MANUFACTURING PLAN AND DFMA - ANALYSIS OF A FREQUENCY CONVERTER FOR A RADIOASTRONOMICAL DEEP SPACE PROBE

Lappeenranta–Lahti University of Technology LUT

Bachelor’s Programme in Mechanical Engineering, Bachelor's thesis

2024

Kaiyang Zheng

Examiner(s) : Professor Harri Eskelinen

Professor Baojun Shi

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Energy Systems

Mechanical Engineering

Double Degree, in co-operation with partner university: Hebei University of Technology

Kaiyang Zheng

Manufacturing plan and DFMA - analysis of a frequency converter for a radioastronomical deep space probe

Bachelor's thesis

2024

45 pages, 15 figures, 8 tables and 7 appendices

Examiner(s) : Professor Harri Eskelinen and Professor Baojun Shi

Keywords: space probe; frequency converter; RF and MW

Due to the continuous exploration of outer space by humans, frequency converter have emerged. As an important component of deep space probe, frequency converters are mainly responsible for processing signal transmission, frequency conversion, and signal amplification. This article mainly introduces the manufacturing scheme and detailed DFMA analysis of the frequency converter for radio astronomy deep space probe. The size of the studied equipment is 85.1 millimeters (length) x 79 millimeters (width) x 22 millimeters (height), equipped with standard SMA connectors, screw fasteners, and PCB circuit boards. The main manufacturing plan of this study is aimed at metal bodies, but other parts are also considered. The application method is triangulation and its results to fully prepare for the manufacturing plan. At the same time, the manufacturability of the equipment was also considered.

"The topic of this thesis belongs to the broader research project at LUT University during year 2024. The research project focuses to the DFMA and sustainability analyses of more than 40 different MW and RF components. The results of this thesis will be utilized later to build an overall picture of the DFMA and sustainability aspects related to MW and RF technology."

Table of contents

Appendices

1 Introduction

A deep space probe can replace humans in carrying out various scientific research tasks in outer space, and the frequency converter, as an important electronic component of the detector, can meet the power requirements of other electric devices by changing the voltage, frequency, and current of the input power supply, thereby ensuring that the deep space probe can operate efficiently and for a long time. For the frequency converter which is researched, it consists of three parts, including two covers and a control system in the middle. The connection between the lid and the middle section will be welded with silver. Their material is made of a special metal and coated with gold on the surface to improve the conductivity of the frequency converter. The control system has four ports, RF, IF, L0, and REF, used for receiving and outputting frequencies. Its main function is to move signals from one frequency in the spectrum to a frequency point acceptable to another detector. (Taravati and Eleftheriades, 2021) SMA male connector and SMA female connector are installed on different ports. The interior of one of the surfaces is a PCB circuit board made of glass and aluminum alloy materials, and each PCB circuit board is tightly connected and fixed with screws, making it very fragile.

The structures in the cavity of this device are different when viewed from the upper and lower directions. As shown in Figure 1, it can be clearly seen that one cavity is composed of PCBs, and the other cavity is composed of metal and wires. In addition to the rough outline of the fully assembled device can also be seen on the far right of the figure.

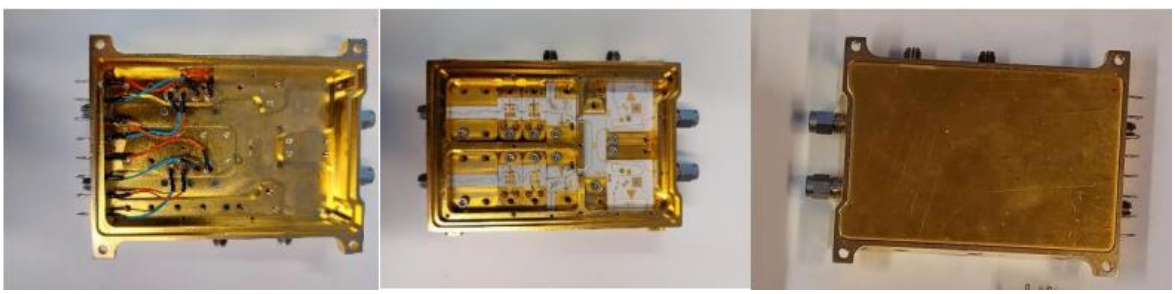


Figure 1. The main structure of the frequency converter.

The four different ports of this device, RF, IF, L0, and REF, as well as the rough outline of the side can be seen in Figure 2, while the different receiving and output ports are also connected to the SMA connector.

Figure 2. Four different receive and output ports, as well as SMA connectors.

1.1 Background and motivation

“The topic of this thesis belongs to the broader research project at LUT University during year 2024. The research project focuses to the DFMA and sustainability analyses of more than 40 different MW and RF components. The results of this thesis will be utilized later to build an overall picture of the DFMA and sustainability aspects related to MW and RF technology.”

1.2 Objective

The main objective of this thesis to analysis the application of frequency converters in deep space probes, determine appropriate metal materials, precise dimensions and processing

methods of the body standard connectors, PCBs, coatings and welding methods, in order to develop a detailed manufacturing plan.

1.3 Research problem and research question

In this device, it is important to combine the performance requirements of the frequency converter with the characteristics of the metal material and the possibility of precision required for manufacturing key geometric shapes. For electrical components, especially micro PCBs, the correct use of housing dimensions and geometric tolerances plays a crucial role in ensuring correct assembly conditions. In addition, different optional manufacturing methods may affect the accuracy parameters of the device. However, there are many standardized components and dimensions that cannot be changed. The most important challenge that needs to be addressed is due to the harsh environmental conditions in space. This will affect material selection and appropriate manufacturing, especially in connection and coating techniques. Finding a compromise solution that meets all requirements simultaneously is a challenge.

After analysis the research problem, this device has three question which I need to solve.

What are the most suitable manufacturing methods of the enclosure geometry and how the quality of the gold platting can be ensured and on what basis?

What would be the most suitable material for the device body and why?

Which dimensional and geometric tolerances should be set to ensure the required performance of the device and how these requirements are justified?

1.4 Research methodology

The method researched for this device is triangulation, which includes three independent methods: Literature review supported with an expert interview, DFMA analysis, and Systematic material selection process. They belong to a parallel relationship, and each independent method is indispensable Figure 3 shows their basic relationship While

applying the triangulation method, the detailed process and results of each independent method can also improve the validity and reliability of the research.

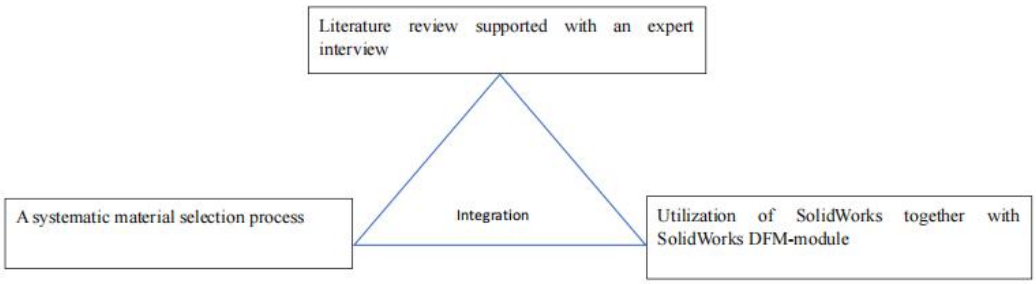


Figure 3. The triangulation's relationship.

1.5 Scope

This device is required suitable metal materials within the existing range, the covers will be soldered with silver, the surface of the equipment is made of metal plates, there are numbers of standardized connectors and screws with standardized mounting dimensions which cannot be changed, the PCBs are made of Al2O3 and some of the feed troughs are made of glass.

1.6 Expected outcomes of the research

The expected outcome of this device research is to determine an environmentally friendly traditional manufacturing method that matches manufacturing accuracy with material properties without affecting material properties. Choose appropriate metal materials to ensure they are not corroded in outer space and can stably adjust voltage and current under harsh conditions in deep space, enabling stable connection of electronic components.

1.7 Device requirements

Before developing research methods, it is necessary to consider the electrical, mechanical, and environmental requirements of this device.(Eskelinen, H., Lätti, K., Pertti Silventoinen & Silventoinen, P, 2004, pp.19). A detailed list of requirements is necessary to develop a detailed manufacturing plan. Regarding electrical requirements, since the electronic components of this device are PCBs, the manufacturing of PCBs is extremely cumbersome and not within the scope of this thesis. Therefore, only the connection issue should be considered. In mechanical requirements, it is necessary to consider the standard size SMA connector for frequency range DC-18 GHz, while also ensuring it can be connected with other standard connectors. The connection method of PCBs needs to be tightened with standard screws. The surface of some key components needs to be smooth and low roughness, and the shape and size cannot be changed, in order to ensure tight connection with other parts. In terms of environmental requirements, the harsh environment of outer space greatly reduces the usage lifetime of frequency converters. The selection of materials should consider being able to withstand extreme temperatures in outer space, generally averaging -270.3 ℃. Strong radiation in outer space may cause rapid corrosion and failure of materials, so the materials should have good corrosion resistance. Finally, in the high-speed environment of outer space, collisions between some micro meteoroids and device may penetrate the materials, so the materials should have high strength.

1.8 Literature review

RF frequency converters with frequencies between 24.25-30 GHz are widely used in mmWave, but unnecessary output harmonics, especially intermodulation in the RF frequency band, can affect the linearity of the system. To solve this problem, a new process called gallium arsenide has emerged, which has better noise and current density characteristics and natural advantages in high-performance applications such as instruments. It is suitable for a wider range of applications.(Zheng S. et al. 2023, pp. 1943-1951)

PCBs is a key circuit in frequency converters. A flexible DC-DC converter for OLED applications is a multi MHz power converter that can greatly reduce size and shape, making it more suitable for flexible applications. In this type of multi megahertz power converter, the role of polychlorinated biphenyls is the most important. They are designed through technological means as a curved circuit to reduce the impact on passive components, thus helping to achieve flexible passive components.(Xu, D, Guan, Y, Wang, Y. & Zhang, X 2021, pp. 55-72)

In the application of metal materials in outer space, coating process is crucial. Anodizing process can greatly improve the corrosion resistance of materials, but due to the limitations of single step anodizing process, it is suitable for large-scale production This resulted in a multi-step oxidation process that did not require specialized equipment. This process increased the current on the surface of aluminum alloy in two, four, and eight steps using different constant currents R1, R2, R3, and R4, respectively. It was found that the coating produced by R1 and R2 current treatment had a burnt and powdery appearance, while the coating produced by R3 and R4 exhibited a smooth solid surface. After comparison, it was found that the oxide growth rate produced by R3 and R4 was higher than that of R1 and R2, and the pore size was reduced, resulting in improved wear resistance.(Totaro, P & Khusid, B 2021, pp. 20-30)

Through a review of scientific and commercial literature, I have found that the electronic components that have the most significant impact on the performance of frequency converters are their PCBs circuit boards. By changing the linear angle of PCBs, we can meet the requirements for circuit inductance. As the frequency converter I am studying is a linear circuit, it may have an impact on passive components, so it is also necessary to consider appropriate PCBs in the design (Xu, D., Guan, Y., Wang, Y.&Zhang, X 2021, pp. 55-72) In the selection of coating technology for metal materials, different coating technologies may have a significant impact on material properties, so the requirements for coating technology are constantly increasing.

2 Method

The research method for developing the manufacturing plan of the frequency converter in deep space probe of this analysis is based on triangulation method, This chapter will provide a detailed introduction to how this method is applied to the research of this device, as well as the specific process and details of its application.

2.1 Literature review supported with an expert review

The first part of the considerations of the integration of literature review and an expert interview. The final integration reference result will be presented in a table format.

2.1.1 Literature review

The method of collecting literature in this thesis follows the flowchart in Figure 4, which consists of two parallel parts. The first type of literature is scientific literature, including literature on frequency converters, materials, DFMA, and manufacturing technology. These scientific literature were collected from professional websites such as IEEE, Springer, Elsevier, etc., with a collection time of no more than 5 years. Another type is business literature, because the device I am analyzing is also a commercial product, and necessary business literature is also crucial. The collection of business literature requires searching for information on similar types of products, discovering similarities and differences, and the collected website must be a trustworthy company official website or a professional data website. Finally, the collected scientific literature and business literature are integrated, and the studied problem is compared at least three times.

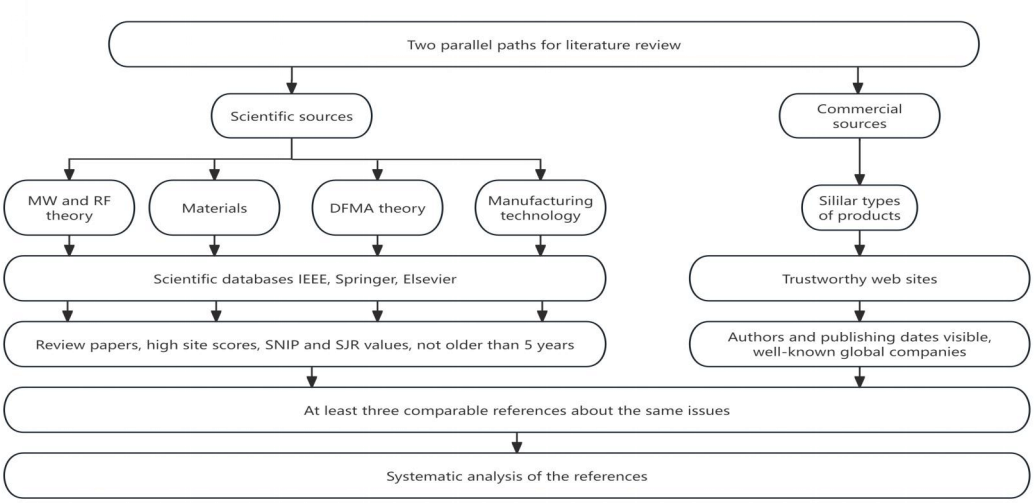


Figure 4. Flowchart to illustrate the practical implementation of the literature search.

2.1.2 Expert review

The expert to be interviewed is the highly respected and distinguished professor from Aalto University and he has several decades' experience in designing, testing, and building various types of MW and RF components. As mentioned, the topic of this thesis belongs to the broader research project at LUT University during the year 2024. The research project focuses on the DFMA and sustainability analyses of more than 40 different MW and RF components. The results of this thesis will be utilized later to build an overall picture of the DFMA, and sustainability aspects related to MW and RF technology. This fact makes it reasonable to arrange the expert interview so that all the questions and answers will be collected in a common file and the collected information will be used to support all topics of the broader research project – not just this individual device.

In the expert interview, I asked two questions about this device. The first question was are there any special requirements to close and seal the enclosure and if so, why?

The expert replied to me that the role of two covers are very important. They must be welded to the middle part to ensure that the lid does not fall in outer space and provides protection for key electronic components such as PCBs. At the same time, the internal electrical components are also very expensive. Welding the lid and middle part can also reduce the risk of parts falling off. From Figure 5, it can be seen that there are many

grooves and rounded corners in the cavity of this device, so some chamfers and grooves in the middle part, attention should be paid to their size and precise tolerances to ensure a tight fit with other components.

Figure 5. Some grooves and rounded corners marked in the cavity.

In expert interviews, the second question I asked the experts was, are there any metal materials suitable for application in outer space?

Expert replied to me that as far as your research equipment is concerned, aluminum alloy is a good choice and it is also widely used in other RF components. It is also feasible to consider appropriate gold as the coating material.

Through interviews with experts, I have gained a clear understanding of the device I am researching. I have gained an understanding of the relationships between the different components of this device and their functions, which has given me a clear direction for my next research.

Finally, the Table 1 is formed, which recorded the material selection guidelines, aspects dealing with the performance, manufacturing aspects, tolerances and Ra values, and assembly conditions and specifications related to this device. The table also recorded the

sources of scientific literature on these aspects, as well as the content of expert interviews, leaving ample preparation for the next step of the research thesis.

Table 1. The procedure to integrate the results of the expert interview and the literature review.

Refereces 1-N	Criteria 1 “Material selection guidelines”	Criteria 2 “Aspects dealing with the performance”	Criteria 3 “Manufacturing aspects”	Criteria 4 “Tolerances and Ra values”	Criteria 5 “Assembly conditions and specifications”
Ref #1 Name:	Bond, D.K., Goddard, B., Singleterry, R.C. & Bilbao y León, S. 2019, "Evaluating the effectiveness of common aerospace materials at lowering the whole body effective dose equivalent in deep space", Acta Astronautica, vol. 165, pp. 68-95.	Dennison, J.R., Cheng, S., Sharma, A., Lehtonen, J., Dalal, N., Wallis, R. & Matlin, D. 2022a, "X-band GaN SSPA for Near Earth and Deep Space Missions", IEEE, Piscataway, pp. 1.	Dennison, J.R., Cheng, S., Sharma, A., Lehtonen, J., Dalal, N., Wallis, R. & Matlin, D. 2022a, "X-band GaN SSPA for Near Earth and Deep Space Missions", IEEE, Piscataway, pp. 1.	Surface roughness conversion table.2024 Available:www.engineersedge.com/manufacturing/surface-roughness-conversion.htm	commercial websitc.2024 Available:www.globalspec.com
Ref #2 Name:		VSWR calculator.2024. Available:www.globalspec.com		IT grades table chart ISO 286-1.2024 Available:www.engineersedge.com/international_tol.htm	
Expert interview	Question number 1:Are there any special requirements to close and seal the enclosure and if so, why?	Question number 2: What materials are more suitable for deep space?			

2.2 Utilization of SolidWorks together with SolidWorks DFM-module

This method involves three stages. The first stage was invited by the professor to conduct a detailed observation of the actual device and use a vernier caliper to measure the dimensions of the device in detail, except for some standard parts such as threaded fasteners and SMA connectors As a result, a preliminary manuscript of some basic dimensions of the device was obtained. Figure 6 shows the preliminary dimensions of the outer contour of the middle part of the device, all in millimeters.The physical image of this device corresponding to the dimensions shown in Figure 6 is shown in Figure 7. These preliminary measurement data provide sufficient preparation for modeling using Solidworks software. The second point is also to establish critical dimensions along with

required dimensions and tolerances and Ra values based on functional requirements.Table 2 records in detail the surface roughness and tolerance levels corresponding to different frequencies of the equipment. The second stage is to use the DFM module in Solidworks software to conduct DFM analysis on the modeled object and discover some potential problems that may arise in actual production.

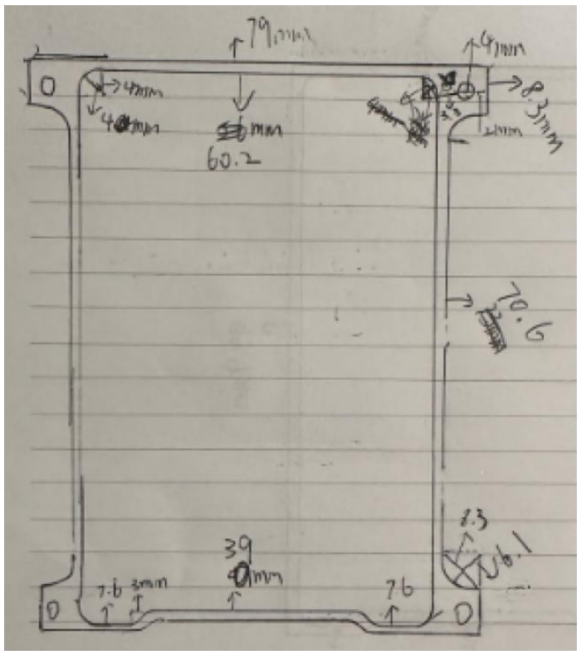


Figure 6. A hand drawn draft of the size of the device observed from above.

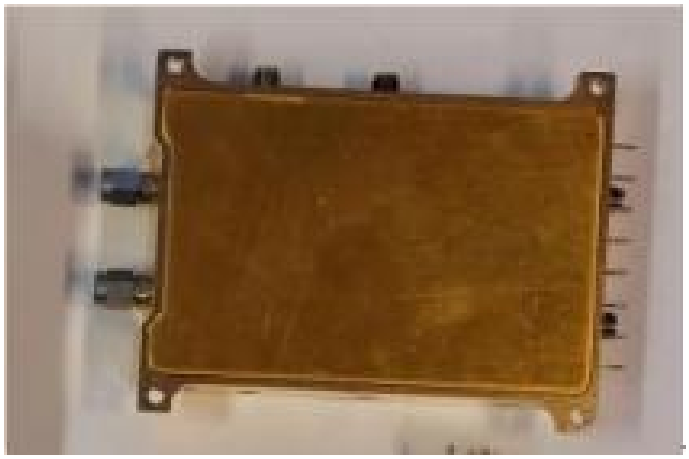


Figure 7. A physical image draft of the size of the device observed from above.

Table 2. Required accuracy depending on the operating frequency.

Frequency (GHz)	Surface roughness	Tolerance grade
300-600	0.8 μm	IT5
150-300	1.6 μm	IT6
75-150	3.2 μm	IT7
35-75	6.4 μm	IT8
15-35	12.8 μm	IT9-10

2.3 Systematic material selection process

For material selection, the device needs to be considered the manufacturability and performance of the material, as the performance of the frequency converter may be directly affected by the material. In addition to the standard SMA connector, what I need to only focus on is the metal material of the middle part of the device. Therefore, I will select the appropriate material and compare it based on the following five processes, elaboration of the requirements profile,decision about the selection strategy, pre-selection of possible materials, elaboration of the materials' property profile and integration of the requirement and the property profiles. The specific process is shown in Figure 8.

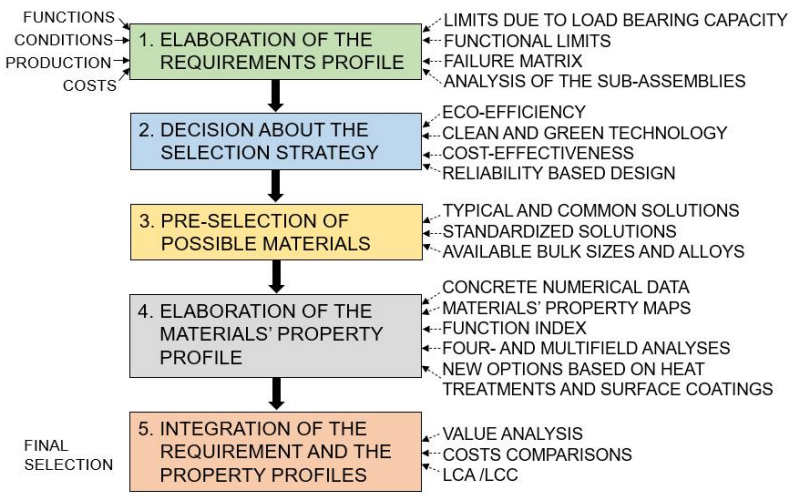


Figure 8. Stepwise process of the systematic material selection.

In addition to detailed performance analysis of the material, the cost of the material is also worth considering. The cost of the material may directly affect the cost of the overall device. Since this material is used in outer space, special chemical elements and processing methods may be required, and the cost may very expensive, so a reasonable cost analysis is also necessary.

2.4 Utilization of the triangulation

After having completed the three methodological approaches of the triangulation the final step is to integrate the results. The specific content is to combine the results and information collected from expert interview, literature review, SolidWorks analysis and systematic material selection methods with the performance oriented aspects of the device and possible changes of the original device of the frequency converter to determine a detailed manufacturing plan.

3 Result

The results chapter of the thesis will describe in detail the selected metal materials, analyze the results of the DFM-moudle research, the cost analysis of the entire device, and also develop a complete frequency converter manufacturing plan.

3.1 Integration of device requirements with material properties in different parts

The main material chosen for the frequency converter was aluminum alloy 7075, but it was also taken into account that silver was used as the soldering material for the covers and the middle part, the PCBs were made of aluminum oxide, and gold was used as the coating for the entire device.

Aluminum alloy is a common alloy that we know of. Adding quantitative alloying elements such as Si, Cu, Zn, Mg, Mn, etc. to metallic aluminum can improve its mechanical properties. Generally speaking, aluminum alloy has good corrosion resistance in the atmosphere, and its conductivity is second only to gold, silver, and copper. It has low strength and high toughness, and can be processed and cast well. Moreover, it is not brittle or magnetic at low temperatures.So we chose aluminum alloy 7075, which is an excellent aerospace and marine sheet metal. Its properties can be seen in Table 3-5.

Table 3. Physical properties of aluminum alloy 7075(7075 ALZN5.5MGCU - ISO209 2007 - material database) (Eskelinen, H., Lätti, K., Pertti Silventoinen & Silventoinen, P 2004 pp. 27).

Melting Temperature	638°C
Conductivity	19 MS/m
Resistance	0.0515nΩm
Tensile Strength	570Mpa
Modulus of Elasticity (tension)	72Gpa
Modulus of Rigidity (torsion)	66Gpa

Density	2.81g/cm^3
Coefficient of Thermal Expansion	23.6×10^{-6}K^{-1}
Thermal Conductivity	130W/(m.K)

Table 4. Fabricating properties of aluminum alloy 7075(World Material 7075 Aluminum Alloy Properties).

Cold Working Capacity	good
Hot Working Capacity	good
Hot Working Temperature	375-475°C
Annealing Temperature	413-477°C
Stress Relieving Temperature	120-190°C
Machinability Rating	poor
Polishing/Electroplating Finish	fair

Table 5. Joining properties of aluminum alloy 7075(World Material 7075 Aluminum Alloy Properties).

Soft Soldering	poor
Silver Soldering	fair
Brazing (Hard Soldering)	good
Oxy-Acetylene Welding	poor
Gas Shielded Arc Welding (GTAW/TIG, GMAW/MIG)	Fair
Coated Metal Arc Welding (Manual electrodes)	Fair
Resistance Welding	good

Aluminum alloy 7075 is one of the materials with smaller springback during molding. Its general corrosion resistance, except for stress corrosion, is similar to that of 2024 alloy. In the T6 state, it is very sensitive to stress corrosion cracking in the short transverse direction. The T73 and T76 states can greatly improve the alloy's stress corrosion resistance. The T73 state has the highest stress corrosion resistance, while the T76 state has higher strength,

stress corrosion resistance, and peeling corrosion resistance. The formability of this alloy in the annealed state is not as good as 2024, and it is similar to 2024 in the solid solution state. The room temperature formability in the T6 state is poor, and increasing the temperature can improve its formability. The alloy has good cutting performance in the heat treated state.(7075 ALZN5.5MGCU - ISO209 2007 - material database). Its chemical elemental composition is shown in Table 6.

Table 6. Main chemical composition materials(Eskelinen, H., Lätti, K., Pertti S & Silventoinen, P 2004, pp. 27).

Component	Weight (%)
Cr	0.18-0.28
Cu	1.2-2
Zn	5.1-6.1
Mg	2.1-2.9
Al	Remaining

The covers and middle part are welded with silver:

The reason for welding aluminum alloy with silver is that the melting point of aluminum alloy is relatively low, and silver welding uses lower temperatures usually below 900 degrees, effectively avoiding the melting of the parent material. On the other hand, the strength and ductility of silver alloy provide reliable joint integrity and good corrosion resistance. Silver welding can also precisely control the amount of filler material used, thereby achieving cleaner and more precise welding(IntechOpen 2024)(Verma, R.P. & Kumar Lila, M. 2021)

PCBs material:

The PCBs circuit in the middle of the frequency converter is mainly made of aluminum oxide, which is a ceramic material that makes PCBs more resistant to high temperature, high voltage, high frequency, and high insulation performance than traditional PCBs boards. This makes PCBs well adapted to the outer space environment.(D.Chen et al. 2020)

Product surface gold-plated:

Compared with traditional silver and nickel plating processes, gold has high conductivity, stable chemical properties, and low infrared emissivity. It can effectively resist radiation and oxidation from outer space (high-energy particles and cosmic dust), greatly improving the service life of frequency converters.

3.2 Analysis of the DFM-module

In Chapter 2.2, the specific data obtained after the physical object is measured is explained, and modeling will be carried out based on the measurement data.

After modeling the cover of the frequency converter, Figure 9 shows the modeling of the cover. Later, the model will be applied to the DFM module to perform virtual manufacturing on the cover, pointing out some design errors that occurred during the design and production process.

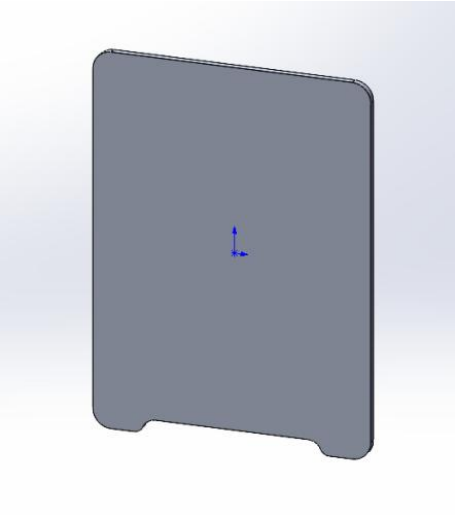
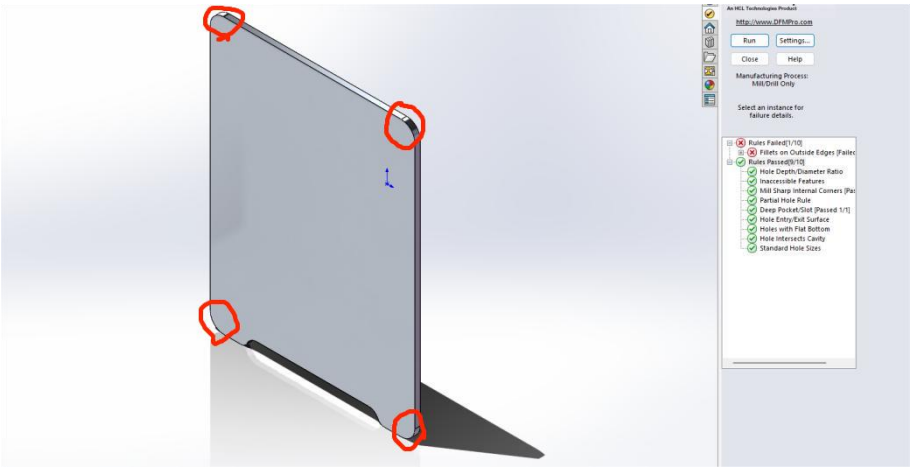


Figure 9. Cover of the device.

According to the DMF analysis of Solidworks moulding in Figures 10,where is marked need to be pay attention to the rounded corners that need to be machined, it is found that the rounded corners of the covers of the frequency converter are difficult to be processed using traditional grinding methods. The report suggests that precision machining should be

carried out using a shovel tooth milling cutter.According to DFM-moudle analysis report on the cover, problems that may arise in actual production are pointed out. Therefore, more advanced technologies need to be considered when the cover of this equipment is processed.



.Figure 10. DFM analysis of the cover.

By measuring the middle section, Figure 11 shows the modeling of the middle section. There are many threads with standard dimensions in the cavity. The model of the middle section will be applied to DFM analysis later.

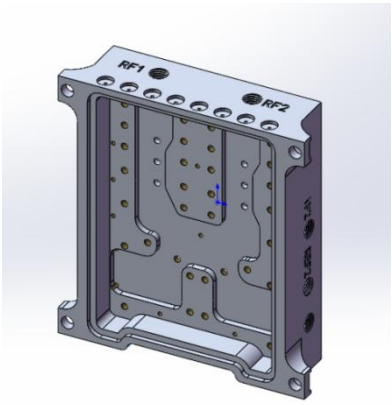


Figure 11. Middle part of the device.

According to the DFM module analysis in Figure 12, it can be seen that the groove in the middle part is difficult to machine and requires the use of a milling cutter. However, milling cutters are prone to vibration, making it difficult to achieve better tolerances. The ratio of depth to diameter is 5.0, and it is recommended to use 2.75. The diameter size of the standard hole should be 0.15mm, and flat bottomed holes are prone to problems when reaming. It is difficult to grind the inner corners of the grinding points using traditional grinding methods. The ratio of groove depth to diameter is 5.5, while the maximum ratio recommended by DFM is 3. The last issue is that if the drilling intersects with the existing hole, the drilling axis should be located outside the hole.

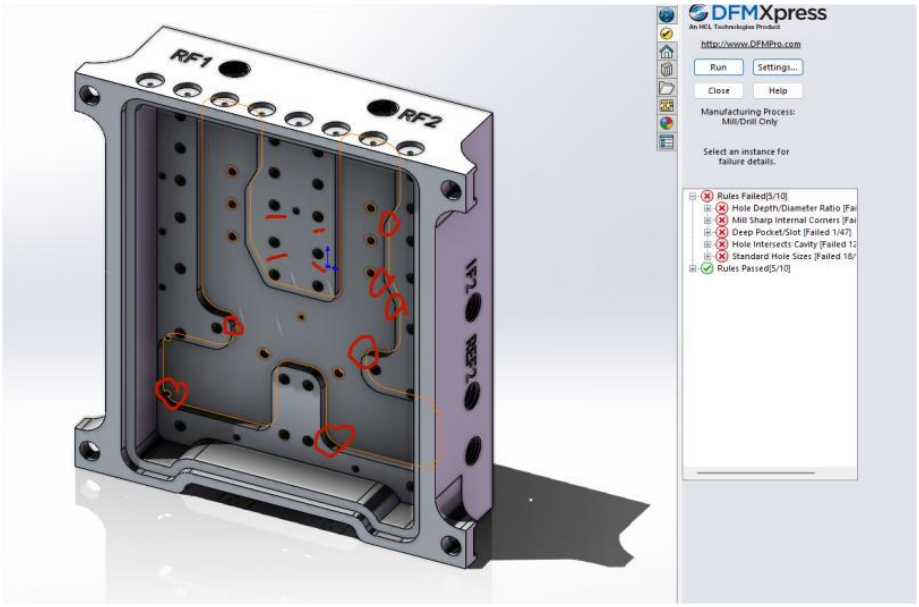


Figure 12. Middle part of the device.

3.3 Develop pre-manufacturing plan

The manufacturing methods was used milling and drilling. The advantage of milling is that the first point is the alternating machining of multiple cutting edges, which has good cooling effect on the cutting edge, high machining production efficiency, and wide machining range. Using various types of milling cutters on ordinary milling machines can complete machining tasks such as flat surfaces (parallel surfaces, vertical surfaces, inclined surfaces), steps, grooves (right angle grooves, V-grooves, T-grooves, dovetail grooves, and

other special grooves), and special surfaces. Combined with the use of indexing heads and other milling machine accessories, it can also complete the milling of workpieces such as spline shafts, spiral shafts, and gear clutches. Milling processing has high machining accuracy, with an economic machining accuracy of IT9-IT7 and a surface roughness Ra value of 12.8-3.2μM. The precision of precision milling can reach IT5, and the surface roughness Ra value can reach 0.20μm.(Kaymakci, M., Kilic, Z.M. & Altintas, Y 2012, pp.54-55, pp.34-45)The advantage of drilling is that it is easy to ensure the positional accuracy of each machining surface of the workpiece (coaxiality and verticality requirements), has high production efficiency, low production cost, and is suitable for a wide range of materials to be processed. Its accuracy is generally IT8-IT7, and the surface roughness is Ra6.4-3.2μM; When precision turning, the machining accuracy can reach IT6-IT5, and the roughness can reach Ra0.8-1.6μM.(Wesite jusfit, 2023)

The middle shell part is the main research part of the frequency converter, and measuring its specific size is crucial for its design and manufacturing. The unchangeable connectors and screws will be introduced in the following text.

Considering the connection issue between SAM connectors and screws :

The size of the screws used to fix the PCBS circuit board in the frequency converter is standardized. Through measurement of the actual frequency converter, it is roughly known that the screw specification is M2.5 screw. After tightening with M2.5 screw, the PCB circuit board will be well fixed on the frequency converter and not easily loosened.

The modeling of the SMA female connector is shown in Figure 13, and the modeling of the SMA male connector is shown in Figure 14. Due to the highest frequency of the studied frequency converter being 18GHz, the tolerance of the SMA connector is IT9 level, and the surface roughness is 12.8μM (Eskelinen, H., Lätti, K., Pertti Silventoinen & Silventoinen, P. 2004). The main material of SAM connectors is made of stainless steel, and the surface coating of the theme has been passivated. The material of the ring is brass, and the coating material of the ring is nickel. The coupling mechanism of RF connectors is threaded coupling, with a working temperature range of -65°C to 165°C. The specification standard for SMA female connector is amphenol 901-9023, which can be found in the appendix. The standard for SMA male connectors is 901-9038, which can be found in the appendix.

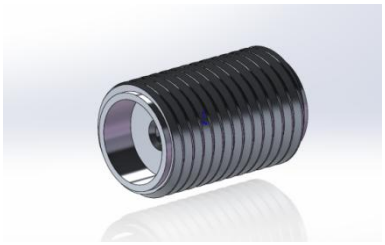


Figure 13. SMA female connector.

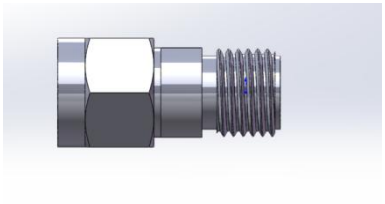
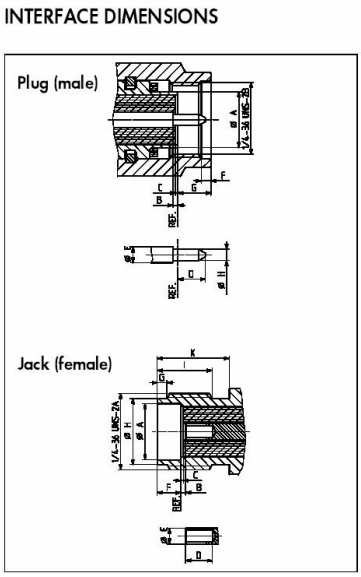


Figure 14. SMA male connector.

In addition, in order to enable the male and female ends of this SMA connector to be connected to other standardized SMA connectors, dimensional deviations are necessary and are shown in the following Figure 15.



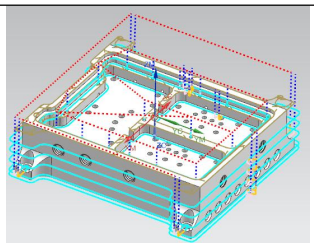
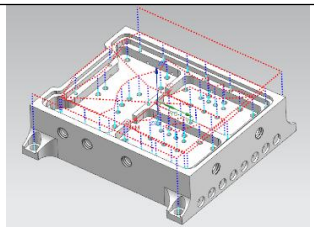
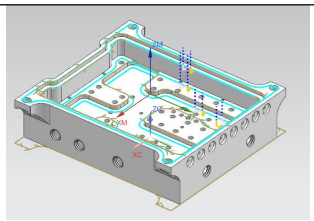
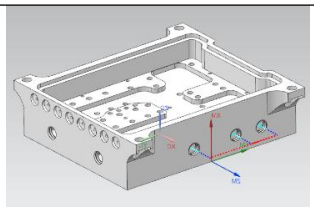
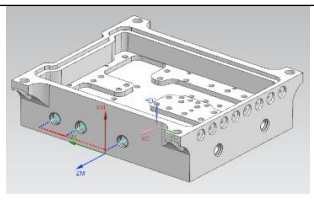
INTERFACE DIMENSIONS (MM / *INCHES*)

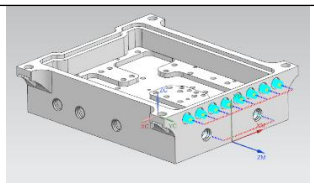
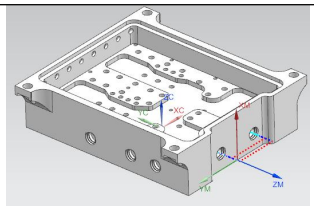
	Plug		Jack	
	min.	max.	min.	max.
A	--	4.59/.181	4.59/.181	--
B	0.00/.000	0.25/.010	0.00/.000	0.25/.010
C	0.00/.000	0.25/.010	0.00/.000	0.25/.010
D	--	2.54/.100	2.67/.105	--
E	1.24/.049	1.29/.051	1.24/.049	1.29/.051
F	0.38/.015	1.14/.045	1.88/.074	1.98/.078
G	--	3.43/.135	0.38/.015	1.14/.045
H	0.90/.036	0.94/.037	5.28/.208	5.49/.216
I	--	--	4.32/.170	--
K	--	--	5.54/.218	--

Figure 15. Interface dimensions for SMA-type plugs and jacks.

3.4 Process flow diagram of the middle part of the frequency converter

This is a flow chart for the processing of this device, using a three-axis machine tool and traditional milling and drilling methods. It shows the time and percentage of time a blank is processed from front to back.

Machining stage	Geometry	Simulated time	%（of total time）	
Milling（up）		10min 50S	38.11%	
Drilling,Drilling and threads（up）		10min 7s	1.59%	
Milling（down）		4min 59S	3.08%	
Drilling,Drilling and threads（left)		44s	1.59%	
Drilling,Drilling and threads（right）		44s	3.08%	

Milling,Drilling and thread （front）		5min 31s	40.34%	
Drilling and threads（back）		34S	12.21%	
Total		942S		

3.5 In terms of design and manufacturing costs

When considering the cost of the frequency converter for a deep space, the following four aspects should be considered:, The first aspect is the material and design manufacturing costs of the main body of the frequency converter. The second aspect is the purchase cost of standard SMA connectors and M2.5 screw costs. The third aspect is the cost of coating the entire equipment. The fourth aspect is the cost of connection, the cost of welding the cover and middle part.

Material and design costs:

The material of this frequency converter is selected as aluminum alloy 7075 space material. As this frequency converter is an RF component that will be used for missions in outer space, special chemical elements need to be added. Therefore, this material needs to be controlled by changing the casting conditions while also controlling the proportion of material elements, which will be a high cost. The cost of these materials is usually about 10 times that of traditional materials (Eskelinen, H., Lätti, K., Pertti Silventoinen & Silventoinen 2004 pp.33-36)In addition, the middle part of the frequency converter will require more time and design costs compared to traditional manufacturing methods. Some of its rounded corners, grooves, and sharp inner corners require high precision because it is necessary to ensure that the upper and lower covers can be tightened to ensure that the

internal PCB circuit board is not corroded by space and fails. Therefore, its time and design costs are almost twice that of ordinary products.

Standard components costs:

There are many suppliers of SMA connectors for RF components, which can be ordered from amphenol suppliers. The SMA connector female model I have chosen is 901-9023, the SMA connector male model is 901-9038, and the maximum frequency is 18GHz. M2.5 hex screws can be easily purchased on websites and are made of stainless steel.

Coating costs:

The central part and two covers of the frequency converter need to be gold-plated to resist corrosion from external space and improve the conductivity of the equipment. The equipment is electroplated with gold, but due to the raw material being aluminum alloy, aluminum alloy is easily oxidized in the air. If electroplated directly with gold, deposits will be generated in the electrolyte solution in advance, which is not conducive to gold adsorption, resulting in surface voids and uneven material. Therefore, special surface treatment (nickel, copper, zinc) is required before successful electroplating. Without considering the materials, this series of processing requires professional settings and high-precision equipment for the production system, resulting in production costs of approximately 600% to 1000% of ordinary costs.(Milan Paunovic and Mordechay Schlesinger, 2010)

Connection costs, such as (welding):

The two covers and the middle part are welded with silver using the MIG Welding Silver method, which requires a low current output MIG welding machine to adjust special parameters and advanced technical means to deal with possible welding problems (porosity and air pockets, insufficient penetration) to ensure the sealing of the cover and the degree of damage to the raw materials, without affecting the dimensional tolerance of the component. This series of operations requires a lot of manpower and material resources to achieve, and its cost is very high.

3.6 Manufacturability

Analyzing the manufacturability of a product can prevent critical errors from occurring during early modeling and avoid costly errors from being invested in manufacturing later on. Because the frequency converter needs to be applied in deep space and the materials are very expensive, a manufacturability analysis of this product is necessary.

This thesis' sustainability analysis of this product into three stages: feasibility analysis, cost analysis and environmental analysis.

Feasibility analysis:

Before the actual design and manufacturing of the product, I analyzed the equipment using the DFM module of Solidworks, as shown in Chapter 3.2. I set up a traditional three-axis machine tool to simulate machining using milling and drilling methods, but during the analysis, the following 5 errors occurred, The first problem is that Deep and narrow grooves are difficult to machine (drill bits are prone to breakage, and the debris generated during drill processing is difficult to clean). The second problem is that Sharp inner corners are difficult to handle with grinding (requiring the use of EDM) The third problem is The groove at the bottom is difficult to machine The fourth problem is Drilling intersects with other types of holes The fifth problem is Some holes are not standard holes (additional tools need to be purchased for processing).

Cost analysis:

The cost related issues can be found in Chapter 3.4 which have analyzed the overall cost of this equipment, including the following four aspects, Materials and Design costs, purchase costs, coating cost and connection costs.

Environmental analysis:

The environmental impact of a product also needs to be comprehensively analyzed before it is put into design and manufacturing. As this equipment needs to be put into space for use, the term "space waste" has been increasing in recent years. Therefore, we have to consider the impact of this product on the environment after its service life, as well as the impact during production.

The main material we use is aluminum alloy. Although the aluminum alloy of this equipment is gold-plated, some small parts will fall into space and become space debris when exposed to corrosion in outer space for a long time. Although the midpoint effect is minimal, we also need to prevent it. The main impact is in the production stage. This aluminum alloy is 7075 space aluminum alloy material, which requires the addition of rare chemical elements to improve its performance. These chemical elements need to be cast and processed, which consume a large amount of electricity and fuel to produce greenhouse gases. At the same time, the waste and wastewater generated during the processing of aluminum alloy also need to be properly treated.

4 Discussion

After going through step-by-step analysis, This have obtained preliminary manufacturing results. In the discussion section, this thesis will focus on introducing material tolerances, comparing with previous literature, reliability, key findings, and exploring future topics related to this equipment.

4.1 Analysis of Dimensional and Geometric Tolerance

In the middle part of our design and the two covers, there are many linear dimensions, fillet dimensions, and symmetry. The standard tolerances for the Linear Dimensions are shown in Table 7 and the Angular Dimensions are shown in Table 8, so determining a unified tolerance can ensure that all characteristic dimensions and geometric shapes can be completed as required. The tolerance I have selected is ISO-2768-mk tolerance, which is developed by the International Organization for Standardization, including fine medium coarse and very corase tolerance levels.

Table 7. Linear Dimensions(Lead Technology(HK) Group, 2014).

Permissible deviations in mm for ranges in nominal lengths	Tolerance Class Designation (Description)			
	f (fine)	m (medium)	c (coarse)	v (very coarse)
0.5 up to 3	±0.05	±0.1	±0.2	--
over 3 up to 6	±0.05	±0.1	±0.3	±0.5
over 6 up to 30	±0.1	±0.2	±0.5	±1.0
over 30 up to 120	±0.15	±0.3	±0.8	±1.5
over 120 up to 400	±0.2	±0.5	±1.2	±2.5
over 400 up to 1000	±0.3	±0.8	±2.0	±4.0
over 1000 up to 2000	±0.5	±1.2	±3.0	±6.0
over 2000 up to 4000	--	±2.0	±4.0	±8.0

Table 8. Angular Dimensions(Lead Technology(HK) Group, 2014).

Permissible deviations in mm for ranges in nominal lengths	Tolerance Class Designation (Description)			
	f (fine)	m (medium)	c (coarse)	v (very coarse)
up to 10	±1°	±1°	±1°30′	±3°
over 10 up to 50	±0°30′	±0°30′	±1°	±2°
over 50 up to 120	±0°20′	±0°20′	±0°30′	±1°
over 120 up to 400	±0°10′	±0°10′	±0°20′	±0°30′
over 400	±0°5′	±0°5′	±0°10′	±0°20′

4.2 Comparison with the findings of literature research

This thesis mainly introduces the manufacturing methods and material selection, and compares them with the design and manufacturing of previous frequency converters. In the manufacturing method stage, due to the widespread use of DMF modules in Solidworks, we can understand many modeling errors in the formal production stage, which may not be possible to operate with the original processing equipment. This helps us to improve the design in advance and avoid the high costs caused by improvements in subsequent manufacturing. In terms of material selection, compared with traditional frequency converter materials, stainless steel and magnesium alloy are mainly chosen. However, due to the application of the frequency converter I am researching in outer space, the harsh environment of outer space must be considered, and the corrosion resistance of magnesium alloy is poor. Although aluminum alloy has better corrosion resistance than traditional frequency converter materials. Stainless steel, but considering its lightweight design, its density is relatively high. Due to the design of many rounded corners and arcs in the frequency converter, it is also necessary to consider materials that are easy to process. The processing performance of stainless steel and magnesium alloy is poor, which is not conducive to processing. In short, I have chosen aluminum alloy as the main material for design, manufacturing, and processing. In terms of coating, using aluminum oxide as the material for PCBs circuit boards is more resistant to high temperature, high voltage, high frequency, and high insulation performance than traditional PCBs circuit boards.

4.3 Reliability aspects of research

The research method of this thesis is triangulation, including Literature review supported with an expert review, DFMA analysis, and Systematic material selection process. The discussion of the authenticity of this method includes five aspects.

Expert interview: Interviewed with respected distinguished professors from the University of Alto, who have decades of experience in testing and manufacturing various types of microwave and radio frequency components. See section 2.1.2 for questions and answers

Literature review: Information is retrieved from professional academic paper websites such as IEEE and LUT library. The selected literature should not exceed 5 years and should also incorporate relevant commercial literature.

SolidWorks analysis: Basic modeling of equipment was carried out using Solidworks software, and DFM modules were also used for analysis before investment in design and manufacturing. Many errors were discovered, and the analysis of some manufacturing plans was also correct.

Systematic material selection: The selected aluminum alloy 7075 material was determined, and a detailed analysis was conducted on its physical properties, fabric properties, and joining properties, demonstrating its feasibility for application in outer space and as a variable frequency equipment material.

Connection and coating: Analyzed the standard dimensions and potential suppliers of some possible SMA connectors, analyzed the reasons why aluminum oxide material is used as PCB circuit board material, and the principle of surface gold plating.

These five aspects combine to prove the reliability of my research method.

4.4 Key findings and Conclusions

Through analysis, this thesis has been found that some fillets, slots, and grooves in the DFM module of Solidworks are difficult to machine using traditional machining methods, such as drilling and milling. This is also why I need to consider the application of new

machining methods in the future. For the key findings of the material, through a detailed search and performance comparison of aluminum alloys, I found that aluminum alloy materials are widely used in aerospace materials, and more importantly, in aircraft structural materials. Different types of aluminum alloys contain different chemical elements. In recent years, the exploration of aluminum alloy materials in various countries has been increasing, mainly divided into the 2000 series and 7000 series. Therefore, combined with the excellent properties of aluminum alloys, I believe that the application of aluminum alloy 7075 in this equipment is a good choice.

Regarding the coating, due to task requirements, the surface of the frequency converter is treated with gold plating, using electroplating as the method. However, considering that the surface of aluminum alloy is extremely prone to oxidation in the air and has strong redox properties, it is difficult to treat the surface. After removing the oxide film, it will generate the oxide film for a short period of time, resulting in poor adhesion with the coating material. Moreover, its coefficient of expansion is large. Therefore, in electroplating with large temperature changes, aluminum alloy is not suitable, and it will generate stress with the gold coating, affecting the adhesion with gold. Therefore, it is found that the Micro-ArcOxidation method can be used to generate a ceramic oxide film protective layer on the surface of aluminum alloy. Compared with other metal coatings, the ceramic oxide film protective layer has obvious advantages, such as high wear resistance, low friction coefficient, and much lower corrosion rate than stainless steel. This can effectively cope with the harsh environment of outer space.However, due to the complexity of operational techniques and high investment costs, their applications are limited, but they are bound to become one of the surface treatment technologies for future aviation materials.

4.5 Topics for further research

Connection issues and solutions for aviation detectors and frequency converters

Due to the theme of this paper being the manufacturing plan of frequency converters applied to space probes, I can consider the connection between frequency converters and detectors in future research. I believe this is a topic worthy of in-depth research, and it is

worth considering what connectors should be used for stable operation in outer space environments.

The working principle, performance testing, and circuit processing of aviation detectors

This topic requires in-depth research on frequency converters and analysis using professional equipment. Considering that various factors may affect the performance of frequency converters in harsh outer space environments, how to design a perfect control system.

5 Summary

This thesis provides a detailed analysis of the design, manufacturing plan and DFMA analysis of the frequency converter for a deep space probe. The measurement method used is triangulation. In terms of literature search, I integrated bachelor's literature and business materials (Material selection guidelines, Aspects dealing with the performance, Manufacturing aspects, Tolerance and Ra values, Assembly conditions and specifications) from five aspects and created tables, which helped to ensure the authenticity of my paper and the subsequent development of the paper. In terms of SolidWorks, I modeled the measurement results and analyzed them using the DFM module, obtaining improved methods while also taking into account the issues of standard SMA connectors, screws, and PCB circuit boards. In terms of material selection, I analyzed aluminum alloy 7075 from the perspectives of physical properties, manufacturing performance, and connection properties. This method helped me identify and integrate the most relevant perspectives to identify key aspects of the manufacturing plan. In this chapter, I used many tables to record the content, which simplified the design content and helped us better understand.

In the results section, the device is researched by DFM module, created a manufacturing flowchart for manufacturing the physical object, analyzing the cost and manufacturability. Through this chapter, it is understood that if the selection of RF component materials, processing methods, and connection methods are not correct, it may lead to a sharp decrease in manufacturability and a significant increase in cost. Therefore, it is recommended to have a professional design team and utilize cross technology design teams to provide functional and cost competitive products for RF applications.

References

Chen, D., Hsu, J., Su T., & Li, Y. L. 2020.Enhanced board level design methodology by statistical analysis, pp. 236-238.

Eskelinen, H., Lätti, K., Pertti S & Silventoinen, P.2004. DFM(A)-Aspects for an sma connector design lut, pp. 19-40.

Liao, Y., Tang, H., Luo, Z., Wang, J. & Wang, W. 2023, "Analysis of Frequency Offset Errors Through Interval Arithmetic in Frequency Diverse Arrays",IEEE Transactions on Aerospace and Electronic Systems,vol. 59, no. 3, pp. 1-8.

Lead Technology(HK) Group Limited. 2024 . “The basics of General Tolerance Standard - ISO 2768-MK - LEADRP - Rapid Prototyping and Manufacturing Service”.

Available : https://leadrp.net/blog/the-basics-of-general-tolerance-standard-iso-2768-mk/.

Kaymakci, M., Kilic, Z.M. & Altintas, Y. 2012, "Unified cutting force model for turning, boring, drilling and milling operations", International journal of machine tools & manufacture,vol. 54-55, pp. 34-45.

Material database . 2007. 7075 ALZN5.5MGCU - ISO209-2007.

Available : https://www.caishuku.com/material/detail.php?mid=azhlNWIxMTQ4NzI=.

Milan P& Mordechay S.2010 .Modern Electroplating.pp115-130.

Available : https://onlinelibrary.wiley.com/doi/book/10.1002/9780470602638

Sanjeev Kumar.2024.Welding: Materials, Fabrication Processes, and Industry 5.0.pp10-20.

Taravati, S. & Eleftheriades, G.V. 2021,Pure and Linear Frequency Converter Temporal Metasurface, Ithaca.pp. 20-63.

Totaro, P. & Khusid, B. 2021, "Multistep anodization of 7075 – T6 aluminum alloy", Surface & Coatings Technology, vol. 421, pp. 20-30.

Verma, R.P. & Kumar Lila, M. 2021. A short review on aluminium alloys and welding in structural applications", Elsevier Ltd, , pp. 10687.

Wesite jusfit. 2023.The Advantages and Disadvantages of Drilling Machines.

Available:https://jusfitools.com/blogs/our-blog/the-advantages-and-disadvantages-of-drilling-machines.

World Material .2024.7075 Aluminum Alloy Properties, AA 7075-T6, T7351, T651, Density, Composition, Yield strength.

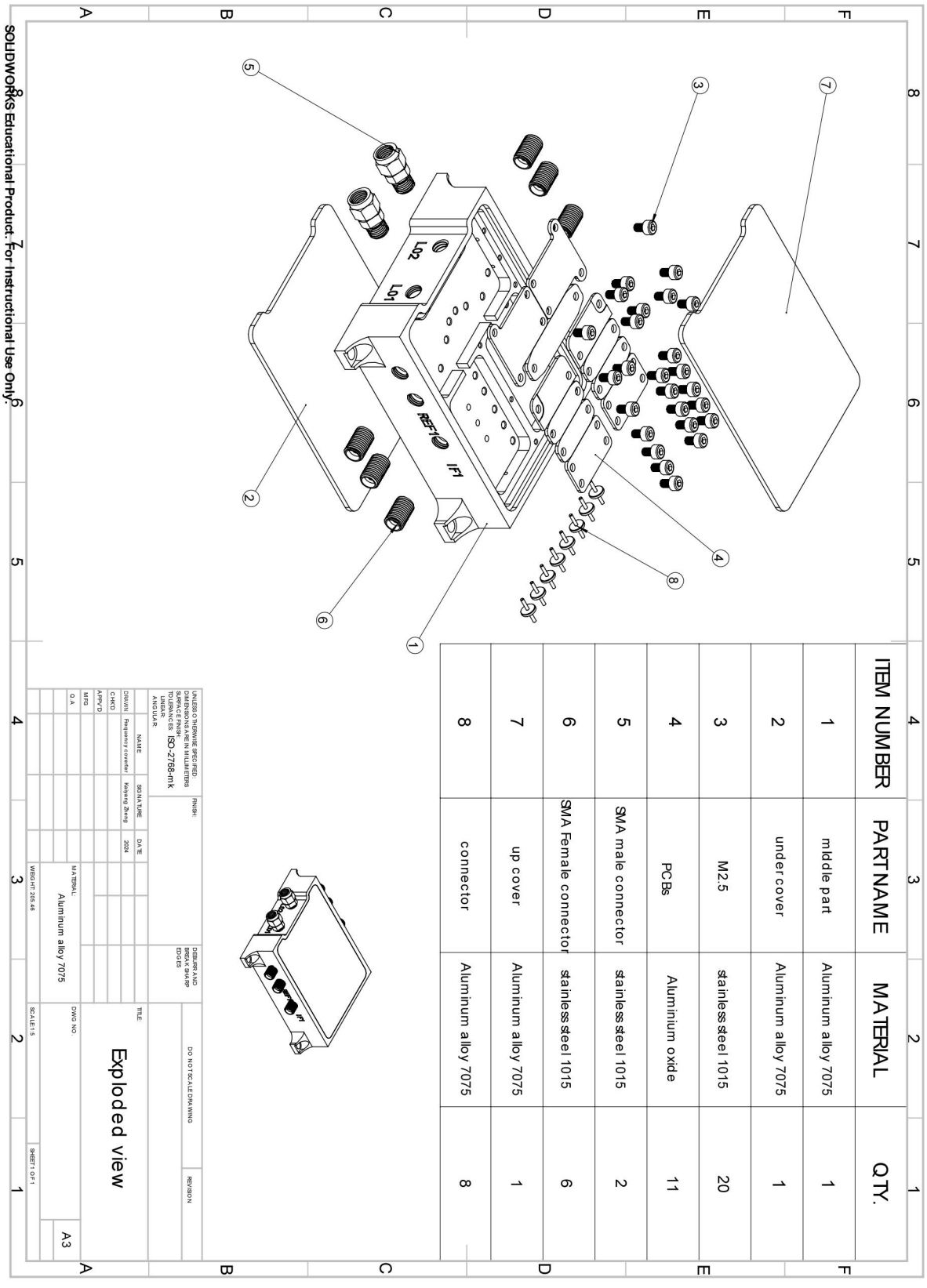
Available : https://www.theworldmaterial.com/al-7075-aluminum-alloy/.

Xu, D., Guan, Y., Wang, Y. & Zhang, X. 2021, Multi-MHz High Frequency Resonant DC-DC Power Converter,1st edn, Springer Singapore, pp. 55-72.

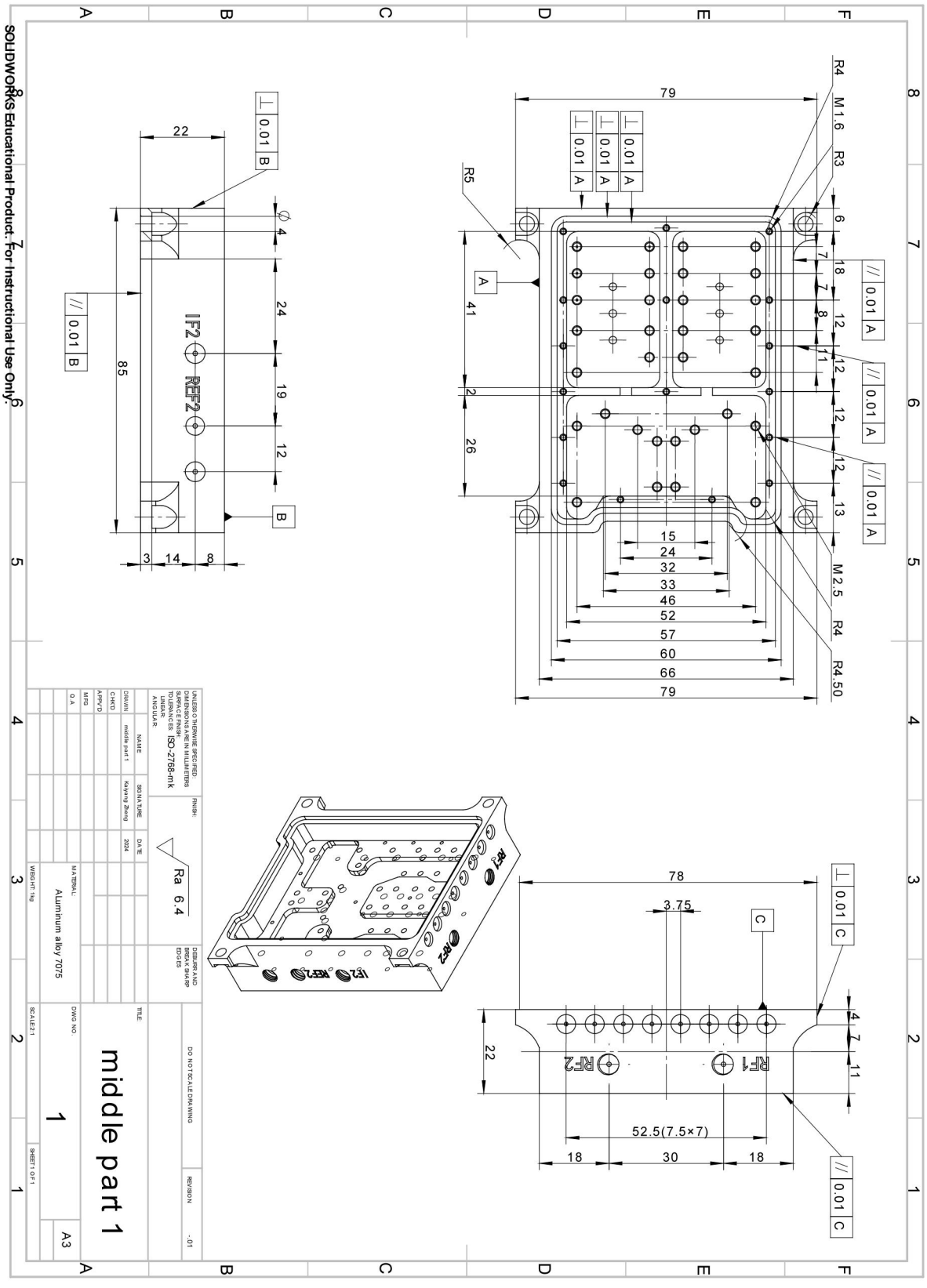
Available :https://link-springer-com.ezproxy.cc.lut.fi/book/10.1007/978-981-15-7424-5

Zheng, S., Hou, D., Wang, C., Zhou, P., Chen, J. & Hong, W. 2023, "A 24.25–30 GHz radio frequency up-down converter with harmonic distortions rejection for 5G millimeter wave radio channel emulator applications",Microwave and Optical Technology Letters, vol. 65, no. 7, pp. 1943-1951..

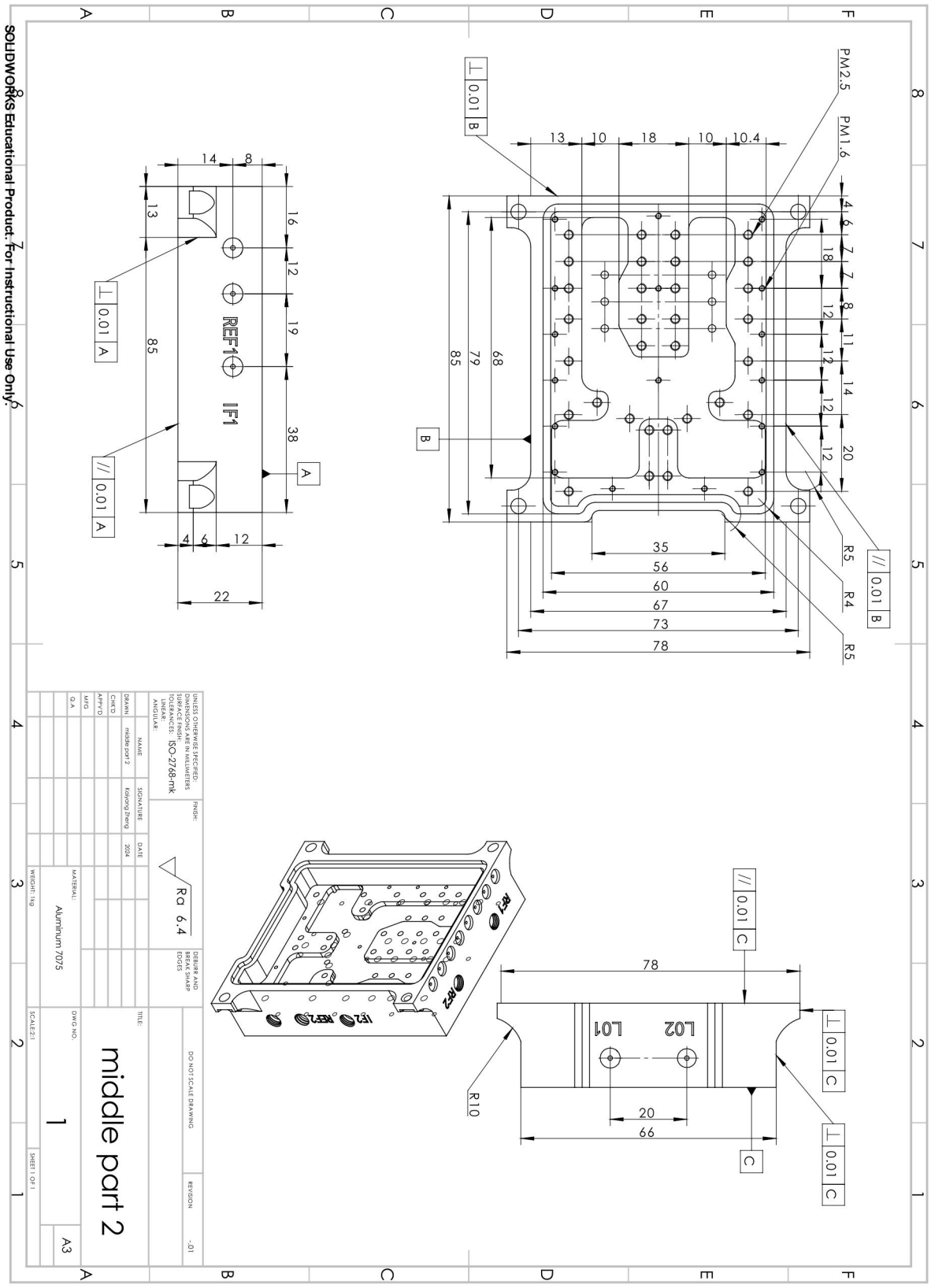
Appendix 1. Explosion view



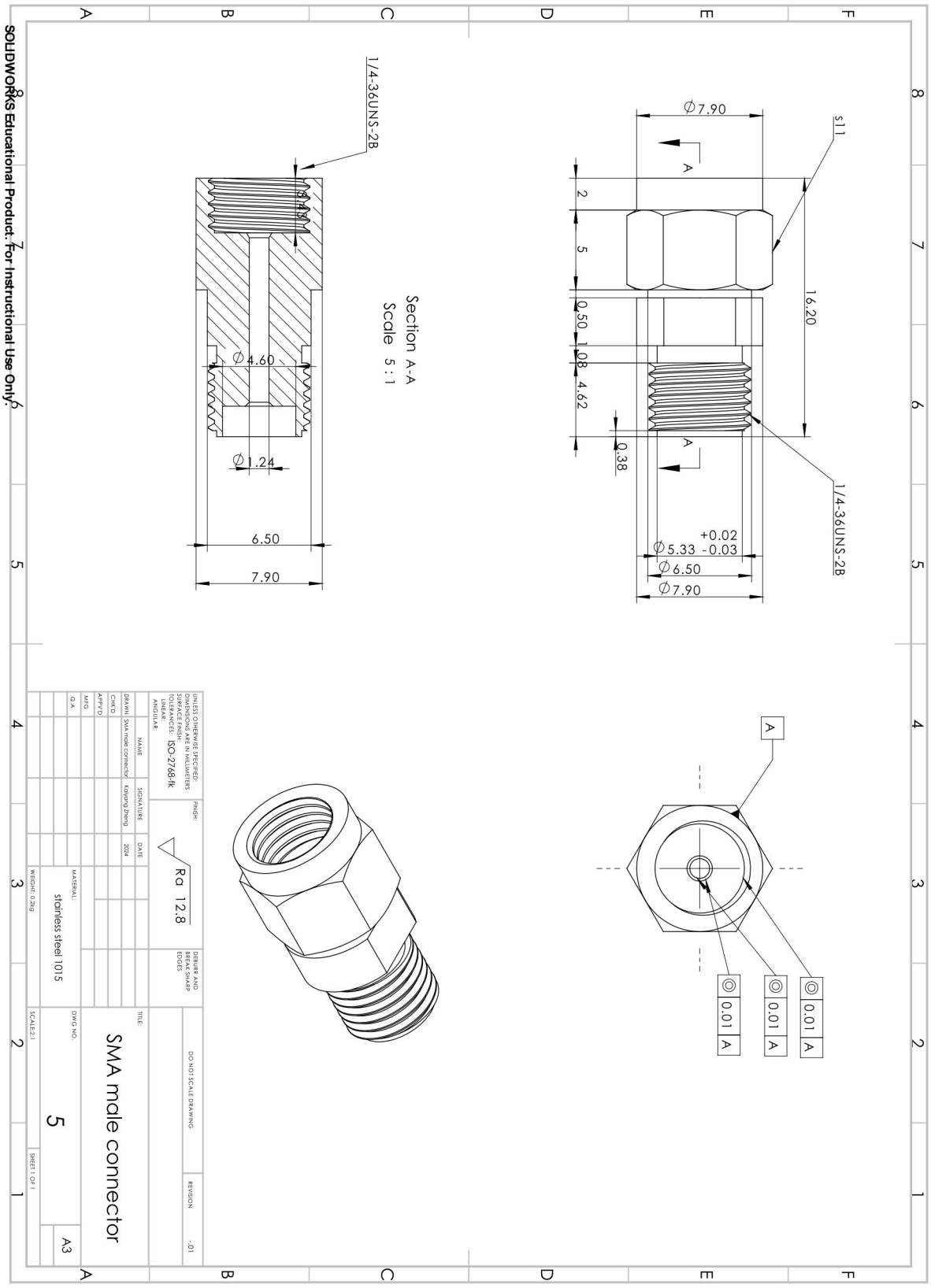
Appendix 2. Engineering drawing for the middle part 1



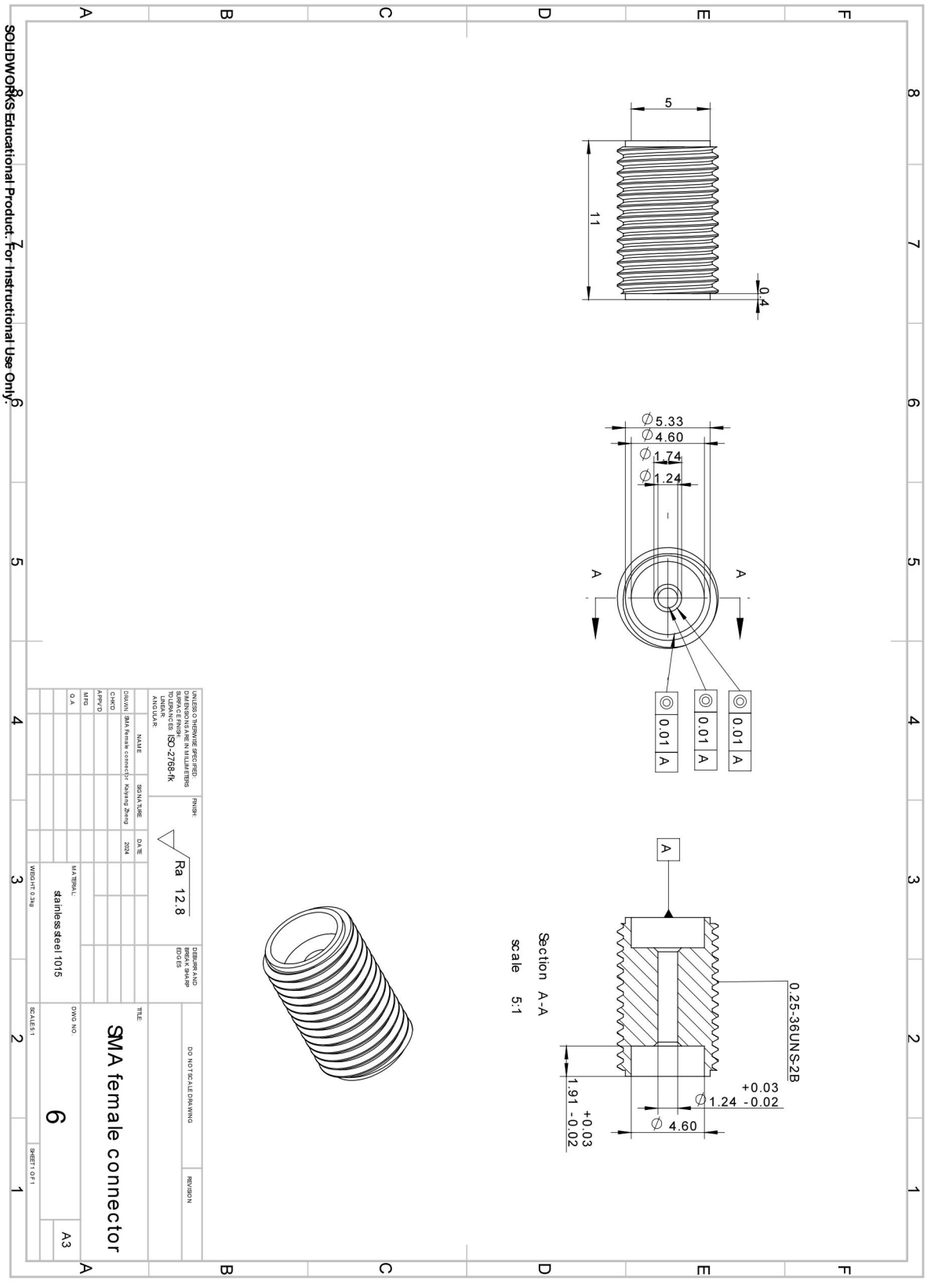
Appendix 3. Engineering drawing for the middle part 2



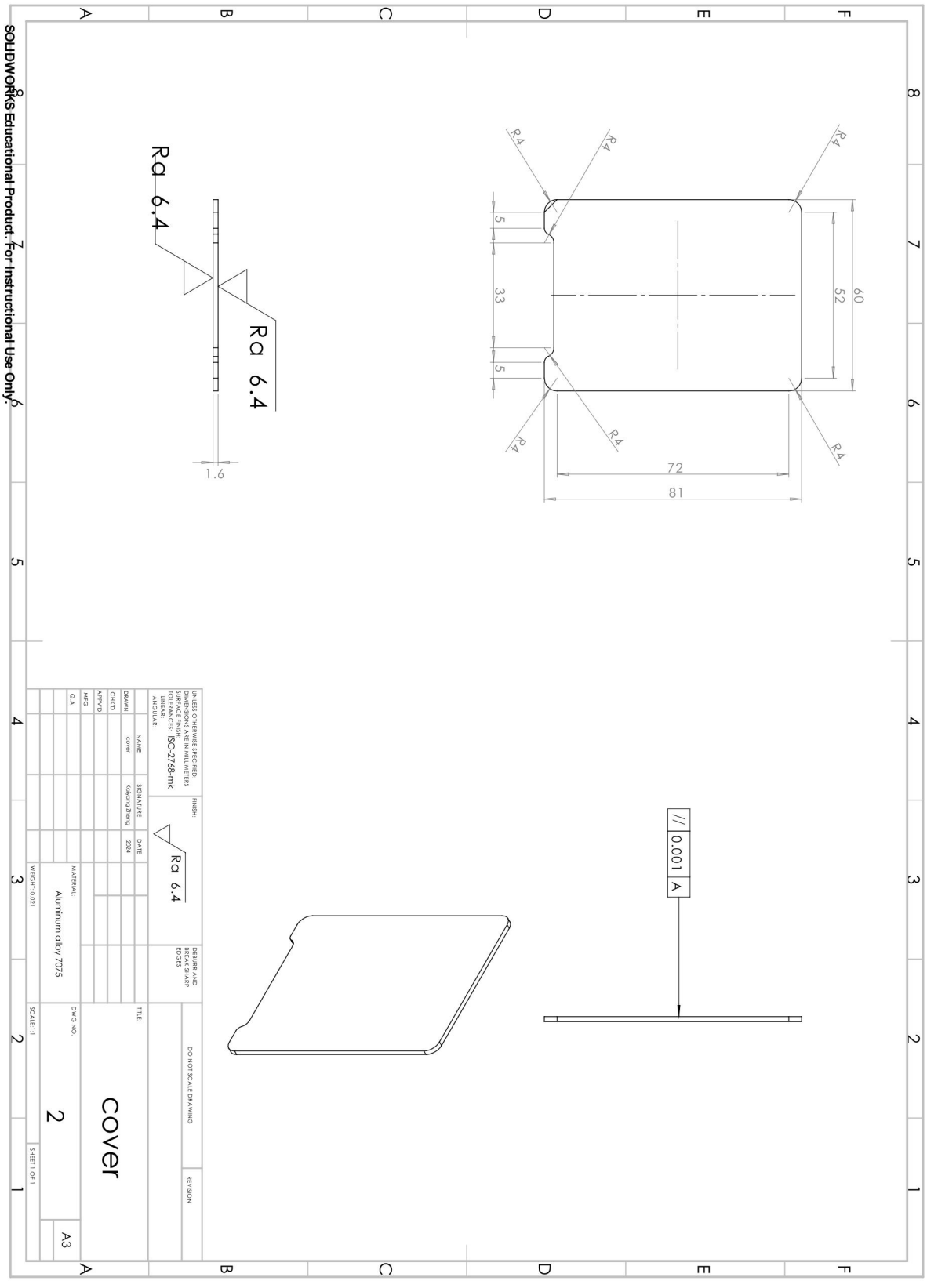
Appendix 4. Engineering drawing for SMA male connector



Appendix 5. Engineering drawing for SMA female connector



Appendix 6. Engineering drawing for cover



Appendix 7. Engineering drawing for connector