통신해양기상위성 통신 중계기용 MMIC의 우주인증

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Space Qualification of MMICs for COMS Communications Transponder

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요 약

본 논문에서는 통신해양기상위성 Ka대역 위성통신중계기에 사용하기 위해 개발한 MMIC의 인증 시험에 대해 다루었다. 통신해양기상위성의 통신중계기에 사용될 Ka대역 능동부품은 총 12종의 MMIC를 이용하여 개발되었다. 12종의 MMIC중에는 저잡음 증폭기, 중전력 증폭기, 주파수 혼합기, 주파수 체배기, RF 스위치, 그리고 감쇄기 기능을 갖는 MMIC들이 포함되어 있다. MMIC의 제조 공정은 우주 인증된 시설인 미국 NGST사의 0.15um GaAs pHEMT공정을 이용하였으며, 지난 수십년간 많은 우주 산업 관련 부품 생산 경험을 가지고 있다. 제작된 모든 MMIC에 대하여 Visual Inspection을 수행하였으며, Wafer Lot Acceptance 판정을 위하여 SEM(Scanning Electron Microscope) Inspection을 수행하였다. MMIC의 동작 수명을 보증하기 위해 Test Fixture를 제작하여 125°C의 온도에서240시간 동안의 Burn-in 시험과 1000시간 동안의 가속 수명 시험이 수행되었다. MMIC 부품의 성능 저하 또는 수명 단축의 가장 큰 요인인 pHEMT의 채널온도 상승을 확인하기 위하여 적외선 온도 측정 시험과 유한요소법을 이용한 pHEMT의 채널 온도 해석을 수행하였다.

Key Words : COMS Transponder, MMIC, Space Qualification, Life Test

ABSTRACT

This paper describes the MMIC product qualification of the Ka band satellite transponder for the COMS(Communication, Ocean and Meteorological Satellite). Ka-band active equipment for the COMS communications transponder are being developed by using 12 kinds of MMICs which include low noise amplifiers, medium power amplifiers, frequency mixers, frequency multipliers, RF switch, and HEMT attenuator MMIC. Those MMICs had been fabricated at the MMIC production foundry of Northrop Grumman Space Technology (Velocium) which is qualified for space application and experienced in various space programs during past decades. For the MMIC product qualification, Visual inspection and SEM inspection had been performed, and burn-in test for 240 hours and accelerated life-test for 1000 hours had been done on test fixtures of individual MMIC products at 125°C. Additionally, infrared temperature scanning and finite element simulation were performed to analyze and confirm the channel temperature of semiconductor devices on several representatives of those MMIC products that is one of the most important factors in performance degradation and life reduction.

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Ⅰ. Introduction

Recently, communication satellites rely heavily on microwave and millimeter-wave carriers for signal transmission. Therefore, microwave and millimeter-wave components play an important role in communication satellites. MMIC technology is known for the key technology to enhance the performance of those components. Because of the unique environment in space, design requirements of microwave components are also unique. The expensive operation of transporting the satellite to space demands that payloads be small and light. The limited amount of energy from solar cells demands efficient operation of the electronics while radiating sufficient microwave power for signal transmission. The 10 to 15 years of service requirement without the possibility of field repair demands that every component be extremely reliable.

The reliability must not be compromised for any other performance requirement. By employing MMICs as the functional building blocks, the size and weight of the electronic payload will be dictated by the other electronic circuits and their packages. Therefore, reducing the size of the MMICs themselves is not a key issue. Higher functional levels of integration are desirable to reduce the size and weight of the MMIC circuit package. In addition, having fewer components and wirebonds in the manufacturing process will also improve the system reliability. In summary, the design parameters of the MMICs for satellite communications in order of their importance are (1) reliability, (2) performance, (3) power consumption, and (4) size and weight [1],[2].

We are developing the communications payload for COMS (Communications, Ocean, and Meteorological Satellite) which will be launched in 2008, and several equipments integrated to the payload. We have developed MMICs to use in manufacturingactive equipments such as low noise amplifier, downconverter, upconverter, channel amplifier, and microwave switch matrix. For the development of MMICs, we had designed 12 kinds of MMICs and used the MMIC production foundry of NGST (Northrop Grumman Space Technology) to fabricate those MMICs.

In this paper, we describe the procedure, test method, and result for space qualification for our developed MMIC products.

Ⅱ. Space Qualification Procedure

Qualification can be defined as the verification that a particular component's design, fabrication, workmanship, and application are suitable and adequate to assure the operation and survivability under the required environmental and performance conditions.

The space qualification for MMIC products is divided into process qualification and product acceptance test including product qualification [3],[4][5],[6].

Process qualification is a set of procedures the manufacturer follows to demonstrate the control of the entire process of design and fabrication using a specific process technology.

Those MMIC products for active equipments of COMS communications payload has been fabricated by using NGST's 0.15um GaAs pHEMT process which is a space-qualified MMIC process and has many experiences in manufacturing components for many space programs during past decades.

We followed thoroughly the MMIC design guide provided by NGST in the design step of MMIC circuits and performed the procedures of design verification prior to MMIC fabrication.

In the MMIC fabrication, NGST ran the standard MMIC process for space productsand performed the test for the process monitoring patterns and technology characterization vehicles to verify the validity of the process [7].

Even if the MMIC products may be designed byhighly qualified personnel, fabricated on a process qualified production line, and verified through measurements to meet the design goals, MMIC products with poor reliability characteristics still may exist. This may be due to variations in the fabrication process, or material flaws that were undetected. Regardless of the cause, these weak products must be found and removed before they are integrated into equipments. Therefore, the product acceptance test is required to increase the confidence in the reliability of the MMIC products. Figure 1 shows the typical space qualification flowchart of the product acceptance test [8].

Space qualification except for process qualification of MMIC products consists of wafer-level lot acceptance test, visual inspection, and QCI (Quality Confidence Inspection) test. Another important qualification step is thermal analysis and test determiningthe thermal characteristics of the MMIC products. Thermal analysis and test will be presented in Section 4.

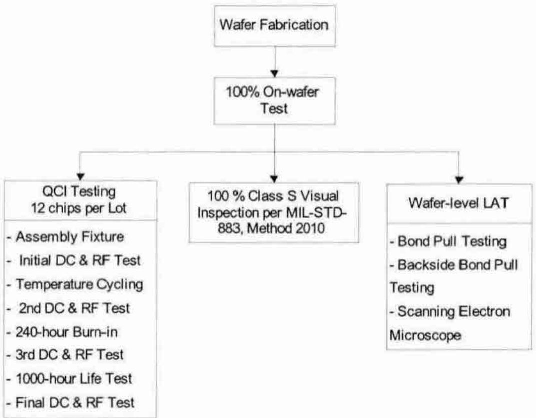

Figure 1. Typical Space Qualification Flowchart

Ⅲ. MMIC Samples

12 kinds of MMICs have been developed to be use in manufacturing active equipment for COMS communications payload. Those developed MMICs could be functionally divided into six kinds of groups composed of low noise amplifier (LNA), medium power amplifier (MPA), frequency mixer, voltage controlled attenuator, frequency multiplier, and RF switch.

LNA group includes two Ka-band LNA (BLNA1A, WLNA1) and a K-band LNA (GLNA1), and MPA group consists of Ka-band MPA (KADRA1), K-band MPA (DRIVER1), and S-band MPA (MPA3G).

Frequency Mixer group is composed of Ka to S-band mixer (MIXER3A) and S to K-band mixer (MIXER2A), and K-band doubler (DBL1) and Ka-band tripler (TRPL2) belong to the frequency multiplier group. A voltage controlled attenuator (ATTEN1) operates in K-band frequency range, and a RF switch (SW03A) operates in S-band frequency range[9].

Table 1 shows the summary for the primary function and performances of 12 MMICs developed for COMS.

Table 1. Functions and typical performances ofdeveloped MMICs

Function	Name	Gain	NF
LNA	BLNA1A	18dB	1.7dB
	WLNA1	17dB	2.7dB
	GLNA1	19dB	1.7dB
		Gain	P1dB
MPA	KADRA1	15dB	24dBm
	DRIVER1	16dB	23dBm
	MPA3G	15dB	26.5dBm
		CL	OIP3
Frequency Mixer	MIXER3A	7.5dB	8dBm
	MIXER2A	6dB	8dBm
		CL	Harmonic Rej.
Multiplier	TRPL2	5dB	20dBc
	DBL1	3dB	10dBc
		DR	
VCA	ATTEN1	27dB	
		IL	Isolation
RF Switch	SW03A	2dB	63dB

** Notes : DR : Dynamic Range,
CL : Conversion Loss,
IL : Insertion Loss,
OIP3 : 3rd order output intercept point

Ⅳ. Thermal Analysis

Maximum channel temperature of HEMTs on MMIC chip is an important factor in MMIC qualification related to the lifetime of the chip. According to the documents of JPL derating guideline, the maximum channel temperature should be limited to 125°C. It meansthat the device could be operated without the degradation of performance when the channel temperature of HEMT is maintained below 125°C in the operating environment.

We can find the MTF of 0.15um GaAs pHEMT is $1x10^{10}$ hours at the channel temperature of 125°C from the document provided by NGST.
The objective of the thermal analysis and testing is to find out the maximum channel temperature on our MMIC chips under the worst operating condition and confirm that the temperature does not exceed 125°C.

Because measuring the channel temperature of HEMT on MMIC chip is so difficult, it is a useful method that we derive the channel temperature under the worst operating environment from the thermal resistance which was calculated from the temperature of hot spot of HEMT obtained by using IR scan technique for the sample MMIC chip.

Another method to obtain the thermal resistance is to use a commercial analysis tool. We can do the thermal analysis to extract the temperature on the hot spot of HEMT at a specific condition and calculate the thermal resistance of the chip from the temperature.

To obtain more accurate thermal resistance, we performed both method of IR scan and thermal analysis using CAD software for four kinds of MMIC chips which are BLNA1A, WLNA1, DRIVER1, and MPA3G.

The thermal resistances obtained from both methods for each MMIC are very close to each other. However, we used the thermal resistances calculated from numerical analysis to overcome the resolution problems of IR scan results.

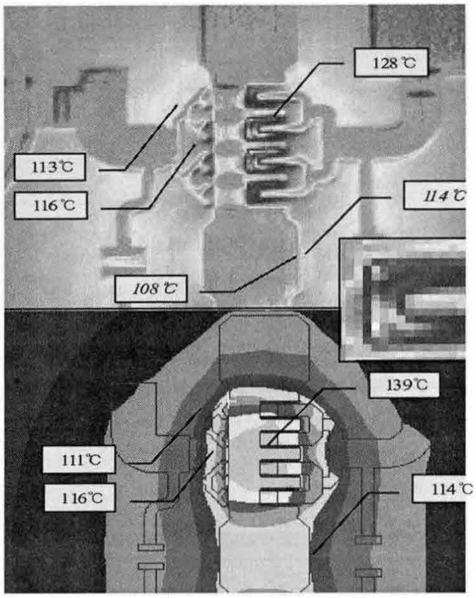

Figure 2. Results of IR scan and thermal analysis for MPA3G MMIC

Figure 2 shows the results of IR scan and thermal analysis for the MPA3G MMIC with the highest power consumption of our developed MMICs. The condition for IR scan and thermal analysis is identical and the base plate temperature is 80°C and the carrier metal to attach MMIC chip is Kovar.

Actually, we use Molybdemum as carrier metal for amplifier MMICs and the thermal resistances for amplifier MMICs is analyzed to be decreased about 3°C/W.

Table 2. Maximum channel temperature of amplifier MMICs

MMIC	Channel Temp.	Equipment Temp.
BLNA1A	87°C	55C
WLNA1	91°C	55C
GLNA1	74°C	55C
KADRA1	85°C	55C
DRIVER1	108°C	55C
MPA3G	120°C	55C

The highest channel temperatures of amplifier MMICs developed for COMS at the worst environment is summarized in Table 2.

The channel temperature in Table 2 is calculated from the thermal resistances and the results of thermal analysis for the equipment. The highest operating temperatures of LNA, downconverter, upconverter, and channel amplifier are 55°C, respectively.

V. Qualification Test

Each MMIC chip fabricated has been done the on-wafer DC probe and RF probe test, and all kinds of MMICs have been achieved the yield more than 80%.

The die visual inspection with MIL-STD-883F Method 2010.11 has been followed for every MMIC chips which passed the on-wafer testing. In addition, SEM (Scanning Electron Microscope) inspection with MIL-STD-883F Method 2018.4has been done 19 samples of those fabricated MMIC chips to check the step coverage and quality of the metallization and passivation of GaAs devices. Figure 3 show a photograph taken in the SEM inspection for MPA3G.

Transistor (MAG X 550)

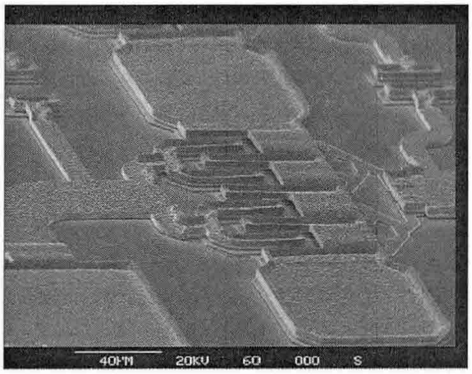

Figure 3. Photograph near HEMT region of MPA3G MMIC

We performed the QCI testing described Figure 1 for 12 kinds of MMICs fabricated.

For QCI testing, 12 test fixtures per each kind of MMICs were manufactured by using the technologies and procedure to assemble the module for COMS equipment.

Each amplifier MMIC chip was attached with a eutectic AuSn preform to a Molybdenum carrier plated with gold, and assembled into each test fixture.For mixer MMICs and attenuator MMIC, switch MMIC which have no characteristics of power dissipation, Kovar carriers were used.

The assembly drawing of the test fixture for MPA3G MMIC is shown in Figure 4, and additional components such as capacitors, EMI feedthrus, RF connectors, and substrates are needed to make the fixtures.

We drew out the test procedures and test specifications for each kind of MMIC considering the characteristics of test fixture. Every test fixture manufactured has been conducted the initial electrical performance tests for the primary parameters described Table 1.

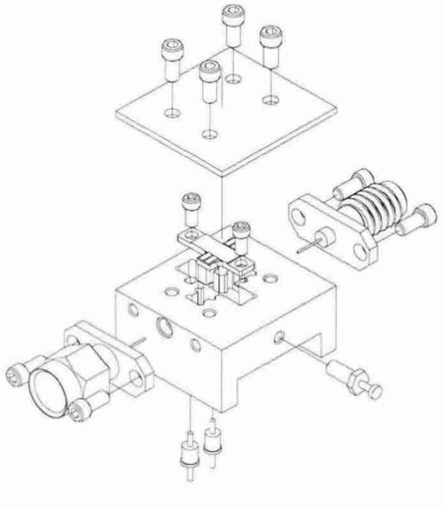

Figure 4. Assembly drawing of test fixture for MPA3G

After the initial test, all of those test fixtures were put in the thermal chamber during 100 times of temperature cycling from -65°C to +150°C. This test is used to detect flaws or weak points in the die attach, wire bonds, and packaging materials that would normally result in early failures. Following the temperature cycling, electrical performances were again measured.

The burn-in step was conducted under DC bias only for HEMT MMICs, and RF power drivingfor mixer MMICs and multiplier MMICs at the fixture temperature of 125°C for 240 hours. And then 3rd electrical performance tests were performed.

Those test fixtures were then subjected to a 1000-hour, accelerated steady-state life test under the same DC bias and RF power driving condition as the burn-in step. Following the steady-state life test, final electrical performance tests have been done.

The following failure criteria are applied between QCI testing steps.

1) A+/- 10% change in product operating current for amplifiers and multipliers

2) A +/- 1dB change in conversion loss from prior electrical test for mixers, multipliers, attenuator, and switch

3) A +/- 1dB change in gain from the prior electrical test for amplifiers

4) A +/- 0.5dB change in noise figure from the prior electrical test for Low Noise amplifiers

5) And/or a +/- 1dB change in P1dB from prior electrical test for medium power amplifiers

The results from QCI testing was summarized and all of test fixtures passed the temperature cycling test, the burn-in test, and the life test without any violation of the above failure criteria. Figure 5 shows the NF test results after the 240-hours burn-in test and Figure 6 shows the NF test results after the 1000-hours life test for the 30GHz LNA MMICs. From those graphs, we can expect that the MMIC will survive to the mission life of 12 years.

Ⅵ. Conclusions

Every component to be usedfor space applications must be space-qualified to guarantee that those components could be operated without trouble for their long life time.

We have developed 12 kinds of MMICs for COMS active equipment with 0.15um GaAs pHEMT process of NGST foundry which is a space-qualified process and has many experiences in the development of space products during past decades.

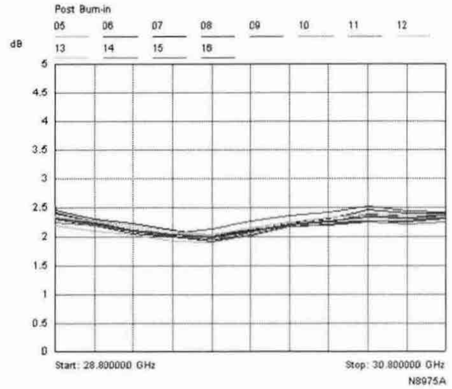

Figure 5. NF Test results after 240-hours Burn-in

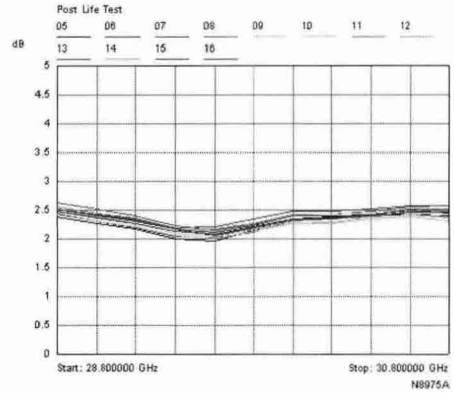

Figure 6. NF Test results after 1000-hours Life test

We conducted the MMIC qualification procedure except for the qualification related to fabrication process. We performedthe wafer-level lot acceptance test, the visual inspection, and QCI testing including accelerated steady-state life test. Our developed MMICs have been qualified for space application because all MMICs met the performance and qualification requirements.

We are currently manufacturing flight equipment with those developed MMICs and the satellite integrated with those equipments will be launched in 2008.

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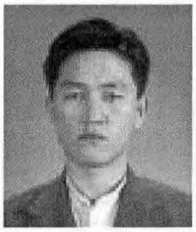

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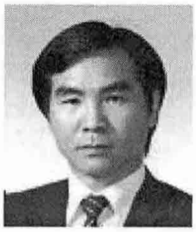

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