Incubating Domestic Space-Qualified Manufacturers Through ROCSAT Programs

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Abstract Taiwan's space program started from 1991. There was no space-qualified manufacturer in Taiwan before that time. The Government decided to incubate domestic space-qualified manufacturers in Taiwan through the development of space program. Consequently, the Government assigned the role of incubating domestic space-qualified manufacturers to the National Space Organization (NSPO). The role is partly completed after 16 years of effort. Major reasons are that Taiwan's space budget is small and all manufacturers are commercially oriented. Fortunately there are still some successful examples. This paper reviews the process of incubating Taiwan's domestic space-qualified manufacturers through ROCSAT space projects (currently called FORMOSAT projects) and introduces the successful examples. It then foresees the potential "blue sea" (or say blue ocean) of NSPO's future space program. There were three space projects in Taiwan's first phase space program which spans 15 years from 1991 to 2006: FORMOSAT-1 (FS1), FORMOSAT-2 (FS2) and FORMOSAT-3 (FS3). A total of 8 companies had been incubated with 23 products manufactured: 5 in FS1, 8 in FS2 and 10 in FS3. Among the 8 incubated companies, 6 continue to participate NSPO's second phase space program started at 2004 and shall end in 2018. Simply speaking, NSPO's experience can be summarized in two points: (1) it is not easy, and (2) it is a long but right way to go. For the potential "blue sea" in the future, NSPO's is developing the "super cluster project" currently. Tens or hundreds or thousands of cheap microsatellites called "astrochicken" with about 2 years of mission life shall be launched for various missions. One important point is that they must be very responsive. Under

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this strategy, Taiwan could be able to copy its successful experience in developing computer industry.

1 Introdution

Taiwan's first phase space program spanned 15 years, from 1991 to 2006; and its second phase spans another 15 years, from 2004 to 2018. There are 3 years of overlap. The National Space Program Office (NSPO) of Taiwan was established in 1991 to perform the space program. It was then changed to the current name National Space Organization with the same acronym NSPO in 2005. Three satellite projects had been successfully completed with 8 satellites launched in the first phase space program: 1 small satellite in FORMOSAT-1 (FS1) project, 1 small satellite in FORMOSAT-2 (FS2) project, and 6 micro satellite as a constellation in FORMOSAT-3 (FS3) project.

One of the major roles of Taiwan's space program is to incubate the domestic space-qualified manufacturers. Therefore, from the beginning NSPO adopted a strategic policy to construct some satellite components by domestic manufacturers in order to build up space industry in Taiwan. A few carefully selected manufacturers obtained technology transfer agreements of space-qualified satellite components from foreign manufacturers. Using the transferred technical know-how, these manufacturers were able to fabricate some spacecraft components for FS1, FS2 and FS3 projects, respectively.

This paper introduces the domestic space-qualified manufacturers incubated and their products. [1] Then the super cluster concept for NSPO's future blue sea policy is presented.

2 Space-Qualified Manufacturers Incubated in FS1 Project [1]

The FS1 project was started in 1994 and completed in 1998. This is a cooperation project between NSPO and TRW of US for developing a small scientific satellite. Four domestic space-qualified manufacturers had been incubated with 5 products provided.

2.1 Acer Incorporation

Acer Incorporation built the on-board computer (OBC) to handle the satellite operation. The computer also performs data and signal processing, command decoding and executing, and subsystems interface control. More details of the on-board computer are listed below:

- Dimension: 21.6cm × 21.3cm × 11.9cm
- Central processing unit (CPU): 80186
- Weight: 3.3 kg

- Maximum power dissipation: 10.3 watt
- Read-only memory (ROM): 512 K Bytes
- Random access memory (RAM): 512 K Bytes
- Subsystem interface: TT&C, C&DH, EPS, ADCS, TCS, RCS, GSE, Payload, etc.
- Data interface: 1553B, RS-422

2.2 Trans System Incorporation

Trans System Incorporation manufactured the remote interface unit (RIU) which decodes and distributes commands to the experimental communication payload. The unit also receives telemetry signals as input and then digitizes them for output to the on-board computer. Its details are as follows:

- Dimension: 27.9 cm × 18.7 cm × 14.1 cm
- Weight: 3.91 kg
- Maximum power dissipation: 3.76 watt
- Signal input module: Bilevel, Serial, Analog

2.3 Victory Industry Company

Victory Industry Company built the diplexer to isolate and filter radio frequency (RF) signals. It has the following details:

- Dimension: 25.4 cm × 21.6 cm × 8.1 cm
- Weight: 1.7 kg
- Uplink frequency: 2039.6 MHz
- Downlink frequency: 2215 MHz
- Bandwidth: Uplink±15 MHz, Downlink ±15 MHz
- Downlink power: 6 watt

Victory Industry Company also built the antenna to transmit and receive S-band RF signals at 2 GHz. The antenna has a diameter of 15.24 cm and an emitting power of 5 watt. Its details are:

- Dimension: 15.24 cm (φ) ×15.24 cm (h)
- Weight: less than 562 grams
- Reception frequency: 2039±5 MHz
- Transmit frequency: 2215±5 MHz
- Polarization: RHCP
- Power: 5 watt
- Characteristic resistance: 50 Ω

2.4 Shihlin Electric & Engineering Corporation (SEEC)

SEEC assembled the silicon solar cells into the solar panel. The cells with electrostatic clean coating have an efficiency of more than 14.6 % and a maximum power of 645 watt:

- Units: silicon solar cells, cover glass, blocking diode, structure and harness
- Weight (two wings): 21.36 kg
- End-of-life maximum power: 547.79 watt
- Maximum power: 645.36 watt
- V open circuit max: 99.0 V (DC)
- I short circuit min: 6.24 A (DC)
- Silicon solar cell efficiency: ≧14.6 %
- V operate at maximum power: 48.07 V (DC)

3 Space-Qualified Manufacturers Incubated in FS2 Project [1]

The FS2 project was started in 2000 and completed in 2004. It is a cooperation project with EADS Astrium of France for the development of a small remote sensing satellite, as shown in Fig. 1.

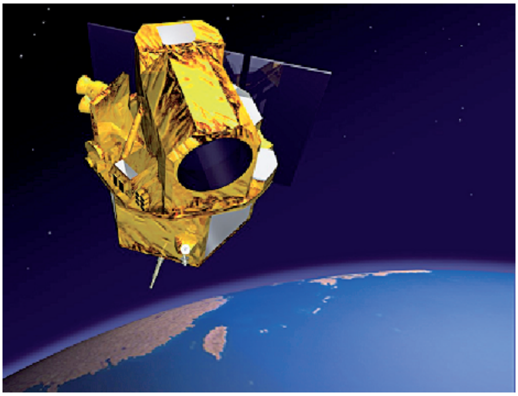

Fig. 1 FS2 satellite

3.1 Acer Incorporation

In cooperation with EADS Astrium, Acer Incorporation participated in the design, manufacture, and test of the on-board management unit (OBMU) of FS2. It is the satellite's central control unit and the core of the secondary system for central command and data processing. The main function of the management unit is to control the satellite's operations, including the processing and execution of uploaded commands, and the collection, processing, storage, and downloading of the satellite's status data. Figure 2 shows the board manufactured by Acer Incorporation.

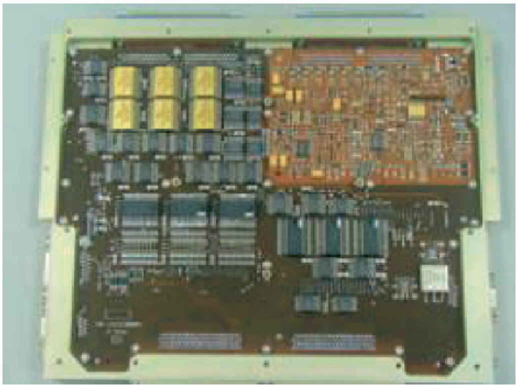

Fig. 2 FS2 OBMU board

3.2 Tatung System Technology Incorporation (TSTI)

The flight software (FSW) of FS2 was co-developed by TSTI and EADS Astrium. Its functions are for managing and controlling the satellite orbit, position, and operation. The FSW is responsible for the calculation of satellite position/orbit, operation of scientific instrument payload, and communication with ground antenna.

3.3 SEEC

The sun senor of FS2 as shown in Fig. 3 was developed by SEEC. It determines the satellite's relative position to the sun according to the direction of the source of sunbeam.

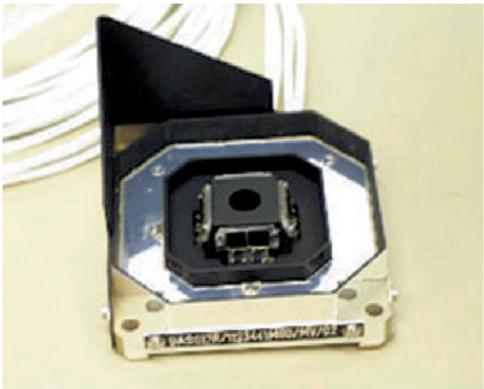

Fig. 3 Sun sensor of FS2

3.4 Victory Industry Company

The two S-band antennas of FS2 as shown in Fig. 4 were designed and manufactured by Victory Industrial Corporation. These antennas are used for receiving commands and transmitting microwave signals. They allow the uploading of ground commands and downloading of satellite information.

Fig. 4 S-band antennas of FS2

3.5 Aerospace Industrial Development Corporation (AIDC)

AIDC manufactured the flight harness by itself, and the primary structure (Fig. 5) along with Taiwan Aerospace Corporation (TAC). The harness wirings are used for connecting satellite modules, components and payloads, and for transmitting power, commands, and signals. The primary structure is designed and analyzed by NSPO, and manufactured by AIDC, and then tested by NSPO. All modules, components harness and payloads of the satellite are mounted to the primary structure, just like a human skeleton system.

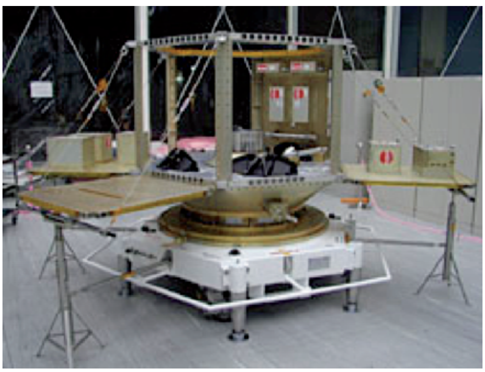

Fig. 5 Primary structure (*upper part*) and VID of FS2 (*lower part* in *white* color)

3.6 Taiwan Aerospace Corporation (TAC)

TAC manufactured the vertical integration dolly (VID, Fig. 5) by itself and the primary structure along with AIDC. VID is the main loading equipment during the satellite integration and test procedures. It has anti-shock and anti-tilting functions and can prevent people from approaching too close to the satellite. TAC also manufactured the payload cone for adapting the satellite to the launch vehicle.

4 Space-Qualified Manufacturers Incubated in FS3 Project [1]

The FS3 project was started in 2002 and completed in 2006. It is a cooperation project with OSC of US for the development of 6 microsatellites to form a constellation observing system for meteorology, ionosphere and climate (COSMIC). Therefore, the whole system is known as FORMOSAT-3/COSMIC internationally. To further promote the domestic manufacturers' participation in the space industry and to solidify Taiwan's space industry development, NSPO incorporated 5 domestic manufacturers to produce 14 modules and components for FS3.

4.1 Acer Incorporation

Acer Incorporation manufactured the OBC of FS3 for the major function of satellite operation control, including data and signal processing, command interpretation and execution, and other secondary system interface control. As shown in Fig. 6, the computer has the following characteristics:

- CPU: Motorola 68302
- ROM: 3M Bytes
- Read-write memory: 512K Bytes
- Data interface: RS-422, RS-485 standard interface
- Weight: 2.6 kg

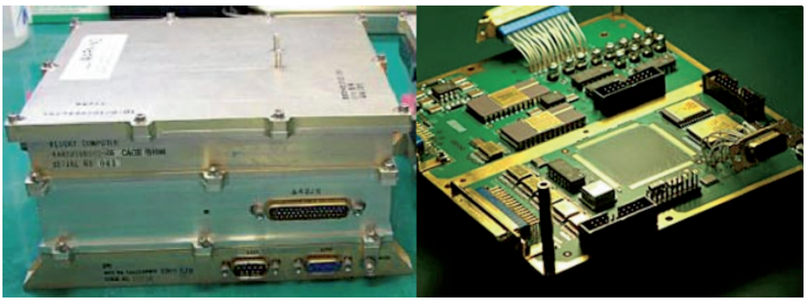

Fig. 6 OBC of FS3

- Dimension: 17cm × 16cm × 9cm
- Max power dissipation: 7.5 watt

Acer Incorporation also manufactured the mission interface unit (MIU, see Fig. 7) to provide the function of communication between satellite and ground system, including the uplink of operation commands and the download of remote sensing and scientific data:

- Secondary system interface: radio frequency secondary system, satellite computer, payload computer, solid-state memory, current converter, and attitude control processing unit
- Weight: 0.68 kg
- Dimension: 17.3cm × 18.6cm × 2.8cm
- Maximum power dissipation: 2.8 watt

Fig. 7 MIU of FS3

4.2 SEEC

SEEC manufactured three modules: solar sensor, rechargeable storage battery and current converter. Major functions of the solar sensor are to detect the sun's position and provide the information for the determination of satellite attitude. It weighs 10.8 grams with the dimension of 6cm × 3.5cm × 0.5cm. The rechargeable storage battery is a part of the secondary power system which provides power to the satellite. It weighs 4.75 kg and has a dimension of 45cm × 20cm × 10cm. Finally, the current converter provides power required for the three payloads: GPS occultation experiment (GOX), tiny ionosphere photometer (TIP) and tri-band beacon (TBB). The weight is 700 grams and the dimension is 16cm × 17cm × 25cm.

4.3 Victory Industry Company

Three modules of FS3 were manufactured by the Victory Industry Company: S-band antennas (Fig. 8), receiving coupler (Fig. 9) and transmitting filter (Fig. 10). FS3's antenna system includes an S-band transmitting antenna for sending satellite microwave signals to ground and an S-band receiving antenna for accepting command signals from ground. The antenna system is able to provide a circular range greater than 85 %. Its weight is 227 grams and its dimension is 10.2cm × 10.2cm × 1.3cm. The receiving coupler has a weight of 100 grams and a dimension of 2.5cm × 3.8cm × 1.3cm. It is used to couple the single transmitter/receiver signal with two S-band antennas in order to provide near-spherical coverage. Finally, the filer can provide effective isolation of the noise and interference. It weighs 348 grams with 1 watt power dissipation and 5.1cm × 5.1cm × 15.2cm dimension.

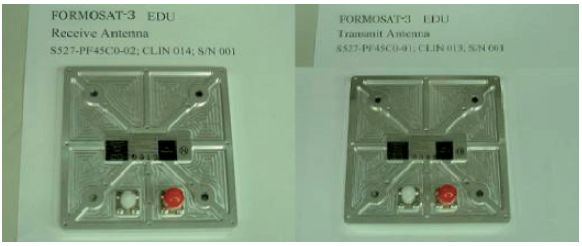

Fig. 8 S-band antennas of FS3

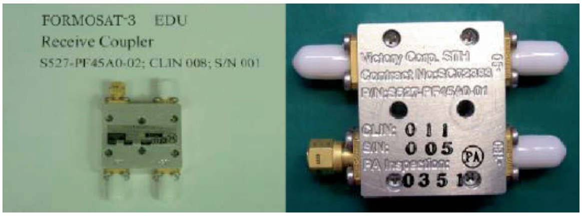

Fig. 9 Receiving coupler of FS3

Fig. 10 Transmitting filter of FS3

4.4 Yung Tien Industrial Corporation (YTIC)

The satellite heating elements were manufactured by YTIC. These heating elements ensure the proper operation of three modules, rechargeable storage battery, fuel tank and thruster wiring. Allowed temperature range is from −65°C to 200 °C.

4.5 AIDC

Again, AIDC manufactured the flight structure. This is the first time of AIDC to develop a set of multi flight structures which needs to be stacked together for launch in one vehicle. Each of the 6 flight structures has the same diameter of 103 cm and height of 16 cm, as shown in Fig. 11.

Fig. 11 Flight structure of FS3

5 Statistics of the Incubation Results

There are 8 space-qualified domestic manufacturers incubated during the first phase space program of Taiwan. Among them, TAC had been closed at about 5 years ago due to policy change of the company. All the others keep participating NSPO's current space projects except Trans System Incorporation. However, we can only say that a few space-qualified manufacturers have been successfully incubated. There is still no real space industry in Taiwan. The reason is simply because that the percentage of the space product value is negligibly small in the whole industrial community. Consequently, NSPO is seeking a possible breakthrough in Taiwan's second phase space program which already started in 2004.

6 NSPO'S Future Development Concept–Super Cluster of Microsatellites

6.1 Insights of Freeman Dyson [2]

In his book, Freeman Dyson mentioned that in order to control the price of a new generation spacecraft to be within several tens thousands US dollars, we need to develop the technologies far more advanced beyond 1988. The spacecraft must be cheaper, lighter and simpler. Further, the weight of the spacecraft should be in the order of pounds instead of tons. Also, each spacecraft could have several missions everyday instead of every year. There are two ways to reach the achievement: "nano- technology" and "genetic engineering". Three paragraphs from his book are quoted bellow:

"I have sketched in a rough fashion how space-technology jumped in the past thirty years, from 1958 to 1988. The von Braun Mars Project represented the technology of 1958. The International Ultraviolet Explorer (IUE) represented the technology of 1988. The Mars Project was the best you could have done with space exploration in 1958, while the IUE was the best you could do in 1988. The point of this comparison is that the jump in cost-effectiveness from the Mars Project to the IUE is not just a factor of 10 or 100 but more like a factor of 10,000 or 100,000."

"When we look forward to 2018 (e.g., thirty years from 1988), we should expect big steps forward in science to come once again from changes in style rather than from marginal improvements in technology. I am saying that another jump by a factor of ten thousand in cost-effectiveness is possible. . . . To improve cost-effectiveness by a factor of ten thousand, we need spacecraft that are radically cheaper, smaller, and quicker than anything we can build with 1988 technology. Spacecraft should weigh pounds rather than tons, they should cost tens of thousands rather than tens of millionsof dollars, and they should fly missions at a rate of several per day rather than several per year. . . . Both mechanical nanotechnology and genetic engineering are vigorously growing industries, and are likely to be transforming our Earth-bound economy during the next thirty years."

"Here is a rough sketch of one possible shape that the 2018 spacecraft might take. I call this model astrochicken because it is about as big as a chicken and about as smart. It is a product of genetic engineering. It does not look like a chicken. It looks more like a butterfly. . . ." Coincidently, the shape of FS3 microsatellite is just like a butterfly, as shown in Fig. 12.

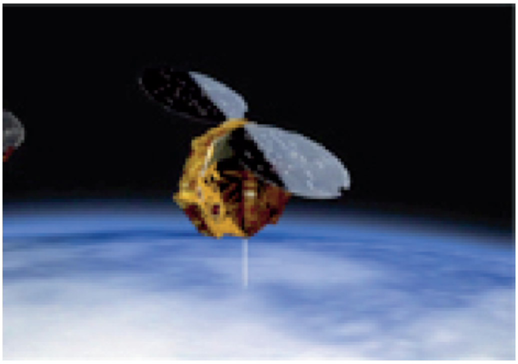

Fig. 12 FS3 microsatellite (6 as a constellation)

6.2 "Blue Sea" Policy

Through the analysis of the strengths of Taiwan industrial community, one very important point is the strength in the area of semiconductor, computer and information technology (IT). On the other hand, two of the weaknesses of NSPO are that both the scale of Taiwan space program and the number of satellite projects are too small. It is very obvious that the current space community is a "red sea" (or say, red ocean) dominated by NASA of USA, ESA of European Countries, JAXA of Japan, China National Space Administration (CNSA) of China, ISRO of India, etc. Within this environment and with the two weakness points, NSPO needs to find its way to go ahead and possibly to win in the future. Consequently, it is necessary for NSPO to seek the "blue sea" (or say blue ocean) policy on how to use the Taiwan's strength in IT. [3, 4] The astrochicken could be one of the ways NSPO can choose. Under the idea of astrochicken, tens or hundreds or even thousands of microsatellites shall be flying in the orbit or even in the interplanetary space. Taiwan can apply the similar road map of its IT industry in the development and mass production of microsatellites.

6.3 Super Cluster Concept

The tens or hundreds or thousands of microsatellites flying in the orbit and the interplanetary space shall form a kind of constellation. We call it the "Super Cluster" temporarily. As long as the microsatellites are so cheap, no high reliability is required. Whenever needed, new satellites can be assembled and launched within a short time. [5, 6] These astrochickens can communicate with the ground stations and also among themselves. The ground stations shall be very powerful so that they can do the job of coordination, tracking, telemetry, command, and data processing. Both image and scientific data shall be collected. Since 2006, NSPO has started the preliminary study phase of this project.

7 Summary and Conclusions

Incubating Taiwan's domestic space-qualified manufacturers was the Government's policy since the first phase space program started at 1991. Four manufacturers made 5 products for the FORMOSAT-1 (FS1), 6 manufacturers made 8 products for the FORMOSAT-2 (FS2), and 5 manufacturers made 10 products for the FORMOSAT-3 (FS3). A total of 8 domestic space-qualified manufacturers had been incubated and 6 of them continue to participate NSPO's current second phase space program which spans from 2004 to 2018. Therefore, it can be concluded that the way is not easy although it is right. In order to conquer the difficulty, NSPO started to develop the super cluster project at 2006. This policy has been made after analyzing NSPO's weakness points and Taiwan's strength in computer industry. It is expected that tens or hundreds or thousands of cheap astrochicken microsatellites capable of doing various missions with reasonable mission life and reliability can be launched responsively in the future. Complicated command and coordination work shall be accomplished by the ground system. Also, the new image processing system and scientific data processing system shall be developed to satisfy the tremendous data processing requirement.

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