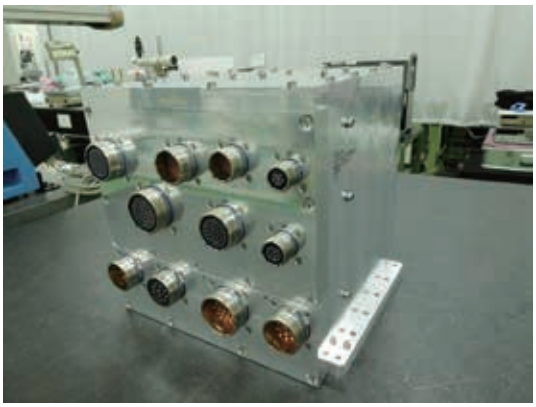
Make Avionics Compact!

From mechanical type to semiconductor type Small-sized lightweight Power Sequence Distribution Box (PSDB) for enhanced Epsilon rockets

Mechanical switches are safe but large and heavy. Semiconductor switches are capable of reducing size and weight but cause anxiety about malfunction. The IHI group solved such a problem to obtain small-sized lightweight avionics by applying the know-how in evaluation of space equipment.

Enhanced Epsilon rocket (Epsilon-2) ©JAXA



Semiconductor-based PSDB developed

Large and heavy electronic equipment

An artificial satellite or probe brought to the space by a rocket is called a payload. In order to mount as many payloads as possible, thorough reductions in size and weight are required for structures and devices constituting a rocket.

The avionics (flight control electronic equipment specific to aircrafts and rockets) of the Epsilon rocket test vehicle launched in September, 2013 included a remarkably big device. The device whose weight is as high as 20 kg is called a Power Sequence Distribution Box (PSDB), and carried an important function in the Epsilon rocket.

On the other hand, in the enhanced Epsilon rocket (Epsilon-2) launched from Uchinoura of Kagoshima Prefecture in December, 2016, such a big and heavy PSDB was no more found. This report introduces a story of reductions in size and weight of PSDB performed in the process of the development of the enhanced Epsilon rocket.

Mechanical relay-based PSDB

A PSDB of an Epsilon rocket has a function of distributing electric power supplied from a ground facility (before launch) or electric power supplied from rocket-mounted batteries to mounted devices and ordnance (equipment

operating with gunpowder) of an electric ignition type. The function of distributing electric power to the ordnance includes not only a flight-related function such as igniting a rocket motor and separating the rocket motor after combustion but also a function of destroying the rocket in an emergency for safety reason.

In the past, as switches for supplying electric power to ordnance inside a PSDB, mechanical relays were used in order to surely cut off electric power by physically non-contact. This is because in case that some problem occurs in a switch, the ordnance may be erroneously ignited to cause tremendous damage.

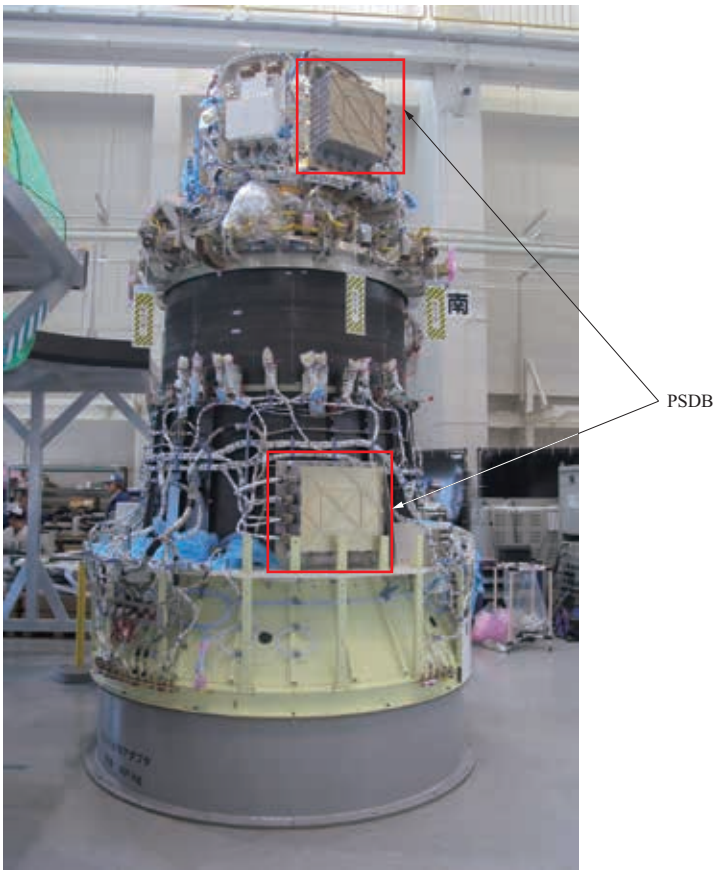
However, the mechanical relay had some problems.

(1) The part itself is large and heavy.
(2) Since the part has the mechanically movable portion, in order to ensure sufficient environment resistance (impact/vibration) under severe environment during flight, it is necessary to take additional measures for devices and mount structures.
(3) Since the part has the mechanically movable portion, reliability is low as compared with other electronic parts.

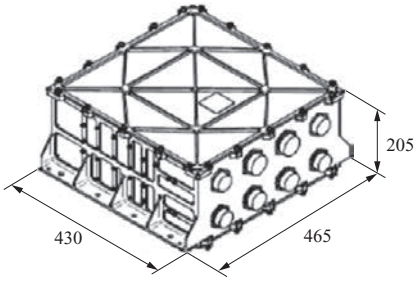
For these reasons, the mechanical relays caused increases in size and weight of the PSDB, and made it difficult to reduce the size and weight. In order to overcome such a situation, IHI AEROSPACE Co., Ltd. (IA) worked on the reduction in size and weight in collaboration with MEISEI ELECTRIC CO., LTD. of the IHI group under the supervision of National Research and Development Agency, Japan Aerospace Exploration Agency (JAXA).

Semiconductor switch-based PSDB

It had been clear that by replacing mechanical switches with semiconductor switches, a reduction in size of the PSDB was possible. However, the semiconductor switch also had some problems such as the possibility of flow of minute amount of leakage current due to noise and the possibility of malfunction due to low radiation tolerance in space. Accordingly, there had been no record of applying semiconductor switches as switches for a rocket requiring high reliability, like a flagship launch vehicle, because the secure safety of ordnance had been focused on. However, in developing the enhanced Epsilon rocket, a launch capability had to be improved. Among devices directly related to the improvement of the launch capability, we decided to start the development of replacing mechanical relays with semiconductor switches for the PSDB which is capable of being significantly reduced in weight.

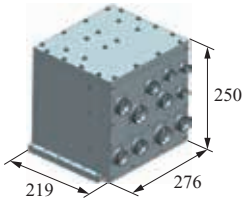


Epsilon rocket test vehicle during assembly
(A total of 3 PSDB are mounted, 1 for 3rd stage and 2 for 2nd stage.)



Relay-based PSDB (Test vehicle)

	Actual weight of test vehicle
PSDB2A/2B	20.0 kg
PSDB3	19.4 kg



Semiconductor-based PSDB (Epsilon-2)

	Actual weight of Epsilon-2
PSDB2A/2B	10.6 kg
PSDB3	10.4 kg

External view of PSDB (unit : mm)

Boost by advent of domestic semiconductor switch

For high-performance semiconductor switches actually used for space devices, we had been only dependent on imports. When a device was designed on the premise of using imports, we were not sufficiently supported by manufacturers and had difficulty developing the device. However, a domestic semiconductor manufacturer succeeded in the development of a highly tolerant space semiconductor switch as a result of joint development with JAXA.

In space, there was a phenomenon that even when a semiconductor chip was exposed to high-energy radiation only once, the chip was burnt. However, it was difficult to clarify the mechanism of the phenomenon, and therefore in the past we had reluctantly took measures to enhance radiation tolerance while sacrificing the original performance of a switch.

In the newly developed semiconductor switch, the previously unknown mechanism of the effect of radiation was successfully grasped by analysis. As a result, the semiconductor chip having sufficient radiation tolerance could be manufactured without sacrificing its original performance.

The improvement of both the availability of the safety-related important part and convenience for use of the part as described above boosted the development of a new PSDB.

Small and lightweight PSDB

Development targets were to obtain all the functions of the conventional PSDB by replacing mechanical relays with small electronic parts mainly including semiconductor-based parts, and reduce size and weight by approximately 1/2 while ensuring safety at least comparable to that of the mechanical relays. We started discussions for achieving both ensuring safety and reducing size and weight.

First, for ensuring safety, we sufficiently examined predictable concerns and a method for verifying measures, on the basis of ordnance-related technologies (such as safety technology and knowledge on ordnance).

Focus items were as follows.

(1) Improvement of noise tolerance

Severe noise contamination test and design for tolerating noise contamination

(2) Reliable operation under flight environment

Safety design against malfunction and improvement of radiation tolerance in space

For confirming the sufficient tolerance of the newly employed parts for severe vibration and thermal environment during flight, reliable evaluation performed by structurally analyzing even microscopic portions such as soldered portions of electronic parts.

For the design and verification described above, know-how cultivated by IA as a rocket manufacturer was fully utilized.

Next, for reducing size and weight, design was carried out with a focus on small size and high density.

(1) Employment of surface mount parts

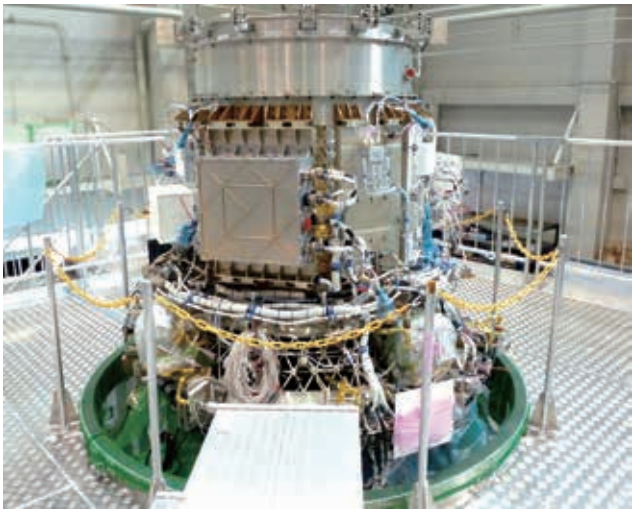
As electronic parts used for the PSDB, surface mount parts were intentionally employed. In particular, many semiconductor switches and diodes as main parts were used in the form of a recently developed high-power surface mount package.

This sort of method allows the occupied space of parts to be reduced and also the need for a soldering space to be eliminated, and is therefore effective for reducing size and weight.

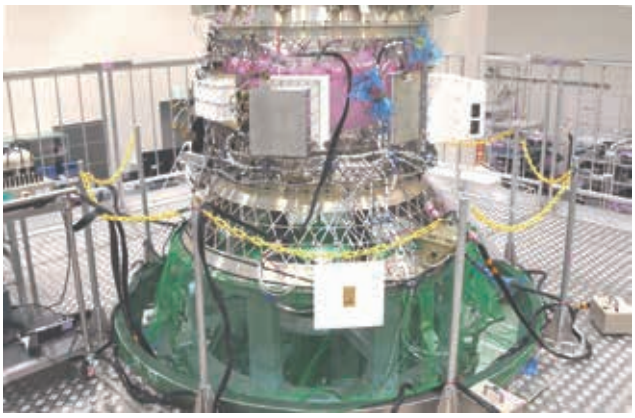
(2) Reduction of wiring space

In addition to the high-density mounting of the parts enabled by the employment of the surface mount parts, the replacement of internal wiring, which was a bundle of cables in the past, with a flexible belt-like board allowed the occupied space of internal wiring to be greatly reduced.

(a) Mechanical relay type PSDB (Epsilon rocket test vehicle)



(b) Semiconductor-based PSDB (Epsilon-2)



PSDB assembled in three-stage device mount structure

Situation of Epsilon-2 mission checkout (MCO) test ©JAXA

Pride of rocket manufacturer

Thus, we succeeded in the reduction in size and weight while satisfying safety requirements. As compared with the conventional product, the weight was reduced by half, from 20 kg to 10.6 kg, and the device size was also halved. In addition, by reducing the number of mechanical movable portions, the reliability of the entire device was improved.

A total of 3 PSDBs in the entire rocket were reduced in weight, and thereby the launch capability was improved by approximately 20 kg (comparable to the weight of one very small satellite).

IA will use semiconductor circuit technology and safety design technology, which were acquired through this development, for future rocket development and such other things, and contribute to the development and advancement of space technology as a rocket manufacturer in the future.

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