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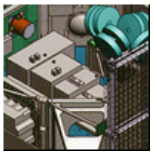
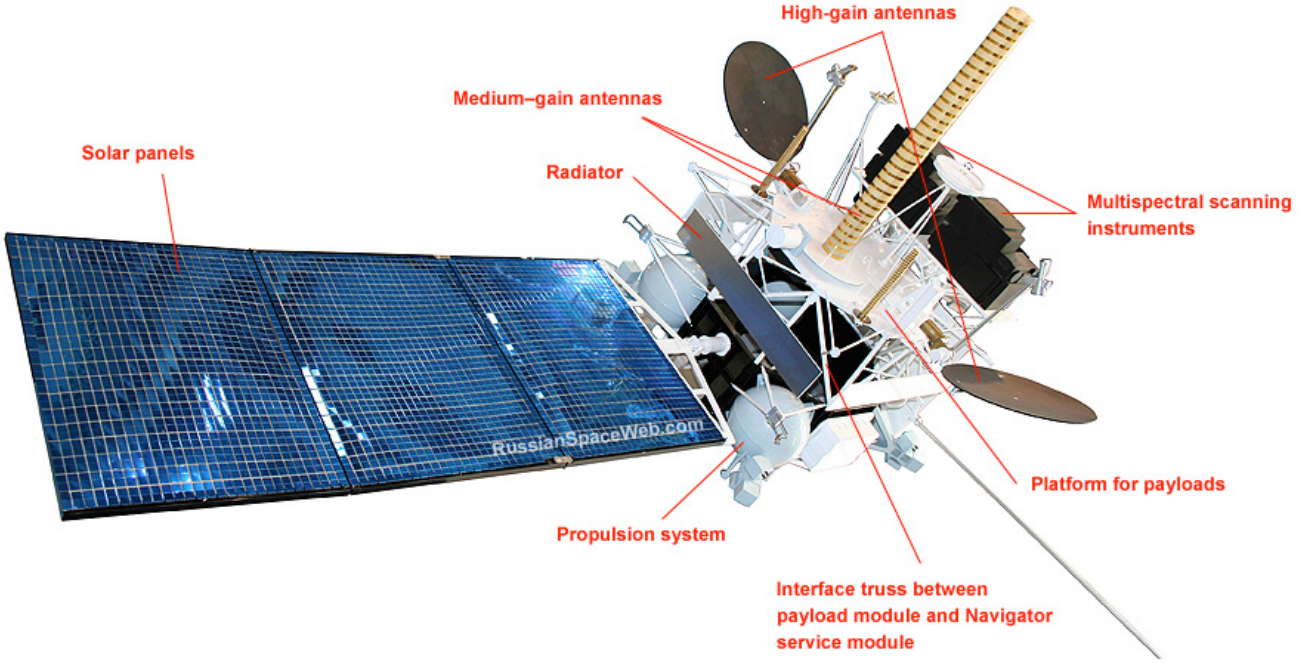


Navigator



Above: Key components of the Elektro-L satellite. Copyright © 2009 Anatoly Zak

Russia to introduce a new generation of spacecraft

The first major spacecraft developed in post-Soviet Russia blasted off from Baikonur Cosmodrome in Kazakhstan Thursday, promising to pave the way to a whole new generation of space projects. A Zenit rocket blasted off on January 20, 2011, at 15:29:01 Moscow Time, carrying the Elektro–L No. 1 weather-forecasting satellite. According to launch broadcast around 10 minutes after liftoff, the vehicle successfully reached its initial parking orbit. The Russian space agency, Roskosmos, confirmed that the spacecraft had entered orbit. After the first planned firing of the engine onboard the Fregat upper stage, Western radar found the vehicle in the predicted orbit. Fregat's second firing was also reported to be successful.

Half an hour after midnight Moscow Time, Roskosmos confirmed that the Fregat upper stage had released the satellite as planned. The same night, Deputy Head of Roskosmos Anatoly Shilov said that Elektro-L had successfully deployed its solar panel and the first series of tests showed flawless operation of all systems onboard the satellite.

The Elektro-L spacecraft was designed to give Russian meteorologists the ability to watch the entire disk of the planet, thanks to the satellite's position in the geostationary orbit 36,000 kilometers above the Equator. For Russia, it became only the second meteorological satellite at this vantage point since the launch of Elektro-1 in 1994. Designed to function in orbit for a decade, Elektro-L will enable local and global weather forecasting, analysis of oceanic conditions, as well as "space weather" monitoring, such as measurements of solar radiation, properties of Earth's ionosphere and magnetic field.

Even more importantly than its primary mission, Elektro-L project promised to pave the way to a whole new generation of advanced Russian spacecraft, first of all sophisticated space observatories such as Spektr-R, Spektr-RG, and Spektr-UF, which would be based on the same platform dubbed **Navigator**. Other spacecraft using similar hardware are likely to follow. Unlike most of Russian spacecraft flying today, the Elektro-L/Navigator project was conceived and developed after the disintegration of the Soviet Union, thus marking the reemergence of the nation's space industry after two decades of economic turmoil.

The launch of the first Elektro-L also validated a brand-new version of the powerful Zenit rocket and the upgraded Fregat upper stage. During the following decade, the Zenit/Fregat-SB combination promises to carry Russia's most critical space exploration missions, starting with the launch of the Phobos-Grunt spacecraft toward Mars.

Origin of the Elektro-L project

The original Elektro geostationary meteorological satellite was under development at VNII Elektromekhaniki since the beginning of the 1980s. Specialized ground stations intended to receive meteorological data from Elektro spacecraft were built in Novosibirsk, Khabarovsk and Moscow. An additional site was built in Tashkent, Uzbekistan, but the facility could not be used after the disintegration of the USSR. (439)

As of 1993, there were plans to launch two Elektro satellites, with the first bird taking position at 76 East longitude over the Equator. However due to the Russian economic troubles of the 1990s, only one Elektro satellite flew in 1994. By that time, US,

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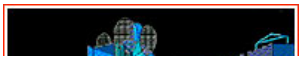
In March 2011, Elektro captured this view of the Moon over the Red Sea region of the Earth. Credit: NPO Lavochkin

On Feb. 26, 2011, at 14:30 Moscow Time, the Elektro-L satellite produced its first breathtaking image of the home planet. Credit: NPO Lavochkin



Japanese and European meteorological satellites already worked in geostationary orbit. The first Elektro satellite stopped functioning in 1998, leaving Russia without crucial meteorological data.

In 2001, the Russian government awarded a new contract for the second-generation meteorological satellites to NPO Lavochkin. The project was dubbed Elektro-L, where "L" signified a version of the satellite proposed by Lavochkin. Russia's meteorological service, Rosgidromet, served as the main customer of the satellite's data.

Lavochkin originally planned to bring the satellite into a geostationary orbit with the help of the lunar gravitational field, by sending the spacecraft on a long loop around the Moon. In the following decade, the project went through another evolution, adopting the company's Navigator platform as a base for its architecture sometimes around 2004. The modular architecture of the satellite was designed to work in the vacuum of space.

The launch of Elektro-L would become the first test flight for Navigator, followed by more complex missions, such as Spektr-R (Radioastron), Spektr-RG and Spektr-UF orbital observatories.

As of 2007, a total of three Elektro-L spacecraft were promised to be launched. The Elektro-L No. 2 satellite was expected to be stationed in the geostationary orbit at 14.5 West longitude.

Elektro-L payloads

The main payload of the satellite would be a special scanner with a 20-degree angle of view, designated MSU-GS, capable of obtaining images in the visible and infrared ranges of the spectrum. From the height of its geostationary orbit, its angle of view would be enough to watch the entire disk of the Earth. Visible and infrared components of the imager were promised to have a resolution of one and four kilometers respectively and be capable of producing images every 30 minutes. For support in emergency situations, images could be snapped as fast as one in 10-15 minutes.

As an additional payload, Elektro-L would carry a "heliophysical" complex GGAK-E developed by the Science monitoring center at Roskosmos in cooperation with the Applied geophysics institute of the Russian meteorological center (Rosgidromet) and the Nuclear physics institute at Moscow State University, NIIYaF MGU. The system was designed to monitor several properties of solar radiation and channel this data to the satellite's communication gear for transmission to Earth.

Finally, the spacecraft was to be equipped with a communication payload developed by the Pilyugin center. It was intended for meteorological data exchange between the main center in Moscow and regional meteorological facilities in Novosibirsk and Khabarovsk in Russia's Far East. The data could be transmitted both ways with a rate of 15.36 Mbits per second at a frequency of 8.2/7.5 GHz. The same payload could also pick data every three hours from up to 800 meteorological platforms spread around Russian territory or in the ocean at a frequency of 0.4/1.7 GHz. Finally, this package could pick and relay to Earth signals from KOSPAS-SARSAT emergency rescue systems at a frequency of 0.4/1.54 GHz.

Mass-saving measures

During the development of the satellite, NPO Lavochkin faced unexpected limitations on the payload mass available for the mission. An engine which was supplied for the Fregat-SB upper stage had lower performance characteristics than originally expected. Also, NPO Yuzhnoe, the manufacturer of the Zenit rocket, was not able to implement a flight profile, where Zenit's engines would burn all the way till complete expenditure of one of its propellant components. As a result, the final mass of the Elektro-L satellite in the geostationary orbit had to be reduced from originally projected 1,900 kilograms to 1,766 kilograms. NPO Lavochkin met this limit mainly by reducing the propellant load onboard Elektro-L. This measure reduced the time period during the lifetime of the satellite, when mission control could adjust a gradual increase in the satellite's orbital inclination. As a result after the expenditure of onboard propellant, Elektro-L's orbital plane was expected to start drifting away from the equatorial plane of the Earth by around one degree per year.

Launch preparations

In the first half of the 2000s, the launch of the original Elektro-L spacecraft was promised in 2006 and the mission eventually slipped to June 2007, the fourth quarter of 2007 and November 2008.

On the night of January 16, 2009, the Zenit rocket intended for the Elektro mission arrived to Baikonur, followed by the shipment of the Fregat upper stage on April 4 of the same year. However in the second half of 2009, the satellite was still waiting for the delivery of its key instrument - the MSU-GS multi-spectral sensor - and the launch of the satellite was then unofficially projected for no earlier than April 2010.

In March 2010, Roskosmos confirmed previous unofficial reports that the MSU-GS instrument would have to be modified to account for problems encountered in the operation of a similar instrument onboard the Meteor-M No. 1 satellite. This delay temporarily pushed the launch of Elektro-L behind the more complex Spektr-R spacecraft. Since both satellites were based on the untested Navigator platform, this schedule change put more risk on the more expensive and valuable Spektr-R mission. As of June 2010, the official schedule called for the Elektro-L launch in December 2010, or about a month after Spektr-R. However the launch of the radio observatory was ultimately delayed to the Spring of 2011.

At the end of January - beginning of February 2010, the flight version of the Elektro-L satellite successfully went through electrical tests at the VK-600 vacuum chamber at NITs RKTs facility in Peresvet near Moscow. At the beginning of November, the Fregat upper stage was loaded with propellant at the fueling station at Site 31.

After last minute delays in delivery of Elektro-L to the launch site from November 22 and 30, the spacecraft finally departed for Baikonur on Dec. 1, 2010. The launch preparation campaign started at Site 31 on the next day. During December 8-11, the satellite was loaded with propellant and five days later the spacecraft was integrated with the Fregat-SB upper stage. However, in the wake of a high-profile failure of the Proton rocket with GLONASS satellites in December 2010, the launch of Elektro-L then scheduled for December 25 at 15:27 Moscow Time was put in limbo again. In the middle of the day on December 16, an order came to Baikonur from the head of the Russian space agency to stop all preparations for launch, even though there were no apparent problems in the campaign itself. Officials were reportedly re-checking all the procedures, especially related to a brand-new Fregat-SB stage. 24 hours later, the work on the payload section of the rocket, known as KGCh, was allowed to proceed, but not on the satellite itself. The launch had to be delayed until January 15-20, 2011, which is after Orthodox christmas holidays in the first half of the month. Critics said that the satellite with full load of propellant onboard had to be essentially mothballed until January 10, since there were no technical problems in the launch campaign. One positive fallout from the delay was the fact that a critical post-launch orbit corrections would no longer fall on pre-new year eve on Dec. 30-31, 2010.

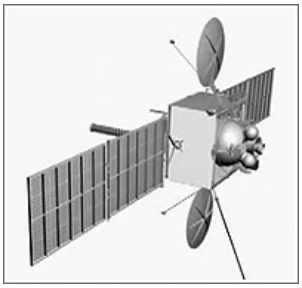
By December 24, the new launch window for Elektro-L was narrowed down to January 20, 2011. Work did resume on January 11, as the satellite with the upper stage was lowered into horizontal position and integrated with the payload fairing. On January 17, the Zenit rocket intended for the mission was placed on its transporter/erector. The next day, the launch vehicle with the satellite was rolled out from the assembly building at Site 42 to the launch pad at Site 45.

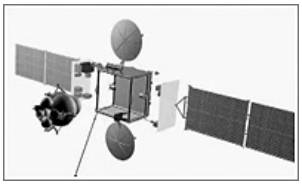
Path to orbit

For its ride to orbit, Elektro-L used a brand-new combination of the Zenit rocket and the Fregat-SB upper stage. In turn, it was the inaugural launch of the Fregat-SB version of the upper stage, featuring an additional jettisonable external tank, or SBB. The same launch vehicle configuration would be used for a number of future Russian launches.

Artist rendering of Elektro-1 satellite in orbital configuration. Credit: NPO Lavochkin

Few images of the original Elektro spacecraft have been released. Credit: RKA





Original architecture of Elektro-L satellite circa 2001. Credit: NPO Lavochkin

Some 8.6 minutes after launch, at an altitude of 205 kilometers the Fregat-SB upper stage with its payload was expected to separate from the second stage of the Zenit rocket entering an initial 178 by 640-kilometer parking orbit. A total of three burns of the Fregat-SB upper stage were planned before delivery of the satellite in its operational orbit. The first burn would use propellant exclusively from the external tank, which would be jettisoned immediately after engine shutdown. This maneuver would leave the stack in a 306 by 4,440-kilometer orbit with a 50.4 degree inclination. Fregat would then fire again entering a 361 by 35,914-kilometers orbit. Finally, the third burn would "circularize" the orbit and reduce its inclination to only 0.5 degrees, after which Fregat would separate and move away into a safe "burial" orbit.

Like its predecessor in the 1990s, Elektro-L was to be "stationed" over the Indian Ocean at 76 degrees East longitude, where it was expected to function for 10 years. Following its separation from the Fregat-SB upper stage, the Elektro-L satellite was initially inserted into a quasi-geostationary orbit at 54 degrees East longitude. It meant that the satellite's orbital altitude was slightly different from that of a regular geostationary orbit causing the spacecraft to "drift" relative to a single point over the Equator, thus carrying it toward final destination.

Immediately after the launch, the Klen–E ground control station in Medvezhi Ozera near Moscow, responsible for sending commands to the satellite and receiving its telemetry, faced problems with accurate tracking of the spacecraft. The initial attempt to precisely lock antennas in Medvezhi Ozera onto Elektro-L according to pre-launch calculations had failed. In order to accurately predict the satellite's movement, the optical tracking station in Terskol in Southern Russia and the Ritm radar facility in Medvezhi Ozera had to be employed. As it turned out, Elektro-L was drifting eastward at a rate of about three degrees per day, which was faster than expected, thus preventing its tracking based on original predictions. In addition, engineers at Lavochkin's control station in Khimki experienced radio–interference apparently from a nearby source of radio waves, which prevented deciphering telemetry signals from the satellite.

In the meantime, faster movement of the satellite meant that by January 25, 2010, ground control would need to start maneuvering the satellite, in order to slow down its approach toward its final destination a day later. Delaying the maneuver could cause the satellite to pass its destination and require additional propellant consumption later in order to reverse its drift.

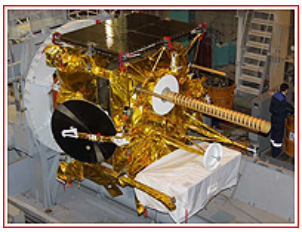
After it had entered its final orbit, the satellite's systems were to undergo tests during the following two or three weeks.

On February 3, 2011, Elektro-L reached its destination at 76 degrees East longitude over the Equator and ground controllers successfully adjusted its orbit to stop further drift of the satellite, so it would remain in its operational position. In the crowded geostationary orbit, a further drift of Elektro-L would have lead to pass as close as 10 kilometers from the SES-7/Indostar-2 communications satellite "parked" at 108.15 degrees East on February 6, 2011.

Elektro L spacecraft as it was envisioned by 2004. Credit: NPO Lavochkin

Elektro-L during assembly at NPO Lavochkin. Credit: NPO Lavochkin

Elektro-L shortly after arrival to Baikonur on Dec. 2, 2010. Credit: Roskosmos



Fueling of the Elektro-L spacecraft in Baikonur on Dec. 8, 2010. Credit: Roskosmos

A Zenit rocket with Elektro-L satellite is being erected on the launch pad in Baikonur on Jan. 18, 2011. Credit:

Elektro-L launch timeline (Moscow Decree Time):

Event	Time	Perigee, km	Apogee, km	Inclination
Liftoff	15:29:01	0	0	-
Stage II separation from Fregat upper stage	15:37:38	178	640	51.3
1st ignition of the Fregat upper stage engine	16:44:26	-	-	-
End of 1st Fregat burn	16:52:40	306	4,440	50.4
Separation of the external tank from Fregat-SB upper stage	16:53:17	-	-	-
2nd ignition of the Fregat upper stage engine	18:58:20	-	-	-
End of 2nd Fregat burn	19:08:59	361	35,914	48.6
3rd ignition of the Fregat upper stage engine	00:19:06	-	-	-
End of 3rd Fregat burn	00:27:43	-	-	-
Separation of Elektro-L satellite from Fregat upper stage	00:28:13	35,413	35,785	0.5
4th ignition of the Fregat upper stage engine	03:28:19	-	-	-
End of 4th Fregat burn	03:29:39	34,195	35,718	0.5

Known specifications of Elektro-L No. 1 satellite:

Spacecraft initial total mass	1,620-1,766 kilograms
Spacecraft mass at the end of projected lifespan	1,180 kilograms
Payload mass	430 kilograms
Total power supply system	1,700 Watts
Power supply for payload consumption	800 Watts
Projected lifespan	10 years
Orbital position in the geostationary orbit	76 East longitude
Accuracy of maintaining orbital longitude and altitude (during availability of onboard propellant)	±0.5 degrees
Launch vehicle (base two-stage rocket)	Zenit-2SB.80 No. 1-2007/1
Upper stage	Fregat-SB
Launch site	Baikonur, Site 45
International designation of the satellite	GOMS No. 2

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Baikonur on Jan. 18, 2011. Credit: Roskosmos

A Zenit rocket with Elektro-L satellite blasts off on Jan. 20, 2011. Credit: TsENKI