

Payloads

Briefing

Starlink is a proposed mega-constellation of 12,000 to 42,000 small broadband communications satellites designed to provide low-latency, high-bandwidth Internet access worldwide. As of the end of May 2021, more than 1,730 Starlink satellites are in low Earth orbit (LEO). The deployment of the first 12,000 satellites is planned for completion for 2027, but global coverage is expected to be reached by the end of 2021 with just under one-quarter of that total in orbit.

Development of Starlink began in 2015. SpaceX announced the plans for the program on January 16 of that year. The company's founder and CEO, Elon Musk, said that SpaceX had submitted requests for orbital slots to the International Telecommunication Union (ITU in Geneva, Switzerland) and that he envisioned a system of some 4,000 satellites that would begin providing services by 2020.

In November 2016, SpaceX filed an application with the US Federal Communications Commission (FCC) for a non-geostationary orbit (NGSO) satellite system consisting of 4,425 Ku- and Ka-band communications satellites at an orbit altitude of 1,200 kilometers. In March 2017, the company filed a second application with the FCC for "very-low Earth orbit (VLEO) system of 7,518 satellites at an orbit altitude of 340 km. The total operational system would consist of 11,943 satellites, plus in-orbit spares.

On February 22, 2018, two demonstration satellites—MicroSat 2a (Tintin A) and MicroSat 2b (Tintin B)—were successfully launched. Each of the satellites weighed 400 kilograms.

On March 29, 2018, the FCC granted SpaceX a license to launch and operate 4,425 Starlinks. On November 15, 2018, the agency granted the company a license to launch and operate the additional 7,518 satellites. On February 8, 2019, SpaceX's sister company, SpaceX Services, Inc., filed a license application with the FCC for up to one million Starlink satellite Earth stations. Later that year in June, the company applied for a license with the FCC to test up to 270 ground terminals for its system.

The first batch of 60 Starlink prototype satellites (Block v0.9) were launched on May 24, 2019. By the end of June 2019, SpaceX had successfully communicated with those satellites. Contact with three of the satellites was lost, but the remaining 57 satellites functioned as planned.

On October 15, 2019, SpaceX filed paperwork asking the ITU for additional orbital slots to accommodate 30,000 more Starlink satellites. The FCC, on behalf of SpaceX, submitted 20 filings to the ITU for 1,500 satellites apiece. On May 26, 2020, SpaceX filed a license application with the FCC to build, launch and operate those 30,000 second-generation (Gen2) Starlink satellites. The Gen2s would operate in E-band, as well as Ku-



and Ka-band, and would have three times the data capacity of the first-generation Starlinks. They would be positioned in 75 orbital planes at altitudes ranging from 328 to 614 km and inclinations of between 30° and 115.7°.

On October 27, 2020, SpaceX launched public beta testing of that Starlink system. At the time, there were just under 900 satellites in orbit. The initial Starlink service was dubbed "Better Than Nothing Beta" and it started with coverage of the United States and Canada and aims to expand globally to populated areas of the world by the end of 2021. Data speeds range between 50 to 150 megabits per second, with latency from 20 to 40 milliseconds. Both speeds and latency are expected to improve as more satellites reach orbit. Notably, top speeds are expected to double to 300 Mbps.

Recent Developments

On April 27, 2021, FCC approved a modification to SpaceX's license for Starlink. The move allows more than 2,800 future Starlink satellites to operate at the same orbit altitude of roughly 550 km at which current Starlinks are operating. Prior to the license modification, those future satellites were to have been positioned at about 1,100 to

1,300 km. Several of SpaceX competitors, including Arianespace, Hughes Network, SES and Viasat have filed complaints to the FCC regarding its decision. The concerns have to do with environmental threats to the Earth's atmosphere and frequency interference of having so many satellites (belonging to one company) at such low orbits. Viasat has petitioned the FCC to

conduct an environmental review of the potential impact of the orbit altitude modification and has threatened to file a lawsuit if the agency does not.

On May 26, 2021, SpaceX completed the launch of its 30th batch of Starlinks, for a total of 1,735 satellites for the system launched since 2019.

Executive

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Specifications

Mass
Block v0.9 (prototypes): 227 kg
Block v1.0 (operational): 260 kg
Dimensions (stowed): 3.2 x 1.6 x 0.2 m
Design lifetime: 5 yr
Electrical power: 6,000 W
Orbit: 550 km, 53°

Subsystems

Frame

The frame of the satellites is a flat-panel bus designed and developed by *SpaceX*. The bus has multiple high-throughput antennas and one solar array.

Launch Systems

The designated launch vehicle for the satellites is *SpaceX's* Falcon 9 v1.2 rocket. Each Falcon 9 can carry and deploy 60 Starlinks at a time from its payload fairing. A planned larger fairing will allow for deployment of more than 60 satellites at a time. *SpaceX's* super heavy Starship reusable rocket will have a capacity to launch 400 Starlinks per mission.

Guidance & Control

Propulsion is provided by krypton-fueled Hall thrusters to maneuver in orbit and maintain altitude. Each satellite also carries a Startracker system for precision pointing and navigation. They will also have optical trackers to detect space debris and allow the satellites to autonomously avoid collisions with other objects in space.

Power

Electrical power for each of the satellites is generated by a single solar array, consisting of 12 panel segments. Our standard is that the heterojunction technology (HIT) solar arrays and solar cells are supplied by *Panasonic Corp.* of Osaka, Japan under contract to *Tesla Corp.* of Palo Alto, CA.

Payload

Each of the satellites carry a Ku- and Ka-band communications payload, with laser transponders. The operational satellites have optical inter-satellite links.

Other Subsystems & Services

Microsoft Corp. Of Redmond, WA is providing its Azure Orbital computing system to connect Starlink satellites directly to its cloud storage network. This is part of a partnership arrangement with SpaceX.

Launch History

Date	Payload	Mass*	Launch Vehicle	Orbit	Launch Site
<i>Batch 1</i>					
05/24/19	Starlink I 01 – Starlink I 60	227 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 2</i>					
11/11/19	Starlink I 61 – Starlink I 120	227/260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 3</i>					
01/07/20	Starlink I 121 – Starlink I 180	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 4</i>					
01/29/20	Starlink I 181 – Starlink I 240	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 5</i>					
02/16/20	Starlink I 241 – Starlink I 300	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 6</i>					
03/18/20	Starlink I 301 – Starlink I 360	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 7</i>					
04/22/20	Starlink I 361 – Starlink I 420	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 8</i>					
06/04/20	Starlink I 421 – Starlink I 480	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS
<i>Batch 9</i>					
06/13/20	Starlink I 481 – Starlink I 538	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS

<i>Batch 10</i>						
08/07/20	Starlink I 539 – Starlink I 595	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 11</i>						
08/18/20	Starlink I 596 – Starlink I 653	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 12</i>						
09/03/20	Starlink I 654 – Starlink I 713	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 13</i>						
10/06/20	Starlink I 714 – Starlink I 773	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 14</i>						
10/18/20	Starlink I 774 – Starlink I 883	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 15</i>						
10/24/20	Starlink I 884 – Starlink I 893	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 16</i>						
11/24/20	Starlink I 894 – Starlink I 953	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 17</i>						
01/20/21	Starlink I 954 – Starlink I 1013	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 18</i>						
01/24/21	Starlink I 1014 – Starlink I 1023	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 19</i>						
02/04/21	Starlink I 1024 – Starlink I 1083	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 20</i>						
02/16/21	Starlink I 1084 – Starlink I 1143	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 21</i>						
03/04/21	Starlink I 1144 – Starlink I 1203	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 22</i>						
03/11/21	Starlink I 1204 – Starlink I 1263	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 23</i>						
03/14/21	Starlink I 1264 – Starlink I 1323	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 24</i>						
03/24/21	Starlink I 1324 – Starlink I 1383	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 25</i>						
04/07/21	Starlink I 1384 – Starlink I 1443	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 26</i>						
04/29/21	Starlink I 1444 – Starlink I 1503	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 27</i>						
05/04/21	Starlink I 1504 – Starlink I 1563	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 28</i>						
05/09/21	Starlink I 1564 – Starlink I 1623	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 29</i>						
05/15/21	Starlink I 1624 – Starlink I 1675	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	
<i>Batch 30</i>						
05/26/21	Starlink I 1676 – Starlink I 1735	260 kg	Falcon 9 v1.2	low earth	Cape Canaveral AFS	

* per satellite

Funding

Starlink is largely funded by SpaceX, although in February 2021 the company did complete

raising \$3.5 billion in equity financing for the program. Also, in December 2020 the company

was awarded \$885.5 million in US federal government subsidy funds by the FCC to support ru-

ral broadband customers through its satellite system. The funds, which will be distributed through the end of the decade in the form of equal monthly payments, are

conditioned on the company meeting of it Starlink deployment milestones.

SpaceX has reportedly received more than half a million

“pre-orders” for Starlink services. Each order brings in sales revenue of \$99 in the form of a refundable deposit.

Costs

System

Estimated cost of developing, building and launching the 12,000-satellite Starlink system is \$10 billion, according to

SpaceX. Independent estimates for the 42,000-satellite system range between \$50 billion to \$120 billion. The cost of manu-

facturing each satellite is under \$500,000.

Service

The cost of accessing Starlink services via a satellite dish is currently estimated at \$99 per

month. There is also an upfront hardware fee of \$499. But those prices are expected to eventually

drop to \$80 per month and a one-time hardware fee of \$100 to \$300.

Teal Group Evaluation

Starlink is the most ambitious and revolutionary satellite program in history. In just two years, more than 1,730 of these powerful satellites have been launched aboard 30 Falcon 9 rockets to LEO and become operational. SpaceX has been manufacturing some 120 Starlinks per month. Both these construction and launch rates are unheard of in the annals of the satellite and space launch industries. But even with that achievement, the program is just getting started. It is precisely this year that the program is set to begin accelerating.

By the end of this decade, SpaceX plans to have launched more than 12,000 Starlinks—roughly three times as many satellites as are currently operating in Earth orbits today and more than all the satellites launched by every country in the world from 1957 until the present. That represents a pace of more than 1,000

satellites a year through 2030. And *even then* the program will still in its relative infancy when you consider that that accomplishment would only complete the first phase of the program. The second phase known as “Gen2” would represent the big challenge—30,000 additional satellites. (Note that SpaceX will have to build and launch the Gen2’s at the same time that it is building and launching replacement satellites for the first-generation satellites.) This is a program that seemingly has no end. If it succeeds, it will radically transform the satellite and launch markets, as well as the infinitely larger and more lucrative telecommunications market. SpaceX will essentially have a monopoly at LEO.

At the moment, the only other satellite constellation that might offer Starlink some competition is OneWeb, but even that system pales in comparison to what SpaceX envisions for its system,

whose price tag could surpass \$100 billion. Remember when Motorola’s 66-satellite Iridium constellation at a cost of \$5 billion was considered outrageous? That provides some perspective of what has been put in motion by Mr. Musk. The \$10 billion cost of Starlink that is often cited is really little more than a generous down payment.

For all practical purposes, Starlink is already operational, with approximately 80 percent of the Earth’s surface covered by its services, even though less than a quarter of the first-generation satellites have been launched. The system currently has 10,000 customers beta testing its services. And our understanding is that SpaceX has more than 700,000 “pre-orders” for more potential customers. Nearly half of the world’s population of about 7.9 billion people does not have access to the Internet. Starlink stands to change that situa-

tion fairly quickly, and some estimates of the financial benefit to SpaceX within the next five years have been pegged at \$30-50 billion a year. It is this revenue that will serve to fund SpaceX's other ventures in space, including the seemingly outrageous idea of colonizing Mars. Elon Musk estimates Starlink may end up capturing 3-4% of the \$1 trillion Internet access market.

Ironically, in some ways what SpaceX is aiming to with Star-

link is even more challenging than Mars. But so far things are going as planned. The huge advantage SpaceX has is it is self-reliant. The company not only builds its own satellites but launches them on its own partially reusable rockets. A unique and aggressive operating paradigm within the two primary segments of the space industry, which is traditionally known for being unusually cautious and risk averse.

SpaceX has an extremely diverse, reliable and lucrative revenue stream from launching satellites and both manned and unmanned supply mission for commercial, military and civil customers government, and it is now positioning itself to make gobs of money as a provider of telecommunications services via Starlink. SpaceX is aiming to have more than 360 million Starlink subscribers within 20 years. It may well accomplish that goal, but that's a long way off.

Launch Forecast

<i>(payload units)</i>	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Starlink	2,000	1,600	1,600	2,000	1,600	1,600	1,000	1,000	1,000	1,000