off mass: 320 tonnes
Payload capacity to SSO: 1,800 Kg
Strap-on boosters: 6

5. PSLV-QL:

Height: 34 meters
Diameter: 2.8 meters
Number of stages: 4
Total lift-off mass: 230 tonnes
Payload capacity to SSO: 500 Kg
Strap-on boosters: 3

As we can see, the PSLV-XL is the most potent variant of the PSLV rockets. In this mission, we must send the satellite to the geostationary orbit. In several tasks, PSLV-XL has been used to send the satellites to the GTO(geostationary transfer orbit). From there, the satellites reach the geostationary orbit. So we selected this variant of the PSLV for the launch of our satellite into geostationary orbit.

Antenna Specifications:

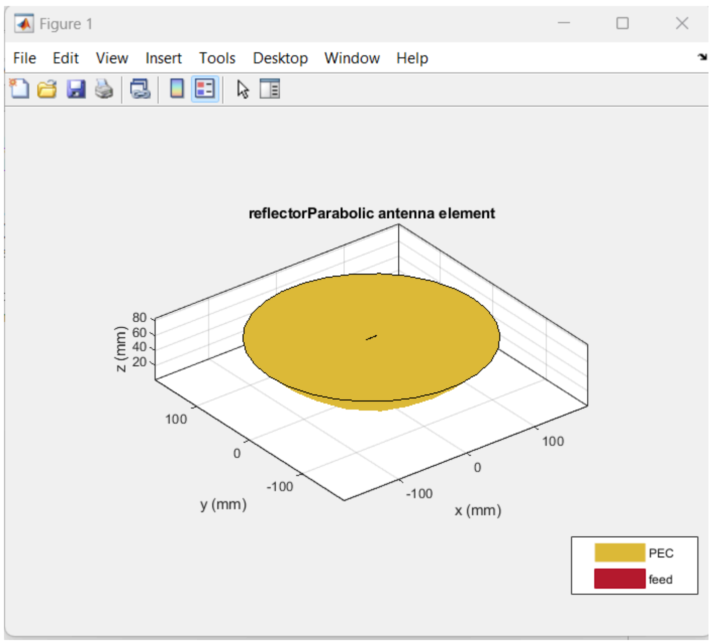
There are different kinds of antennas available for use in satellite communication. We will select the best antenna for our design specifications.

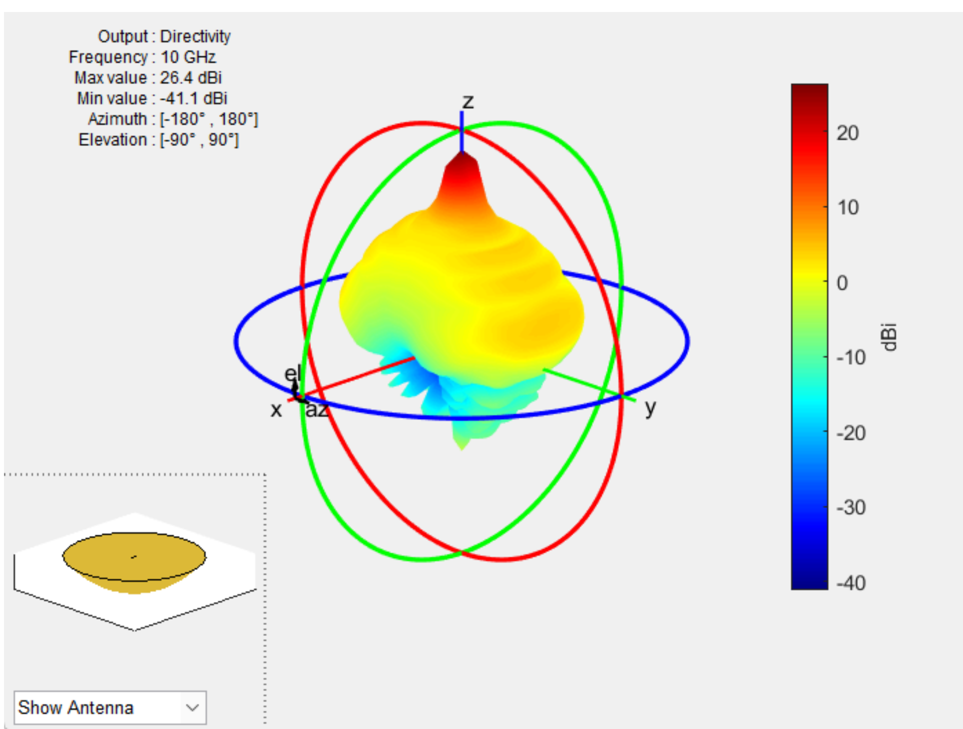
Below are the different types of antennas available for satellite communication. A rigorous analysis has been done to select the best antenna for our specifications, and a Matlab simulation has been done for each antenna.

The radiation patterns of all the antennas are generated at the 10GHz frequency.

1.Parabolic antennas:

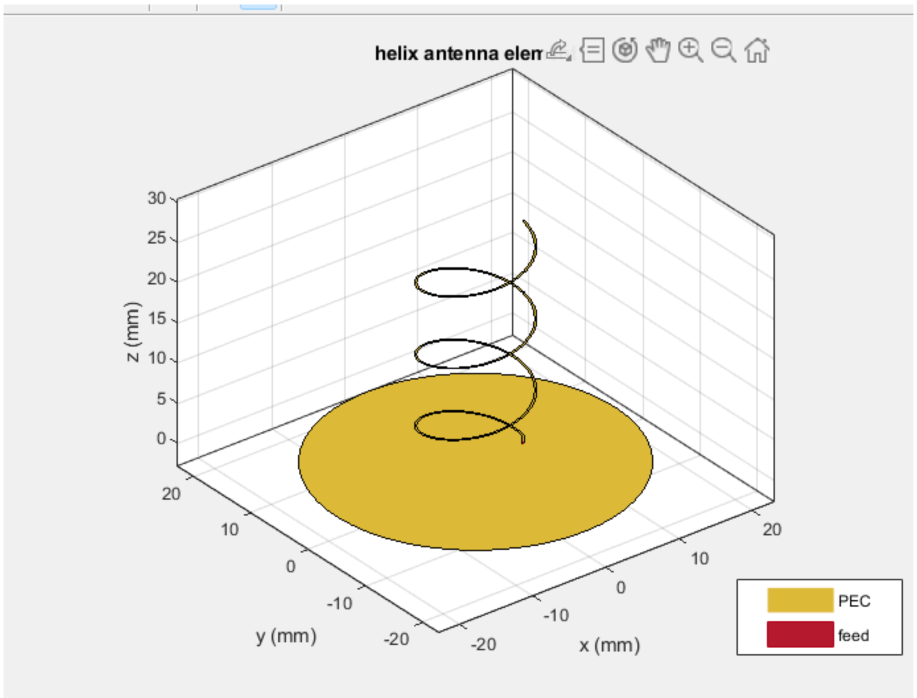
Parabolic antennas are the most commonly used antennas in satellites for communication to the ground. These antennas have a curved surface in the shape of a parabola and use a feed to the focal point to direct the radio waves in a narrow beam toward the ground station. They are used for both transmitting and receiving signals and are highly directional. As we can see, the beamwidth is lower, so the intensity is higher, and the signal quality to the determined base station is increased.

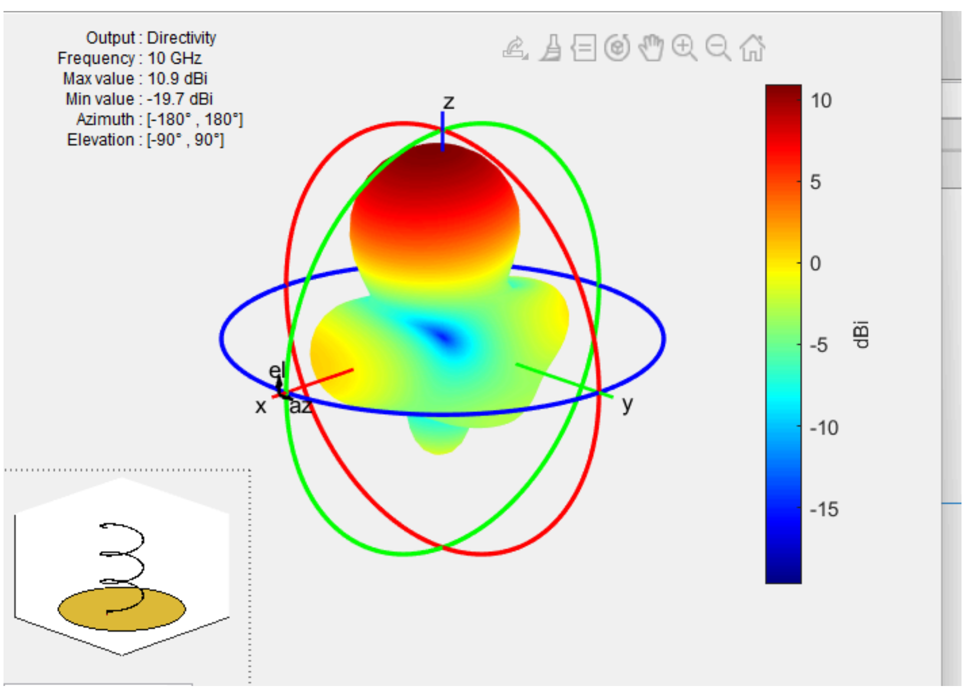




2. Helical antennas:

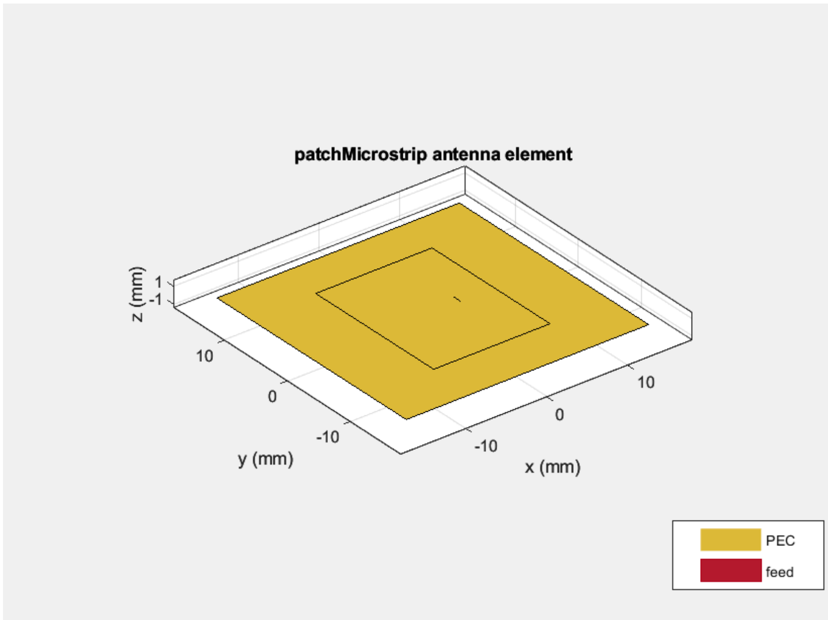
Helical antennas are used for the circular polarization of radio waves, which is essential for some communication systems. They are compact, lightweight, and can operate over various frequencies.

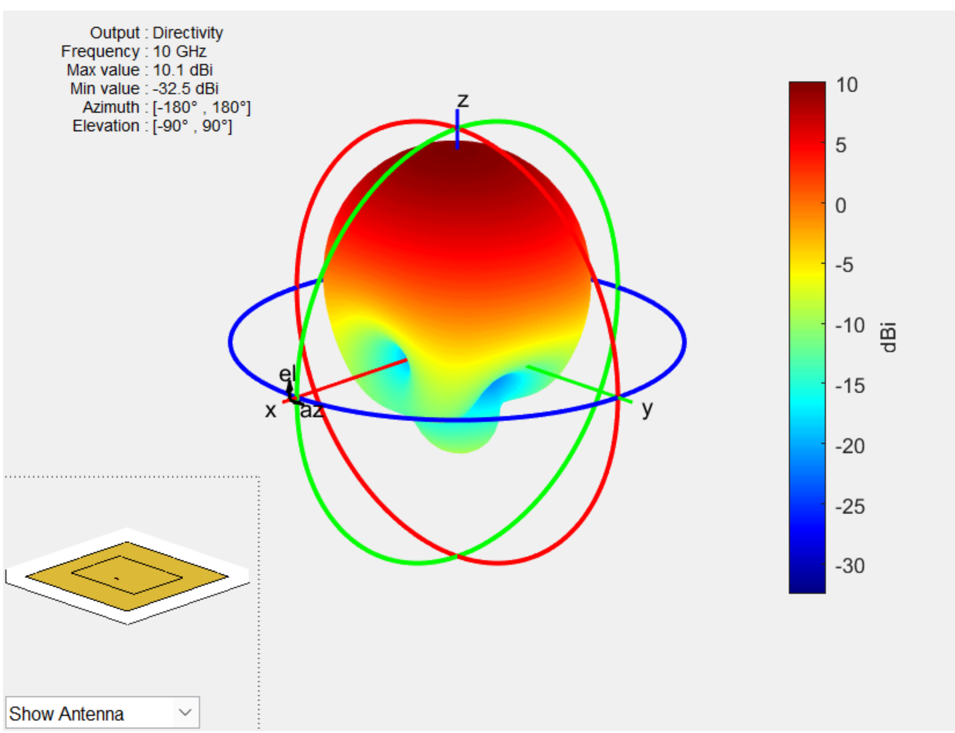




3. Patch antennas:

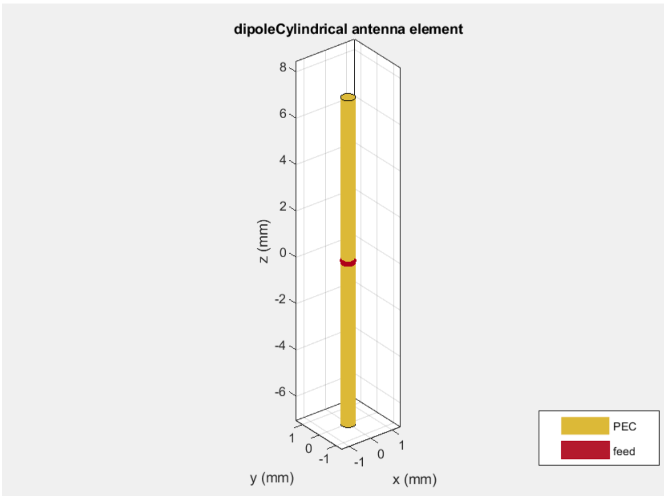
Patch antennas are thin, flat antennas that can be easily integrated into the structure of the satellite. They are commonly used for low-power applications and can operate over various frequencies.

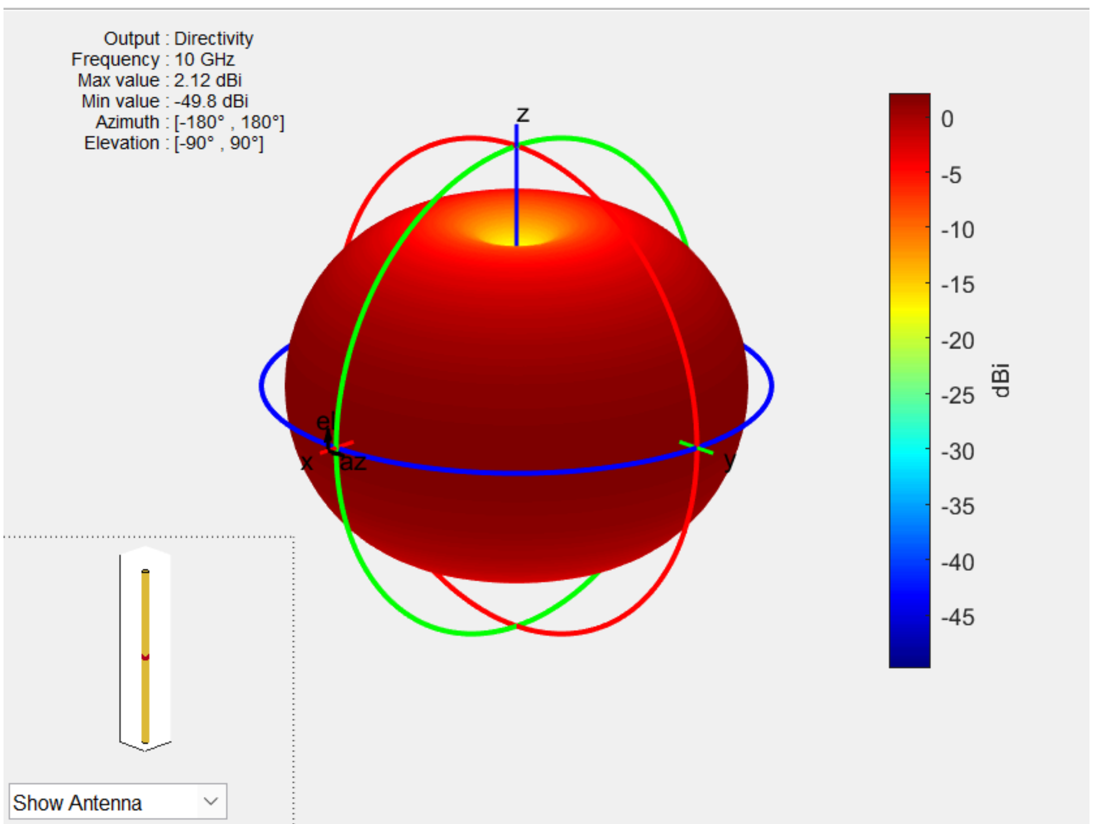




4. Dipole antennas:

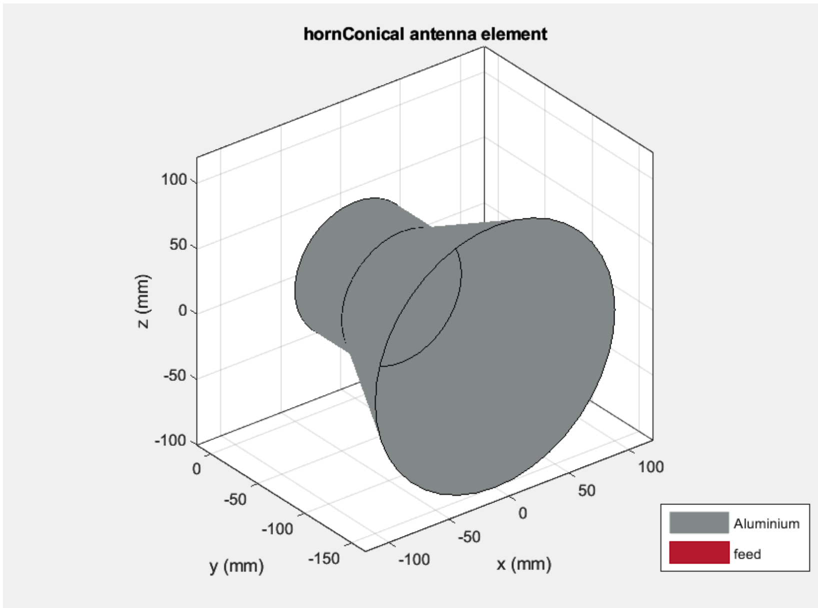
Dipole antennas are simple antennas that consist of two metal rods or wires that are parallel and separated by a small distance. They are used for low-frequency applications and are often used as backup antennas in case the primary antenna fails.

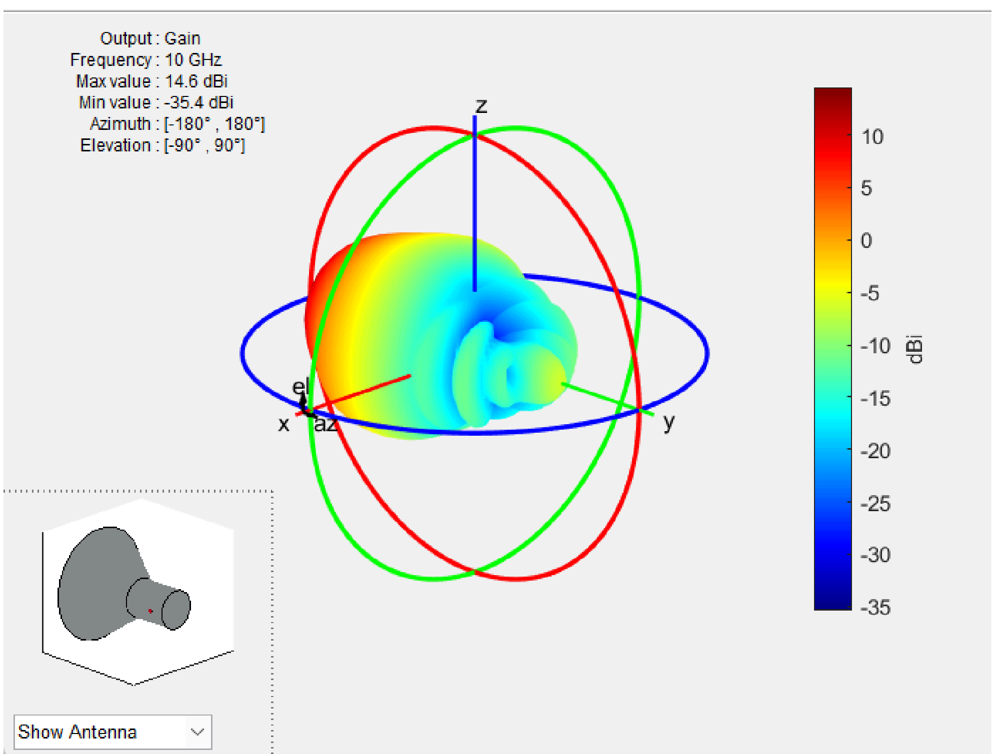




5. Horn antennas:

Horn antennas are conical or pyramidal antennas that are used for high-frequency applications. They have a wide radiation pattern and are commonly used for radar systems and satellite communication.



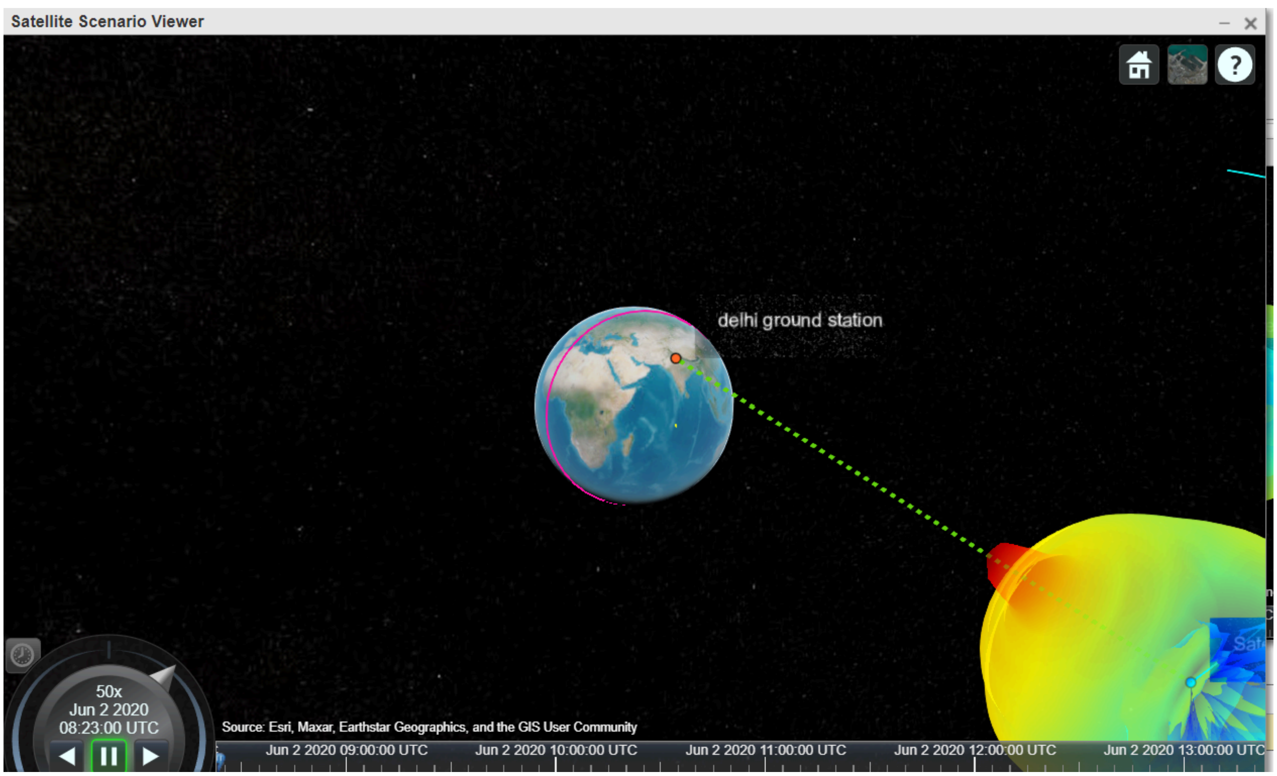


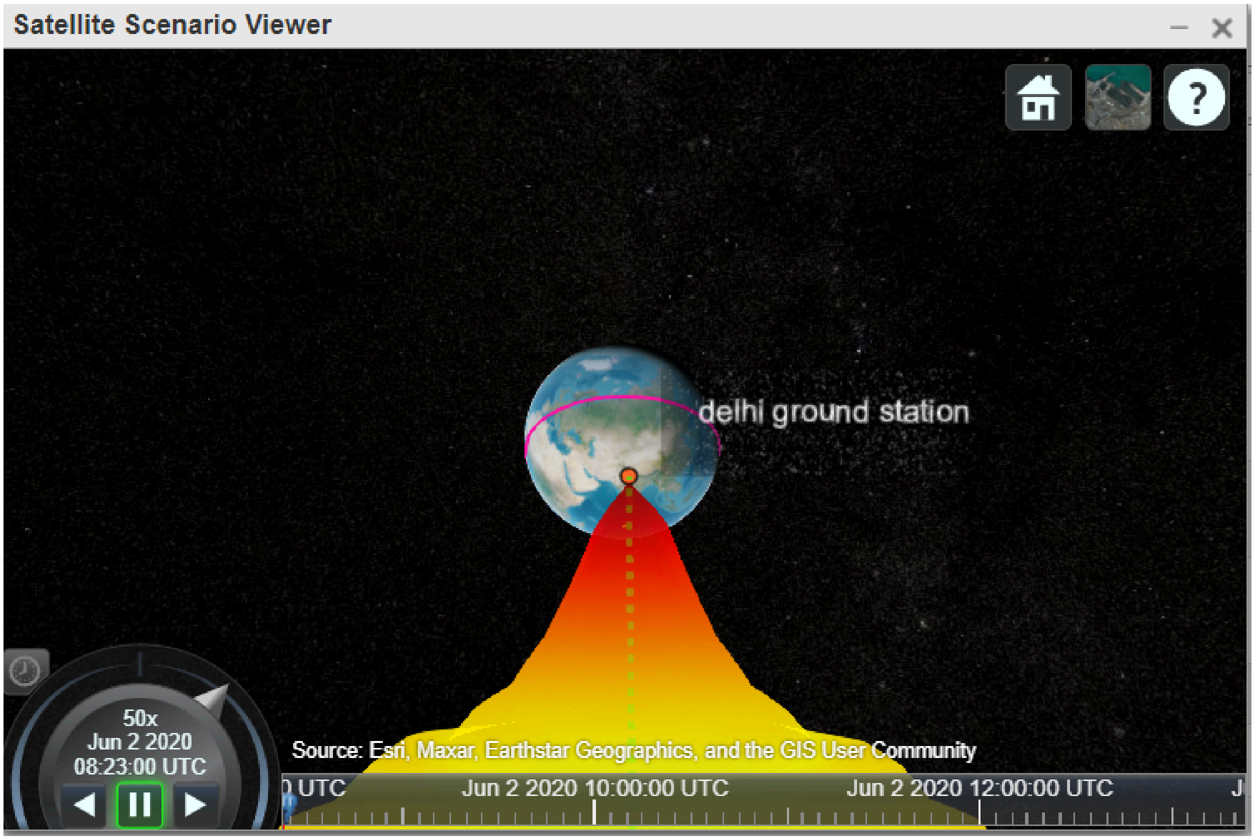
These are different types of antennas used in satellites for communication to the ground. The choice of the antenna depends on various factors, such as the frequency band used, the mission requirements, and the available space and weight constraints.

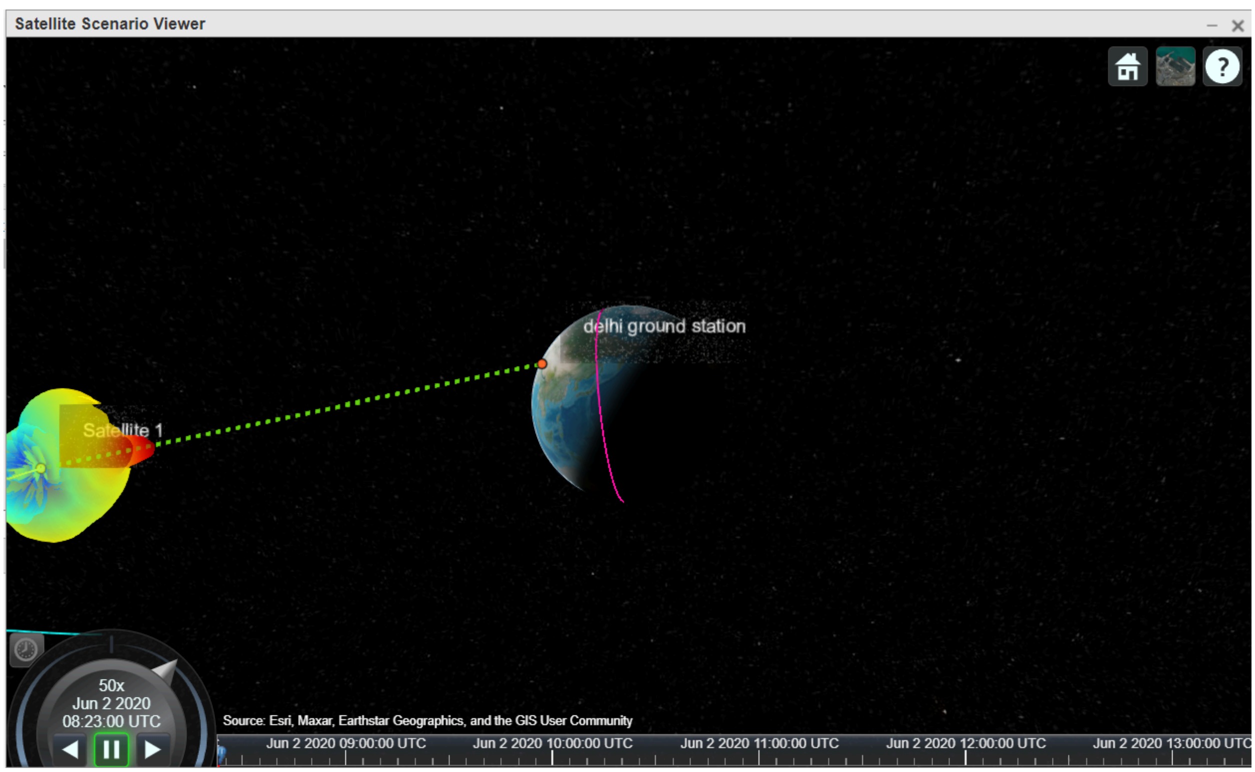
We need to send the images to a specific ground station in our application. We don't need a wide area for coverage. If we observe the above antennas and their radiation pattern, we can see that the parabolic reflector antenna has a more focused radiation pattern.

We can also observe the Max value for the parabolic reflector antenna for 10GHz is 26.4dBi. So for a given signal, we can transfer more of its power. But the power transmitted is concentrated in a particular area. We need an antenna with more beam width if we need extensive coverage for applications such as GPS, where a GPS signal should be sent to many receiver antennas over a wide area.

Below is a simulation of a satellite in geostationary orbit with a parabolic reflector antenna and its radiation pattern.




Satellite Scenario Viewer
delhi ground station
50x
Jun 2 2020
08:23:00 UTC
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
Jun 2 2020 10:00:00 UTC
Jun 2 2020 12:00:00 UTC


Satellite Scenario Viewer
delhi ground station
Satellite 1
50x
Jun 2 2020
08:23:00 UTC
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community
Jun 2 2020 09:00:00 UTC
Jun 2 2020 10:00:00 UTC
Jun 2 2020 11:00:00 UTC
Jun 2 2020 12:00:00 UTC

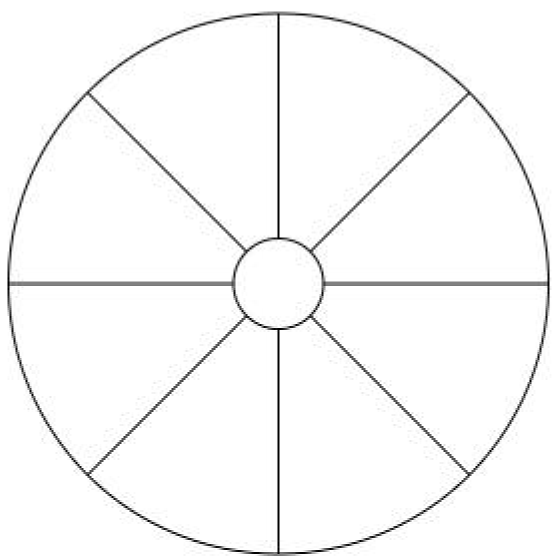
Antenna material selection:

In the parabolic reflector antenna, we can use different materials for the other parts of the antenna. For the feeder, we use aluminum because of its lightweight, cheap, and high conductivity nature.

For the ribs and the parabolic surface, we use carbon fiber. Because it is strong and we don't want the ribs to be damaged.

Antenna deployable structure:

We can create a rib-like structure along the parabolic antenna to fold it, thus creating an antenna of smaller volume. Although for the frequency range of our selection, the antenna is relatively small, with a radius of around 15 centimeters. We can still use the deployable structure to create more volume for our satellite which can be used to carry additional fuel or other scientific research equipment.



References:

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4. https://www.omnicalculator.com/physics/dipole
5. https://www.european-antennas.co.uk/antenna-types-theory/antenna-specification/#:~:text=Most%20antennas%20are%20designed%20to,between%209.5%20to%2010.5GHz.
6. https://www.isro.gov.in/PSLV_CON.html
7. https://in.mathworks.com/videos/satellite-communications-and-ntn-design-with-matlab-1658934527694.html

Timeline:

30th march 12:00 AM - 12:00 PM: No work is done in this period
30th march 12:01 PM - 11:59 PM: Understanding the problem statement and researching the various aspects of the problem statement
31st march 12:00 AM - 12:00 PM: Understanding the problem statement and analyzing the multiple aspects of the problem statement
31st march 12:01 PM - 11:59 PM: Started the report and the coding of Matlab files for simulation of the satellite communication and designing various antennas in Matlab.