The EOS R5 is going to space.

Interview with the developers of the EOS R5 mirrorless camera and CE-SAT-IE micro-satellite

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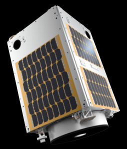
The imaging business is a huge market with great growth potential. Canon is one of the world's leading companies in the field of optics, including photography and image processing. Canon has been leveraging its core product — the EOS interchangeable-lens digital camera system — to expand into new business sectors. One example is a project by Canon and Canon Electronics to develop and install EOS R5 camera modules on satellites, for space exploration. We asked seven members of the development team to discuss Canon's venture into space.



Satellite proprietarily developed by Canon Electronics

Micro-satellite CE-SAT-IE

- Date of Launch : 17th February, 2024 (JST)
- Dimensions : 500 x 500 x 800mm, Mass : 70kg
- Orbit : Sun-synchronous orbit (Altitude : 670km)

Prologue: Exploring a new realm

Q: Tell us about Canon's new initiatives in the field of imaging technology?

Watanabe: Today, many new businesses are emerging that can benefit from the use of Canon's optical technology, sensor technology, and expertise in image processing. Examples include optical cameras that provide clear images even in the dark, industrial cameras that require ultra-high resolution, and 3D imaging systems that require simultaneous image generation from multiple cameras.

Canon's EOS system was developed for products aimed at average consumers, but these advanced technologies can be easily adapted to new business sectors.

Q: It must be a great advantage to be able to use the EOS system, which has already proven itself over many years of use as an interchangeable-lens-type camera?

Watanabe: Yes. The imaging technologies used in the EOS system can be adapted for use in other applications and other fields. The key is to quickly adapt the technology and customize the software to meet the required specifications and purposes of the new application. We are leveraging our knowhow in product customization to meet the challenge of new business opportunities.

Q: When did Canon get the idea of installing the EOS system on satellites?

Watanabe: Canon Electronics, which has been involved in the satellite business for some time, approached us with the idea of installing a high-resolution EOS system on one of their satellites, for use as a space telescope. It was quite a challenge to adapt our autofocusing system to suit the optical system of a reflecting telescope. However, we managed to achieve this breakthrough by installing an external computer on the satellite, to supplement the processing capabilities of the EOS camera.

Tokyo
(captured by CE-SAT-IE)

Canon's camera development division launched a collaborative project with Canon Electronics to address the challenges of this new venture into the aerospace business.

Honolulu
(captured by CE-SAT-IE)

The two companies developed the CE-SAT-IE — an ultra-miniaturized satellite with an EOS R5 unit onboard. It was launched into space from JAXA's Tanegashima Space Center aboard the second H3 Launch Vehicle (H3TF2) on February 17, 2024, successfully reached orbit, and began transmission operations.

This was a major accomplishment for the Canon Group, which was able to leverage the capabilities of group companies to launch a new business in outer space.

1. Overview of optical satellites and reasons why the EOS R5 was chosen

Q: What kind of satellite is the CE-SAT-IE?

Inakawa: CE-SAT-IE is an optical satellite designed mainly to photograph the earth's surface. This micro-satellite measures 50 x 50 x 80 cm and weighs around 70 kg. It orbits at an altitude of about 670 km and is able to take photos of various places on the earth. For example, it passes over Japan two to four times per a day, at which time it can capture images of the Japanese archipelago and transmit the images back to earth.

Q: Why was the EOS R5 camera chosen for use on the satellite?

Mameshiro: The first satellite that Canon Electronics developed was the CE-SAT-I (launched in 2017). It was equipped with an EOS 5D Mark III digital SLR camera. For this project we needed a camera that could generate higher resolution images, and concluded that the EOS R5 would be the best choice. Together with Canon, we launched a project to customize the camera to mount on our satellite.

Inakawa: One of the mission objectives for this satellite was to deliver high quality images from space. The EOS R5 camera generates images with a high resolution of about 45 megapixels. This allows it to capture detailed images of the earth's surface which can be used to create maps, or to check for damage after natural disasters. Another important feature of the satellite is its ability to capture 8K video images.

Watanabe: The EOS R5 interchangeable-lens digital camera has three key features that make it ideal for use on satellites: 1) The performance of the high-pixel CMOS sensor, which Canon developed in-house. 2) Autofocus technology that assures focal accuracy even under severe conditions. 3) The camera's high durability and reliability.

2. Advanced features of EOS R5: CMOS sensor

Uchida: The CMOS image sensor is a key technology that Canon developed in-house, and has been nurturing since the first appearance of digital SLR cameras.

The high-pixel CMOS sensor used in Canon cameras has approximately 45 megapixels. This is enough pixel density to deliver high-resolution still images, as well as 8K/30P video recordings. Though it is technically possible to further increase the pixel number, this would make high-sensitivity shooting more difficult and lower the continuous shooting performance. After carefully considering actual shooting conditions and performance requirements for the sensor, we concluded that a 45-megapixel CMOS sensor offers the best balance of performance and resolution available, at this time.

Q: Is the shutter release mechanism the same as that used on the standard EOS R5 model?

Uchida: The EOS R5 unit on board the satellite is based on a commercial Canon model, so it is also equipped with a mechanical shutter. However, considering the issue of durability in the harsh environment of space, it is more reliable to use an electronic shutter with no mechanical moving parts.

Inakawa: The EOS R5 can capture images at a high speed of approximately 20 frames per second when making use of its electronic shutter. This high-speed burst shooting feature is useful when generating ultra-high-resolution images.

Mameshiro: Another advantage of using the EOS R5 is the camera's ability to generate JPEG image data. Most conventional cameras mounted on optical satellites capture images in RAW format (raw image data before development), which requires more data. The captured images are transmitted back to earth in RAW

format, and developed one by one. By comparison, the EOS R5 is equipped with a DIGIC X image processor, which supports three imaging data formats: uncompressed RAW data, compressed C-RAW (about half the data size of RAW), and JPEG. C-RAW and JPEG formats use much less data than RAW, allowing more images to be transmitted in a limited transmission time. This is a great advantage when used in optical satellites.

Uchida: It was quite a challenge to design a camera system that can generate three image data formats (RAW, C-RAW, and JPEG) while also balancing shooting functions such as burst shooting. However, Canon’s DIGIC X image processor, with its extremely high processing power, allows the camera to instantly capture and record JPEG and C-RAW data while shooting with the electronic shutter at a high speed of approximately 20 frames per second (fps). It can also record 8K/30P video clips. The high-speed readout CMOS sensor, combined with the processing power of the DIGIC X image processor, allows the camera to achieve outstanding shooting performance.

3. Advanced features of EOS R5: Dual Pixel CMOS AF

Q: How does the autofocus mechanism of the EOS R5 operate?

Fukuda: The CMOS sensor which captures the images is equipped with a function that detects the distance to a subject using parallax. This method, which is called phase detection, allows autofocus to operate accurately at a wide range of distances. The first-generation Dual Pixel CMOS AF was introduced in 2013 on Canon digital SLR cameras and enabled high-speed autofocusing during live-view shooting and video recording. The EOS R5 features a more advanced Dual Pixel CMOS AF II, which can perform accurate phase detection for a subject anywhere on the screen. Dual Pixel CMOS AF II is the ideal AF system for mirrorless cameras and is widely used in the EOS R series.

Q: What does “Dual Pixel” mean?

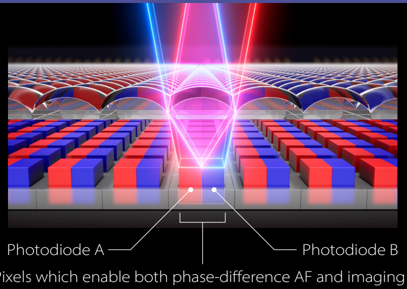
Fukuda: This means that one pixel consists of two photodetection elements and these are used to focus the image. The EOS R5 takes photos with a resolution of about 45 megapixels, but the actual number of light-sensitive elements is twice that number. The camera uses the parallax between the light-sensitive elements, which are arranged in pairs of two, to detect focal distance.

Q: The system uses the same principle as human eyes?

Fukuda: Exactly. The parallax provided by the Dual Pixel CMOS AF II allows Canon RF lenses for mirrorless cameras and EF lenses for SLR cameras to focus quickly and accurately, and supports autofocus for special optical lenses. The RF lens series includes a VR lens for capturing 3D VR images. This lens is designed to capture 3D images using two lenses (left and right), and the Dual Pixel CMOS AF II ensures accurate autofocus for both lenses.

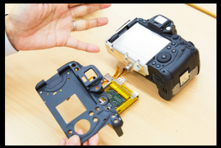
We also considered the elements of mirror-based lenses (interchangeable lenses that use the same mechanism as a reflecting telescope), which are generally difficult to operate using autofocus technology. When Canon Electronics asked if it would be possible to design an autofocus mechanism for a reflecting telescope, we examined the matter and determined that it was technically feasible.

Dual Pixel CMOS AF II (Simulated)



Q: Why is it difficult to design an autofocus system for a reflecting telescope?

Fukuda: In a reflecting telescope, light is reflected by a doughnut-shaped mirror with a hole in the center, called a primary mirror, then reflected



by a secondary mirror into the camera's image sensor. Because of the doughnut shape of the primary mirror, light does not pass through the center of a reflecting telescope's aperture. This makes it difficult to focus. In addition, reflecting telescopes generally have low (dark) aperture values, so there is only a small amount of light to use for focusing. The Dual Pixel CMOS AF II can use the CMOS sensor's light-sensitive elements for autofocusing. Since the densely arranged pixels and high resolution allow it to identify very small differences in parallax, it can focus quickly and accurately even under such difficult conditions.

Q: How did you manage to combine the EOS R5 with a reflecting telescope?

Space Telescopes

Super telephoto optical system for taking high-resolution photographs of the ground from orbit (maximum aperture 400mm)

1. Originally designed high-performance Cassegrain system with correction lenses
2. Equipped with focusing actuator
3. Equipped with a space camera using Canon's CMOS sensor

Fukuda: As in the case of ordinary RF lenses, each combination of optical specifications for each lens and CMOS sensor has to be calibrated individually. We had to create a database of focus detection data to accurately detect and control focus. The same focus detection data required for lens control was prepared for the reflecting telescope. This data allows the EOS R5 to recognize the reflecting telescope as just another one of Canon's many interchangeable lenses.

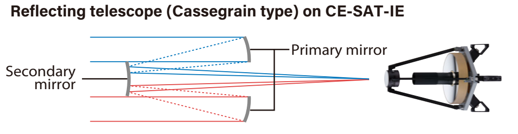
Q: Isn't the reflecting telescope's focus operated from the ground?

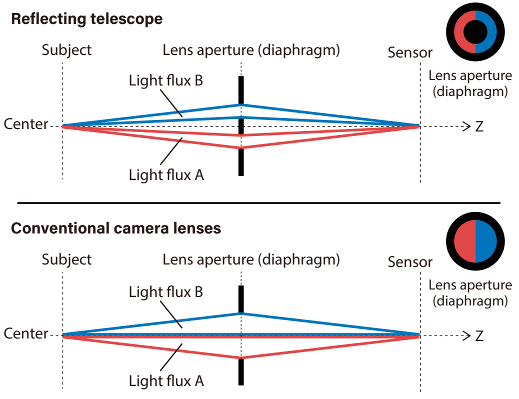
Fukuda: Currently, the EOS R5 mounted on the satellite is able to detect the exact focus distance and amount of focus shift required. However, the focus drive control on the reflecting telescope side has not yet been automated.

Mameshiro: To adjust the focus of the reflecting telescope, instructions need to be sent from the ground. With the CE-SAT-I, the focus was adjusted by examining captured images sent to the ground. However, with the CE-SAT-IE, focus is adjusted based on the images captured by the telescope as well as the focus position data provided by the EOS R5. Focal position data calculated using the Dual Pixel CMOS AF II allows it to focus quickly and accurately. In the future, we aim to develop autofocusing features that can be handled entirely within the satellite.

Differences in Dual Pixel CMOS AF II

Comparison between a reflecting telescope (mirror lens) and conventional camera lenses





4. Advanced features of the EOS R5: Durability

Q: What factors were considered to ensure the durability of the EOS R5 unit used on the satellite?

Urakami: We were aware that an EOS 5D Mark III was mounted on the CE-SAT-I and operating successfully, so we assumed that the EOS R5 would also be able to bear the harsh conditions of space.

We considered all of the requirements suggested by Canon Electronics, over the course of the project, and worked to eliminate concerns one by one.

The first major issue that must be addressed is the fact that space is a vacuum, and it is difficult to dissipate heat in a vacuum. The project team also had to address the effects of cosmic radiation, as well as shock and vibration at the time of launch, on the camera in the launch vehicle.

First, we replaced any parts that might burst in vacuum conditions, such as capacitors, with alternative components. We confirmed that all parts could operate without any problems in vacuum conditions.

Mameshiro: Since there is no air in space to dissipate heat, we adopted a design that uses thermal conduction to direct heat to the magnesium alloy body of the EOS R5, allowing it to be released to the outside. Since the camera’s in-body image stabilization (IBIS) function (that usually needs to move freely in order to operate properly) was not used on the satellite, the CMOS sensor block was fixed in place. The sensor unit was modified by Canon Electronics to allow heat to be released to the camera body. A metal plate was also mounted on the back of the EOS R5, to further release heat.

Q: What kind of countermeasures were taken to address cosmic radiation?

Mameshiro: We tested the EOS R5 repeatedly to see how much radiation the camera could withstand and still function properly. Based on data from these tests, we designed an encapsulating shield that is several millimeters thick and attached it to the satellite. More than a year has passed since operations started, and the camera is still functioning properly.

Q: What countermeasures were taken to address impact and vibration?

Mameshiro: We tested the EOS R5 using vibrational equipment, to see if it could withstand the acceleration force and vibration that can be expected during launch. The test results confirmed that the camera would be able to withstand the conditions of an actual launch of the H3TF2 rocket, so no special countermeasures were taken.

Urakami: Canon originally designed its EOS products, including the EOS R series, to withstand the shock and vibration it might face in demanding shooting conditions. Since they are designed to endure conditions even more severe than those expected during launch, we believe that they will be able withstand the acceleration and vibration they encounter in space, without any special improvements.

Mameshiro: The reflecting telescope is attached to the EOS R5 camera via an RF mount, just like a normal interchangeable lens. We have confirmed that both camera and telescope can withstand the acceleration and vibration conditions experienced during a satellite launch.

Urakami: The high-end models in the EOS R series were also designed to be used in harsh alpine environments. We designed the cameras so that function and performance will not be compromised even when the air pressure is lower than that at sea level.

Uchida: The camera, the lens, and all of the individual components inside the devices were tested to confirm that they can withstand the expected changes in atmospheric pressure. This shows why Canon always strives to design products that surpass the basic requirements for use. The result is a product that can withstand even the extreme conditions of outer space.

5. Description of CE-SAT-IE

Inakawa: The CE-SAT-IE is an optical satellite that was designed mainly to capture images of the earth's surface. It is used for remote sensing projects, collecting geospatial information and natural disaster response activities. The main characteristics of Canon Electronics' satellite is that it uses an "area sensor" which can capture a wide area in a single shot. The in-camera image development capability also allows it to capture 8K video clips. By adopting the commercial EOS R5 model as the base for the optical system, rather than of a custom-made camera, we were able to shorten the development period while maintaining high quality.

Q: What kind of 8K video can be shot with this satellite?

Inakawa: The camera can be pointed at a single spot on the ground and capture 8K/30P video footage for up to approximately two minutes. For example, if you shoot an airport, you can record video of an airplane moving along the runway. Two minutes may sound short, but the CE-SAT-IE is moving at a speed of about 7 km/second in orbit, at an altitude of about 670 km. This is equivalent to traveling the 500 km between Tokyo and Osaka in about 70 seconds. Since the satellite approaches and passes a given spot on the ground at such high speed, the time available to film video of that location is limited. Two minutes of imaging data should be sufficient to cover the area.

Q: Can the satellite rotate, to aim the camera towards outer space?

Reaction wheel

Inakawa: The CE-SAT-IE uses its own sensors to determine the satellite's attitude, and control it by adjusting the speed of reaction wheels. This attitude control can also be used to point the satellite towards the moon, a star or a nebula. The "area sensor" method, which uses detailed attitude control to capture a wide area of earth's surface in a single shot, can be used to capture images of other celestial objects as well.

6. The CE-SAT-IE uses a reflecting telescope

Mameshiro: We concluded that a reflecting telescope design was the best way to achieve a super-telephoto focal length that covers the full-frame sensor of the EOS R5, yet still fit it on a micro-satellite with a total size of just 50 x 50 x 80 cm. The design we chose — called a Cassegrain telescope — has the advantages of a long focal length despite its very short actual length. The lens is an original Canon design with additional optical correction features.

Cassegrain-type reflecting telescope (replica)

The primary mirror (the largest mirror), which determines the telescope's performance, is quite large, at 40 cm in diameter. It was designed by Canon Electronics and ground at the Canon Utsunomiya production facility.

Canon used advanced technology not only for grinding the glass lens, but also for polishing curved mirror surfaces. The reflecting telescope, assembled after exacting mirror surface processing, achieves high optical performance that supports high-pixel photography with the EOS R5.

Q: How is focus operated?

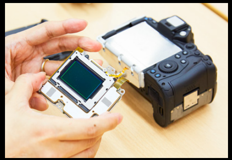
Mameshiro: The camera uses an actuator — an ultrasonic motor used in many Canon interchangeable lenses — that can function and achieve accurate focus even in the vacuum of space.

Q: How is the reflecting telescope able to withstand shocks, vibration, and vacuum conditions?

Mameshiro: The mirror was designed so that it would not be distorted in the vacuum of space, and the structure was built to withstand shock and vibrations during rocket launch. The reflecting telescope, which was carefully assembled and examined by Canon Electronics, is held securely in place by a lightweight and highly rigid housing.

7. As new EOS models are released, the new features can be utilized on satellites.

Niwa: One advantage of using a commercial model (the EOS series) as a component on an optical satellite is that the most recent and advanced technologies can then be quickly adapted to our satellites. Each time a new model in the EOS series comes out, new features are added and the performance of features like image depiction, burst shooting and AF is enhanced. As a satellite developer, Canon Electronics can rely on the fact that its newest satellites will be able to leverage the most up-to-date EOS photographic features.



The CE-SAT-I, launched in 2017, used the Full HD format for video recording. Seven years later, in 2024, the EOS R5 camera model was used on the CE-SAT-IE, allowing it to record video clips in 8K format. This is a huge improvement in video recording capability.

The success of these two satellites has given Canon Electronics confidence that it will be possible to continue to install EOS series camera on its satellites, and that the imaging capabilities of the satellites will always enjoy the capabilities of the latest EOS model. This is one major achievement of the collaborative project between Canon and Canon Electronics.

Q: As the Canon EOS series evolves, can we expect Canon Electronics' optical satellites to continue to improve in function and performance?

Niwa: At present, there are by far few opportunities to utilize commercial technology in the aerospace business, and the hurdles to market entry are high.

The fact that Canon used technology developed for consumer products directly in the space business and proved its performance excellence should be considered quite an accomplishment. I am proud to say that this project was one of the first to successfully use consumer technology in the aerospace business. We plan to continue using EOS series cameras on satellites as we continue to build upon Canon's expertise in space.

Epilogue

Q: The satellite development project begun by Canon Electronics was almost entirely completed by members of the Canon Group alone. Is this one of the company's strengths?

Watanabe: Canon has many divisions and business units, and all teams are committedly engaged in research and development on a daily basis. It might seem that this achievement is simply the result of Canon and the Canon Group companies combining their capabilities, in terms of technology. For me, though, the most important factor in our success is the ability of Canon employees to dream and imagine new possibilities, and work to make them real.

This satellite project succeeded thanks to the cooperation and contributions of Canon's Imaging Business including the divisions that focus on CMOS sensors, autofocus, and mechanical features. Initially, though, it was a relatively minor project in response to a request from Canon Electronics. Only a few teams were assigned to the project at first, but as it progressed and expanded to include more capabilities and a wider focus, more people were assigned to deal with these issues.

Throughout this satellite development project, I had the clear impression that Canon's culture of cooperation across divisions and its ability to set and meet highly challenging goals that leverage the diverse capabilities of the Canon Group, were essential to our success. There were many times when I had to ask some team or division to help with the development work in a way that could very well interrupt their other responsibilities. Yet I was impressed by the willingness of all Canon coworkers to contribute in any way they could.

Canon's strength lies in its corporate culture of cooperation across divisions and subsidiaries, to achieve a single goal. I expect that thus will continue to be important, as we work to perfect our technology even further.