Satellite Space Segment
# Communication Frequencies

<table>
<thead>
<tr>
<th>Band</th>
<th>Uplink</th>
<th>Crosslink</th>
<th>Downlink</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>5.9-6.4</td>
<td></td>
<td>3.7 – 4.2</td>
<td>0.5</td>
</tr>
<tr>
<td>X</td>
<td>7.9-8.4</td>
<td></td>
<td>7.25-7.75</td>
<td>0.5</td>
</tr>
<tr>
<td>Ku</td>
<td>14-14.5</td>
<td></td>
<td>11.7-12.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Ka</td>
<td>27-30</td>
<td></td>
<td>17-20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30-31</td>
<td></td>
<td>20-21</td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td></td>
<td></td>
<td>40-41</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>41-43</td>
<td>2.0</td>
</tr>
<tr>
<td>V</td>
<td>50-51</td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>(ISL)</td>
<td>54-58</td>
<td></td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>59-64</td>
<td></td>
<td>5.0</td>
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</table>
A satellite communications system can be broadly classified into 2 segments:

- **Space Segment**: includes the sat. and ground facilities (TT&C- tracking, telemetry & Command)
- **Earth Segment**: consists of the transmit and receive earth stations.
The Payload & Bus

- The equipment carried aboard the sat. can be classified to:
- The Payload: the equipment used to provide the service for which the sat. has been launched.
- The Bus: refers to the vehicle as well as the subsystems that provide the power, attitude control, orbital control, thermal control, command and telemetry functions required to service the payload.
The primary electrical power for electronic equipments is obtained from solar cells.

Individual cells can generate only small amounts of power → arrays of cells in series-parallel connection are required.
Power Supply: HS 376 Sat.

- 216x660 cm diam.
- The outer cyl. is telescoped over the inner during launch sequence
- 940 W dc power that may drop to 760 W after 10 years.
- During eclipse, 2 Nickel-cadmium long-life batteries are used with 830 W (16 h recharge time)
Higher Powers can be achieved with solar panels in rectangular solar sails.

Solar Sails are folded during launch phase

The full complement of solar cells is exposed to the sunlight, and the sails are arranged to rotate to track the sun → higher Power (2-6 kW)

Figure 7.2  Aussat B1 (renamed Optus B), Hughes first HS 601 communications satellite is prepared for environmental testing. (Courtesy of Hughes Aircraft Company Space and Communications Group.)
Spring and Autumnal Equinoxes: eclipses daily about 72 min 23 days before and after equinox
Attitude Control

- The attitude: refers to the sat. orientation
- Attitude control is required for antenna alignment
- Disturbance torques can alter the attitude
- Usually on board even it can be on earth
- Passive (spin) and Active methods (gas jets and momentum wheels)
Attitude RPW Axes: Roll, Pitch and Yaw

Figure 7.4 (a) Roll, pitch, and yaw axes. The yaw axis is directed toward the earth’s center, the pitch axis is normal to the orbital plane, and the roll axis is perpendicular to the other two. (b) RPY axes for the geostationary orbit. Here, the roll axis is tangential to the orbit and lies along the satellite velocity vector.
Spinner Sats: use the angular momentum of its spinning body to provide roll and yaw stabilization: (50-100 rev/min)
Momentum Wheel Stabilization

Three Axis Sats: the body remains fixed relative to Earth surface while an internal subsystem provides roll and yaw stabilization.

Figure 7.8 Alternative momentum wheel stabilization systems: (a) one-wheel; (b) two-wheel; (c) three-wheel. (Reprinted with permission from Spacecraft Attitude)
Station Keeping

- GEO Sats are to be kept in its correct orbital slot
- Equatorial ellipticity causes Sats to drift slowly along orbit to one of stable points: 75° E and 105° W → jets are used to compensate and pulsed every 2-3 weeks (east-west station keeping maneuvers)
Station Keeping

- GEO drift also In latitude due to sun pull (0.85° /year in inclination)

- Jets are pulsed to correct inclination to zero (north-south station keeping maneuvers)

- These maneuvers are commanded from the TT&C

Figure 7.9 Typical satellite motion. (From Telesat, Canada, 1983; courtesy of Telesat Canada.)
Thermal Control

- Satellites are subject to large thermal gradients:
  1) One side toward sun, the other into space.
  2) Heat from equipments
  3) Heat from ground

- Mirrors and isolators are used
TT&C performs several routine functions:

1) telemetry: attitude info.
2) environmental: mag. Filed intensity
3) spacecraft info: temperature, power supply, etc

Encryption is implemented to protect from unauthorized commands

Specific Frequencies were assigned for TT&C
Transponders

- **Transponder**: the series of interconnected units which forms a single communications channel between the receive and transmit antenna.
- Some units may be common to a number of transponders

![Diagram of transponder system]

- **Antenna**
- **LNA** (Low Noise Amplifier)
- **HPA** (High Power Amplifier)
- **Down Converter Mixer+LO +BPF**

*LNA- Low Noise Amplifier  
HPA- High Power Amplifier*
The Wideband Receiver

Figure 7.13 Satellite transponder channels. (Courtesy of CCIR, CCIR Fixed Satellite Services Handbook, final draft 1984.)
Polarization and Frequency Reuse

- The transponder is considered as an RF-to-RF repeater.
- Additional comm. Channels can be achieved using polarization discrimination and Frequency Reuse.
- Polarization Discrimination can be obtained by making the carriers having the same frequency but with different in polarization.
- Frequency Reuse can be also obtained using spot beam antennas.
Polarization Discrimination

- For circular: left-hand/right-hand circular (LHC/RHC)
- For Linear: Horizontal/Vertical
- With spot beam antennas and XPD, the bandwidth can be doubled twice: $0.5 \rightarrow 2$ GHz

Figure 7.12  Section of an uplink frequency and polarization plan. Numbers refer to frequency in megahertz.
The Antenna Sub-system

- The antennas carried aboard provide the dual functions of Uplink/Downlink RX/TX operations.

- Antennas range from omindirectional (dipole type) to highly directional antennas required for telecom. and TV purposes.

- Directional beams are usually produced by means of reflector-type antennas, the paraboidal reflector being the most common.
The Antenna Sub-system

- Wide beams for global coverage are produced by simple horn antenna at 6/4 GHz.

- Simple biconical dipole antenna is used for tracking and control signals.

- The same feed horn can be used to TX and RX carriers with the same frequency (Diplexer), also XPD can be used.
Antenna Examples: Horn Feeders

Figure 6.10  Horn antennas: (a) smooth-walled conical, (b) corrugated, and (c) pyramidal.

Figure 6.13  A scalar feed.
Ant. Examples: Parabolic Reflectors

Figure 6.20 Copolar and cross-polar radiation patterns. (From FCC Report FCC/OST-R83-2, 1983.)
Ant. Examples: Double Reflectors

Figure 6.22 A 19-m Cassegrain antenna. (Courtesy of...
Ant. Ex. : C band GEO Antenna

- 32 m diameter (256 ton)
- Very narrow beam with calibration
- Heat is required to avoid snow attenuation

Figure 8.7 Standard-A (C-band 6/4 GHz) 32-m antenna
(Courtesy of TIW Systems, Inc., Sunnydale, CA.)
Ant. Examples: Multifeed reflector

Figure 6.28 A multifeed contained-beam reflector antenna. (From Brain and Rudge.)
Parabolic Gain & Beamwidth

- The gain of the paraboloid reflector relative to isotropic radiator:
  \[ G = \eta_I \left( \frac{\pi D}{\lambda} \right)^2 \]
  - \( \eta_I \) - aperture efficiency (typically 0.55)
  - \( \lambda \) - wavelength and \( D \) - reflector diameter

- The 3-dB beamwidth in degrees:
  \[ \theta_{3dB} \approx 70 \left( \frac{\lambda}{D} \right) \]
IntelSat IV Ant. Sub-Systems
The Satellite Footprints

Footprint:
The geographical representation of a Sat. antenna radiation

1- Global (Earth)
2- Hemispherical
   (20% of earth surface)
3- Zone
4- Spot
Mexican Moreles Coverage

(C-band)  (K-band)
IntelSat V Footprint
The Wideband Receiver

Figure 7.13 Satellite transponder channels. (Courtesy of CCIR, CCIR Fixed Satellite Services Handbook, final draft 1984.)
The Wideband Receiver

- Redundant RX: Standby configuration

- First Stage is the Low-Noise Amplifier (LNA):

- Some Transponders may include IF stage similar to AMR / DMR configurations

- LNA ➔ (tunnel diode, FET)

- Amplifier: BJT @ 4 GHz and FET @ 14 GHz
The Input DeMultiplexer

Figure 7.13  Satellite transponder channels. (Courtesy of CCIR, CCIR Fixed Satellite Services Handbook, final draft 1984.)
The Input DeMultiplexer

- The input DeMUX separates the broadband into transponder frequency channels.
- Odd/Even numbered groups provide more frequency separation which reduces adjacent channel interference.
- The output from DeMUX is fed to a power splitter which feeds the two separate chains of circulators.
- Channelizing is achieved using BPFs.
- BPF \(\rightarrow\) 36 MHz BW
The High Power Amplifier: HPA

Figure 7.13 Satellite transponder channels. (Courtesy of CCIR, CCIR Fixed Satellite Services Handbook, final draft 1984.)
The High Power Amplifier: HPA

- HPA Provides the output power for each transponder channel.

- Each HPA is preceded by an input attenuator to permit each amplifier to be adjusted to the desired level.

- The Traveling-Wave Tubes (TWT) are very common devices for HPAs since it provides amplification over a wide range of bandwidth.
General Transponder Block Diagram

0 dB reference level
1 input filter
2 wideband receiver
3 3 dB coupler
4 demultiplexer
5 attenuator (lower position)
6 amplifier
7 multiplexer
Canadian ANIK-D,E

**TABLE 7.1 Anik-E System Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime contractor</td>
<td>Spar Aerospace</td>
</tr>
<tr>
<td>Type of satellite bus</td>
<td>GE Astro Series 5000</td>
</tr>
<tr>
<td>Number of satellites</td>
<td>2</td>
</tr>
<tr>
<td>Launch dates</td>
<td>E1: March 1990; E2: October 1990</td>
</tr>
<tr>
<td>Orbital range, °W</td>
<td>104.5 to 117.5</td>
</tr>
<tr>
<td>Orbital position, °W</td>
<td>E1: 107.5; E2: 110.5</td>
</tr>
<tr>
<td>Design life, years</td>
<td>12</td>
</tr>
<tr>
<td>Fuel life, years</td>
<td>13.5</td>
</tr>
<tr>
<td>Dry weight, kg</td>
<td>1280</td>
</tr>
<tr>
<td>Transfer orbit mass, kg</td>
<td>2900</td>
</tr>
<tr>
<td>Length, m</td>
<td>21.5</td>
</tr>
<tr>
<td>Array power, kW</td>
<td>3.5 (end of life)</td>
</tr>
<tr>
<td>Eclipse capability</td>
<td>100%</td>
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<tr>
<td>Frequency bands, GHz</td>
<td>6/4</td>
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<tr>
<td>Number of channels</td>
<td>24</td>
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<tr>
<td>Transponder bandwidth, MHz</td>
<td>36</td>
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<tr>
<td>HPA* (W)</td>
<td>11.5 (SSPA)</td>
</tr>
<tr>
<td></td>
<td>50 (TWTA)</td>
</tr>
</tbody>
</table>

**SSPA- Solid State Power Amplifier.**

**TWTA- TWT Amplifier**

*Figure 7.28 Anik-E typical C-band coverage, saturated EIRP in dBW (prelaunch EIRP predictive—preliminary). (Courtesy of Telsat Canada.*)*
Figure 7.29 Anik-D 6/4-GHz frequency and polarization plan. (From Telesat Canada, 1985; courtesy of Telesat Canada.)
Canadian ANIK-E

Figure 7.30  Ku-band transponder functional diagram for Anik-E. (Courtesy of Telesat Canada.)
Figure 7.31 Anik-E1 frequency and polarization plan, Ku-band. (Courtesy of Telesat Canada.)