National Remote Sensing Centre

Indian Space Research Organisation, Government of India, Hyderabad.

Science Story

Tri – Axis antenna for Satellite data acquisition

National Remote Sensing Centre (NRSC) developed Tri-axis antenna pedestal and control system for tracking of LEO satellites and data reception. The three Axes mount Viz., AZ, EL and Train, was realized for the first time in ISRO by NRSC. The three axes pedestal is integrated with 7.5m Antenna System for tracking S, X bands and data reception from any Earth Observation/ Remote Sensing Satellites. 3 axes antenna offers many advantages over traditional two axis antennae and enables more accurate tracking and reliable data reception.

Need for Tri-Axis antenna pedastal

The EL over AZ mount pedestal is the better option among other available types of pedestals. The azimuth-elevation pedestals are highly dynamic, capable of continuous tracking of Low Earth Orbit (LEO) satellites and inexpensive. When the ground station encounters its highest elevation angle with the satellite trajectory (90deg.), it is called zenith, the antenna needs to move at a very high speed in azimuth direction in order to follow and track the target and avoid “Cone of Silence” or Key hole in hemispherical coverage. The Key-hole in the case AZ-EL mount pedestal is around 90deg (peak) elevation, hence the Zenith pass demands very high dynamic rates in AZ axis and thus inadequate azimuth speed or failure to meet the high velocity /acceleration in Azimuth axis results in large Lag error and ground station antenna cannot follow/track the satellite continuously and leads to a significant data loss for the passes that approach Zenith /maximum elevation.

The solutions include the use of either a tilted azimuth-elevation pedestal or an X-Y pedestal. As X-Y mount pedestals are bulky and have Key-hole at Horizon (near 0 deg. Elevation), hence it is preferred to use EL-over AZ mount pedestal by incorporating a tilt in Azimuth axis. The direction of the tilt is either towards East or West and the degree of tilt depends on the intended Target trajectory, that is, as per the “Key-hole region” for that particular pass. Further, if the Tilt is incorporated in Eastward direction w.r.t True north / 0 deg Azimuth, then that system has a limitation of tracking Westward trajectory target and cannot avoid Zenith /Key-hole. Similar is the case for Westward Tilt pedestal to track /avoid Zenith in the Eastward trajectory targets. Hence to overcome this fixed tilt constraint and make the system capable of tracking any trajectory, a Train/Tilt -axis with 7 degree tilt wedge is designed and installed below the azimuth mount with +/- 180 deg programmable orientation of 7 degree tilt wedge and operationalized at NRSC ground station for tracking of LEO satellites. The tri-axis antenna mount will enable handling the trajectory of any current and future satellites, all polar sun synchronous satellites and inclined orbit satellites, with no Key Hole at zenith.

Functional Details

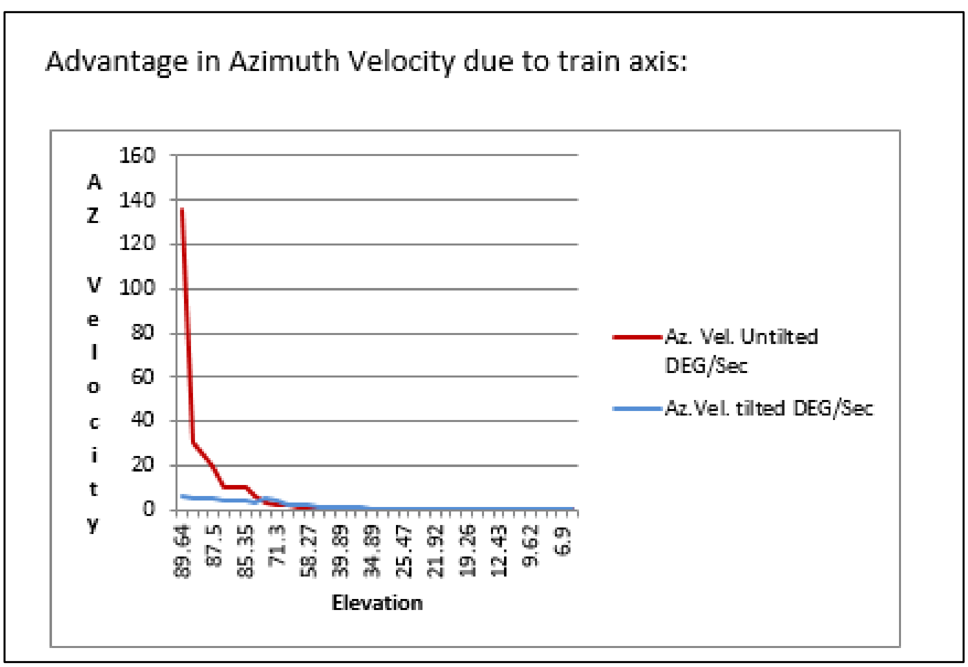
In normal 2 Axis antenna (Elevation over Azimuth Mount) the azimuth velocity requirement is very high beyond 87.5 deg elevation.

Tri-axis Antenna System Pedestal picture

Considering a nominal Remote sensing satellite in LEO orbit (Ex. SCATSAT: 505Km Altitude and Velocity of 7.5 KM/sec) the azimuth velocity is 19.5 deg./sec. The antenna azimuth velocity requirement will reach up to infinity for zenith 90 deg elevation pass. Hence no practical system will track the passes up to 90 deg. Elevation, encounter a ‘’Cone of Silence’’ as stated above.

This limitation will be overcome in Tri-axis system, by adding a third axis (train axis with 7 deg. wedge) beneath the 2-axis mount. By incorporating wedge tilt, the actual maximum elevation of the pass for the antenna will become (90-7=83) 83 deg. Thus, the demand for higher velocities and acceleration will be reduced, accordingly, the sizing of the motors, corresponding drive system will come down, which in turn will reduce the antenna dynamics and power consumption.

The 7 deg. wedge will be oriented in Azimuth direction before each pass based on the Azimuth sector of the pass to get the full coverage from horizon to horizon. The wedge had been made programmable to aid the above said movement. 76 deg. (90 – 2(Train axis tilt)) considered as threshold for computing the optimum train axis orientation.



Impact of Train Axis on system dynamics for understanding based on orbit height:

Antenna satellite altitude (KM)	**No tilt (90deg) Max EL 87.5deg (Existing capability)**		**Tilt angle 5deg Tilted peak EL 85deg**		**Tilt angle 6deg Tilted peak EL 84deg**		**Tilt angle 7deg Tilted peak EL 83deg**	
	AZ (v)	AZ (a)	AZ (v)	AZ (a)	AZ (v)	AZ (a)	AZ (v)	AZ (a)
500	19.98	4.53	9.97	1.12	8.30	0.782	7.10	0.57
400	25.17	7.18	12.56	1.79	10.3	1.2	8.8	0.88
350	28.87	9.45	14.40	2.35	11.7	1.56	10	1.14
300	33.81	12.96	16.87	3.23	13.7	2.13	11.7	1.56
250	40.72	18.81	20.32	4.68	16.4	3.07	14.1	2.24

(v) : velocity ; (a) : acceleration

Salient Features of tri-axis Antenna Control Servo System (ACSS)

- Programmable Train axis with 7° tilt.
- Antenna Tracking rates are reduced by a factor of 3 when compared two axis systems at higher elevations.
- Tracking Accuracy achieved is 30m° RMS.
- On-axis Encoder in Elevation axis.
- Implemented PID, F/F & Adaptive Control Algorithms to cater for Ka band tracking and data reception apart from S/X data reception.

Specifications / Parameters	**2 axis Antenna System**	**Tri-axis Antenna system**
Antenna Mount	AZ-EL	AZ-EL-Train axes
Antenna tilt	-/+ 3.3 ^{o} fixed tilt	Programmable 7 ^{o}tilt
Pointing Accuracy	0.10 ^{o}	0.07 ^{o}
Tracking Accuracy	0.05 ^{o}	0.03 ^{o}
Drive to Stow	100Kmph	100Kmph
Natural resonance frequency	>5Hz	>8Hz
Maximum Tracking Velocity	AZ axis : 20 ^{o}/sec (upto 87.5 ^{o} EL)	AZ axis : 15^{o} /sec (upto 90 ^{o} EL)
	EL axis : 10 ^{o}/sec	EL axis : 6 ^{o}/sec
		Train axis: 6 ^{o}/sec
Maximum Tracking Acceleration	AZ axis: 10 ^{o}/sec^2	AZ axis: 6 ^{o}/sec^2
	EL axis: 5 ^{o}/sec^2	EL axis: 3 ^{o}/sec^2

Specifications / Parameters	**2 axis Antenna System**	**Tri-axis Antenna system**
		Trainaxis : $3^{o}/sec^{2}$
Antenna Travel Range	AZ axis: +/- 360^{o} in CW & CCW	AZ axis: +/- 360^{o}in CW & CCW
	EL axis: -5^{o} to 185^{o} in UP & Down	EL axis: -5^{o} to 185^{o} in UP & Down
		Train axis: +/-180^{o} in CW &CCW
Programmable control parameters	PID, feed forward, torque bias for single/ dual drive configurations	PID, feed forward, torque bias and adaptive control for single/ dual drive configurations
Position loop bandwidth	Field programmable up to 1.0 Hz	Field programmable upto 2.5Hz.

<u>Advantages of Tri-axis system</u>

1. On axis encoder deployed in EL axis for eliminating the non linearity behavior in the encoder assembly.
2. Complete digital control system using real-time ECAT protocol.
3. Advanced control algorithm like adaptive control algorithm is deployed over PID and feed forward algorithms in the system.
4. Tracking accuracy improved to 25mdeg from 50mdeg of existing two axis systems.
5. Programmable tilt axis with 7deg tilt is optimized as per the LEO tracking requirements to avoid the keyhole issue of the EL over AZ pedestal. Thus complete hemispherical coverage possibility is made by this tri-axis system.
6. The tracking dynamics requirements are reduced by a factor of 3 when compared to the two axis systems at higher elevations.
7. Capable of tracking Ka band satellites.
8. It can accommodate tracking of lowest orbit satellites like microsats at present and also in near future.
9. The Tri axis system automatically computes and positions the most optimum train axis programmable tilt for the low, medium and high Elevation pass specific satellite trajectories for both polar and inclined orbits due to which tracking dynamics and power consumption are reduced and also without any loss of tracking and data in zenith and horizon regions, when compared to two axis Antenna.