
STARLINK
August 9, 2022
STARLINK CONSTELLATION AND HARDWARE DEVELOPMENT
BRIGHTNESS MITIGATION BEST PRACTICES FOR SATELLITE OPERATORS
SPACEX

Starlink Project Background

- SpaceX was founded to revolutionize space technology towards making life multiplanetary
- Starlink is making a huge positive impact for hundreds of thousands of people around the world, while advancing space sustainability and safety
  - Supporting connectivity to numerous communities, Tribes, school districts, etc.
  - Supporting enterprise and small businesses
  - Focus initially on remote, rural communities with un/underserved households
  - Helping to close the digital divide in the U.S. and around the world
- We're deeply committed to maintaining a safe orbital environment, protecting human spaceflight, and ensuring the environment is kept sustainable for everyone
  - SpaceX is safely operating 2900+ satellites in Low Earth Orbit despite recent debris surge
  - Unwavering commitment to reduce the brightness of our satellites and ensure there are accurate ephemerides and TLEs available

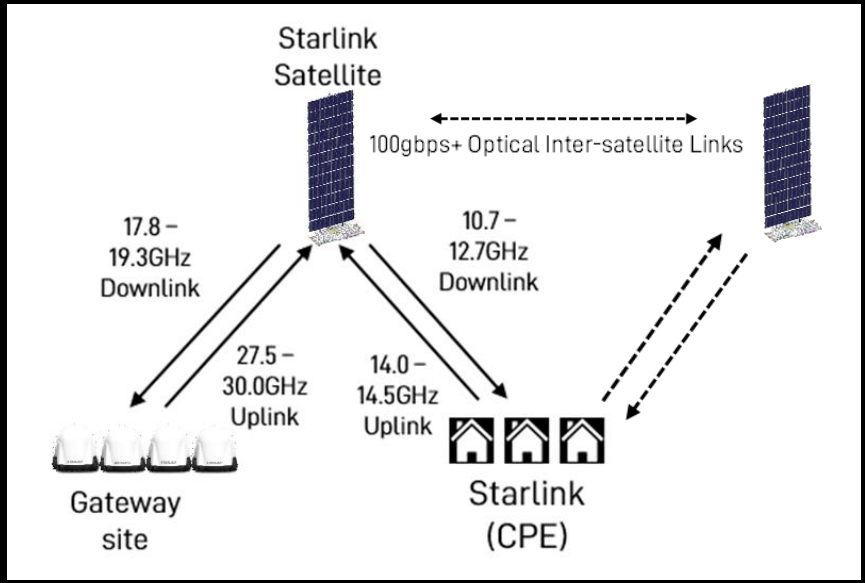
Current Deployment Status

2,900+ satellites launched into low Earth orbit (LEO) across 53 missions

650,000+ customers (with 400,000+ deposits for Starlink service) in 48 states, 37 countries, and 2 territories

200 Mbps (improving to 1 Gbps) speeds far exceed other satellite systems and are competitive with some terrestrial systems

All satellites launched to date are part of the 1st generation constellation.



Next Generation Starlink Constellation

- An expanded 2nd generation constellation is in development and critical to bridging the digital divide.
- 2nd generation Starlink constellation will have 10,548 sats above 500km compared to 4,408 sats in 1st generation Starlink constellation.
- Majority of 2nd generation Starlink constellation to operate at 360km or below.
    - These sats will be illuminated more briefly near dusk/dawn.

1st Generation Starlink Constellation

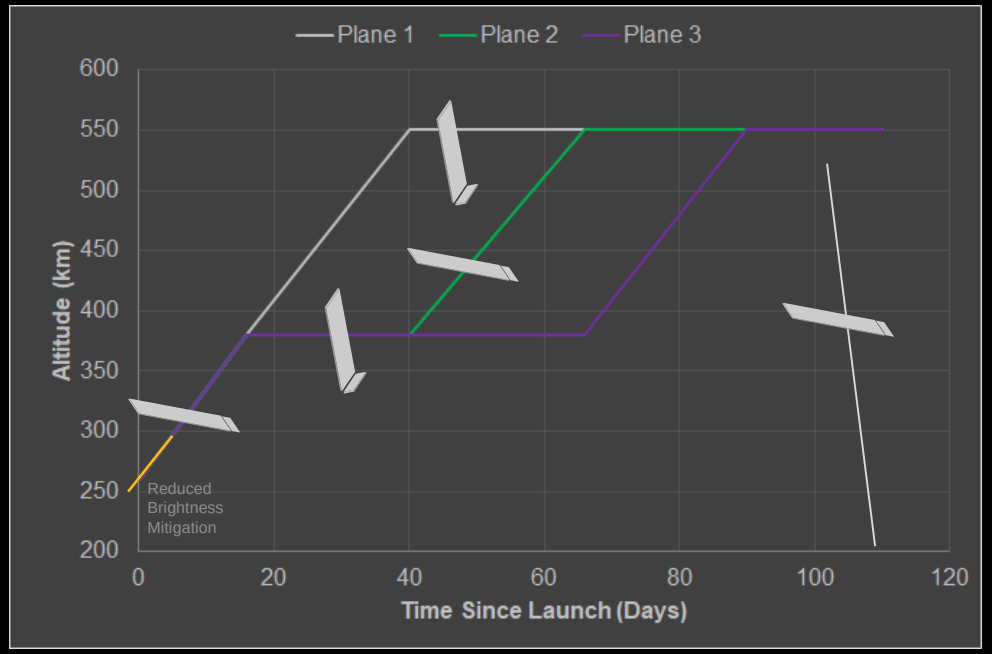
Altitude (km)	Inclination (deg)	Total Planes	Sats per Plane	Total Sats
550	53	72	22	1584
540	53.2	72	22	1584
570	70	36	20	720
560	97.6	6	58	348
560	97.6	4	43	172
			Total	4408

2nd Generation Starlink Constellation

Altitude (km)	Inclination (deg)	Total Planes	Sats per Plane	Total Sats
340	53	48	110	5280
345	46	48	110	5280
350	38	48	110	5280
360	96.9	30	120	3600
525	53	28	120	3360
530	43	28	120	3360
535	33	28	120	3360
604	148	12	12	144
614	115.7	18	18	324
			Total	29988

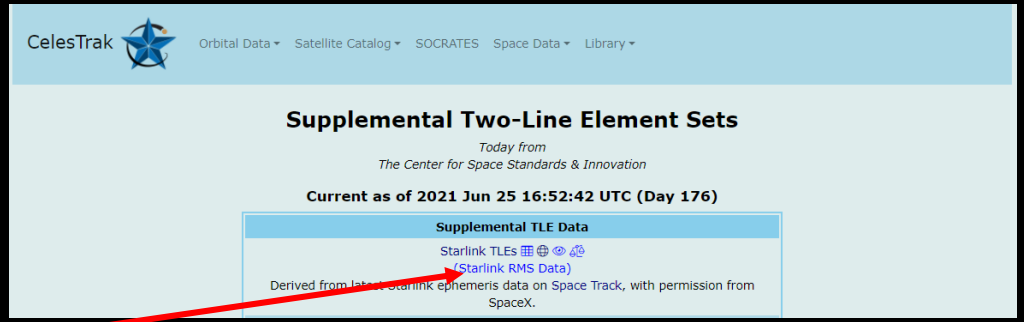
Starlink Operational Phases

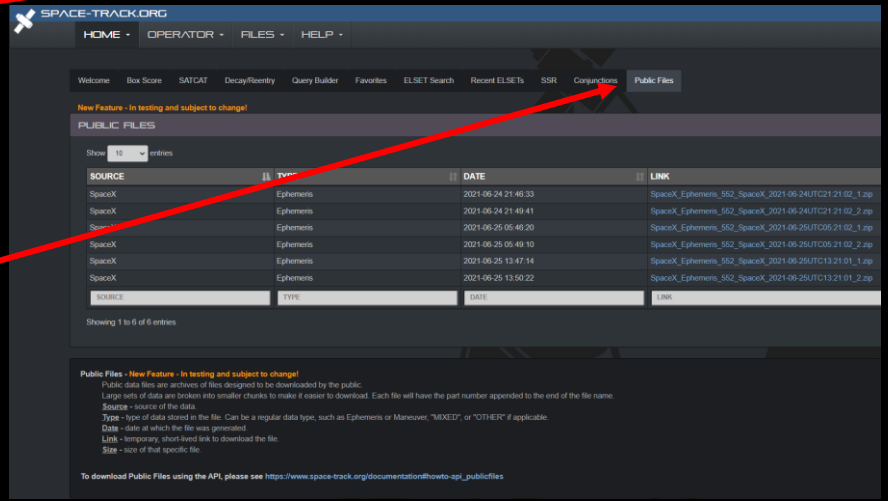
- Launch and deployment
- Post deployment to parking
- Parking (really RAAN rephasing)
- Parking orbit to operational orbit
- Operations
- Deorbit / disposal



Starlink TLEs and Ephemerides

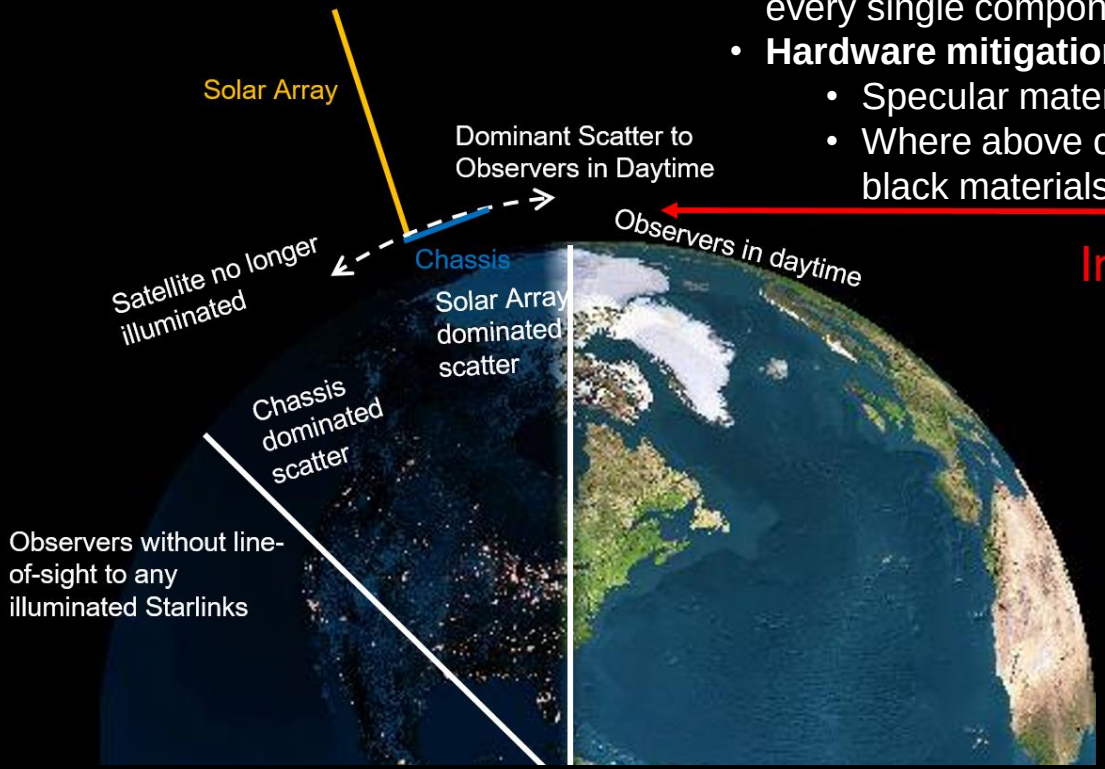
- SpaceX publishes a variety of Starlink orbital data “publicly”
- Traditional TLEs are available on Space-Track.org after the satellites are cataloged
- Supplemental TLEs are available on Celestrak.org
  - These are TLEs fit to Starlink propagated ephemerides
- Propagated ephemerides and covariance are available to anyone with a Space-Track.org account in their Public Files





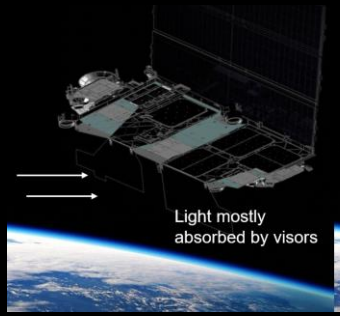
Mechanism for Satellite Brightness

- Mag 7 target corresponds to ~8U (0.08m^2) white cubesat so every single component must be considered.
- **Hardware mitigation strategies:**
  - Specular materials can scatter light away from Earth.
  - Where above cannot be achieved due to geometry, black materials are used to absorb light.

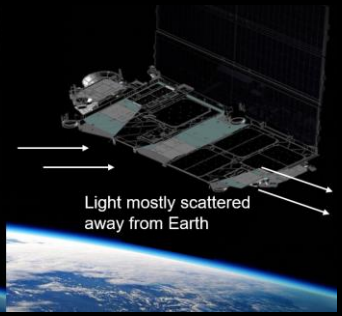


Dielectric Bragg Mirrors

Visors



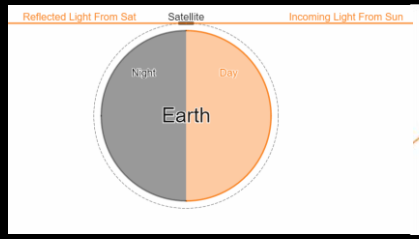
Mirrors



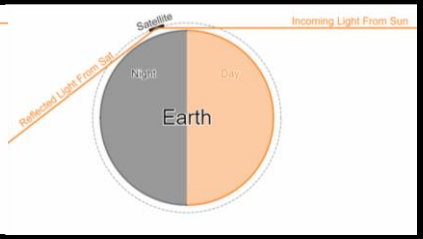
- SpaceX has switched from using visors to block light to using bragg mirrors to scatter light away from Earth.
- Brightness as observed from Earth is lowered as BRDF becomes more specular and diffuse tails decrease.
  - Intrinsic defects and surface roughness cause diffuse scatter.
- Current Starlink v1.5 satellites use the Gen1 dielectric mirrors and Gen2 dielectric mirrors are implemented for Starlink v2.

Perfect Reflection During Orbit

Sat Over Terminator

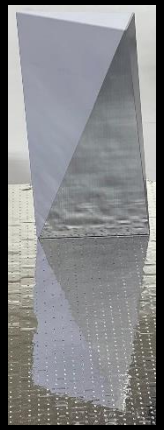


Sat Near Eclipse



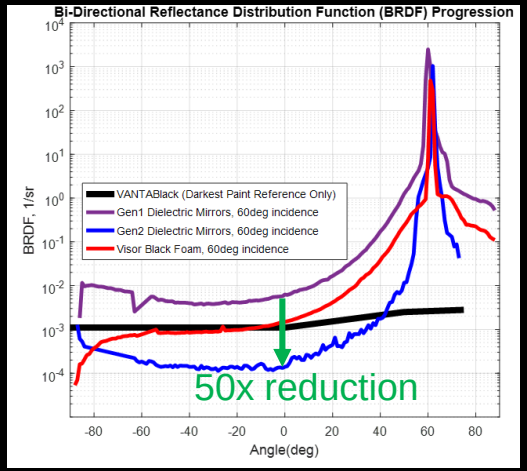
Dielectric Mirrors

Gen1



Gen2

Scatter Properties

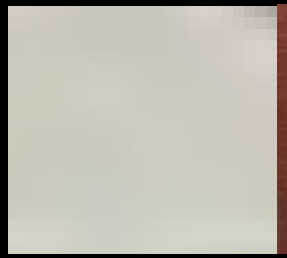


Solar Array Development

- Starlink satellites currently being launched have a pigmented solar array that reduces scatter to Earth observers.
- Starlink v2 has optimized the solar array architecture such that it can be off-pointed so diffuse scatter goes away from Earth.
  - Plane of solar array is terminator tracking.
  - Satellite power generation and network efficiency is reduced significantly.

Starlink v1 Mitigation

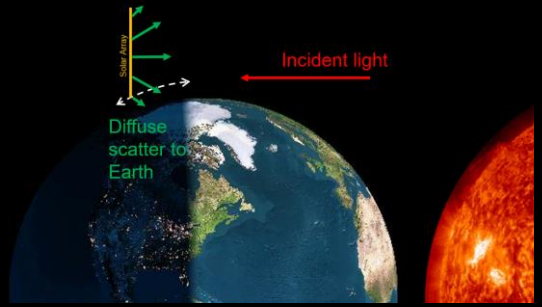
Initial v1 Inter-Cell Material



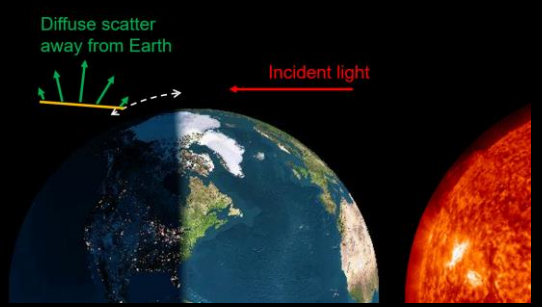
Darkened v1 Inter-Cell Material

Starlink v2 Mitigation

Sun Tracking
Ideal Power Generation



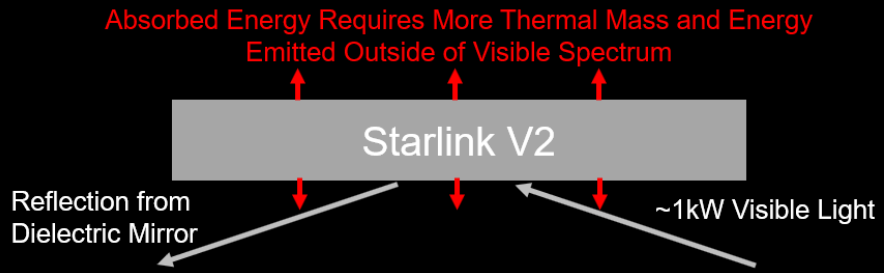
Brightness Mitigation
Reduced Power Generation



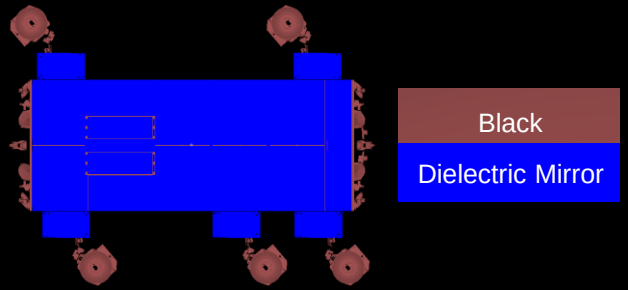
Black Materials

- For visible components that do not have a flat surface aligned zenith, black materials are used.
  - Using black materials is less efficient for satellite functionality and is brighter than using mirrors.
- SpaceX qualified many components to higher temperatures and added thermal mass to enable black material implementation.
- SpaceX developed a low reflectivity black paint to be used for Starlink v2.
  - Specular content is reduced by 5 times compared to paint previously used.
- Black materials were utilized for all components exposed nadir including:
  - Black tape over harnessing.
  - Black plastic for twist capsules and space laser components.
  - Black paint for parabolic dishes and exposed metals.

Thermal Considerations



Starlink v2 Mirrored Surfaces vs. Black Materials



For more information, please check out our recent blog post:

“BRIGHTNESS MITIGATION BEST PRACTICES FOR SATELLITE OPERATORS” at https://www.starlink.com/resources

Full PDF Available: https://api.starlink.com/public-files/BrightnessMitigationBestPracticesSatelliteOperators.pdf