Development of a Receiver Downconverter Module for Ka-band Satellite Payload

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Abstract ---- **This paper describes the design and the test results of the receiver-downconverter module for a Ka-band Satellite Payload. The developed module has the low noise amplification in front stage and frequency down conversion which translates from 30.6 GHz ~ 31.0 GHz to 20.8 GHz ~ 21.2 GHz.. It has been fabricated and tested by the qualified satellite component manufacturing process and it shows the best performance of the receiver-downconverter modules operating at Ka-band frequency up to date. The module has the performance of 1.9 dB of NF, 55 dB of Gain, and 57dBc of C/I3 for the two-tone signals of –59dBm input power, respectively, at ambient temperature. It is a small and light module with the size of 93mm X 84mm X 26mm and the weight of 240g.**

I. Introduction

Recently, the demand on the development of the millimeter wave components increases for the broadband communication service. The receiver is a important components placed in the front stage of the communication system. Especially, it is one of important components for the system performance of the sensitivity in the satellite transponder payload.

A Ka-band receiver-downconverter module has been developed to be used in a communication satellite payload. The module has been fabricated, assembled, and then tested according to the space-qualified process and procedure in the development step of the engineering qualification model (EQM). The developed module has the performance of 1.9dB of NF at room temperature and 2.3dB of NF at the highest operating temperature of 65□C, which shows the best performance of the receiver-downconverter module operating at Ka-band frequency up to date. The module has the function of the temperature compensation for the gain performance. The module would be assembled with a local oscillator module and a DC-DC converter module to make up the ka-band receiver downconverter equipment.

II. Design

The main performance requirements of the receiver-downconverter module to be developed are summarized in Table 1. The module should be operated over the temperature range of -15□C ~ +65□C and required to have noise figure(NF) performance of less than 2.3dB over the temperature range and C/I3 of more than 56dBc, and gain of 55dB 1dB over the operating frequency range at ambient temperature.

Table 1 Performance Requirement of the Ka-band Receiver-Downconverter

Parameter	Requirement
Operating Frequency (GHz)	30.6 ~ 31.0GHz(Up Link)
	20.8 ~ 21.2GHz(Down Link)
Input Power	~ -56dBm
Gain	55 ± 1 dB
Gain Flatness	0.6dB/100MHz
	1.5/400MHz
Gain Slope	0.02dB/MHz
Noise Figure	2.3dB@65°C
Noise Figure Variation	0.1dB/10°C
Group Delay Variation	1ns P-P/100MHz
Group Delay Ripple	0.2ns P-P/any channel
Phase Shift Variation	2.0°(–76~-56dBm input)
Amplitude Linearity	-56dBc
AM/PM Conversion	0.1°/dB(– 76~-56dBm input)
Inband Spurious	-103dBm /Any 4kHz
	-98dBm / Any 1MHz
Out of band Spurious	- 64dBm Any 4kHz
	-30dBc / LO 2nd Harmonic
Input VSWR	1.25:1
Output VSWR	1.35:1
Operating Temperature	-15~65°C

In the design of the module, amplifiers had been selected to consider the NF and the amplitude linearity performance requirements. The filters, also, had been designed to comply with the out-of-band spurious requirements. An attenuator had been used to control the overall gain and the gain compensation for the temperature variation. Several isolators had been put between sub-components to improve the impedance mismatching. The designed block diagram is shown as Fig. 1.

This module must be connected to WR-28 waveguide at the input port and WR-51 waveguide at the output port.

As shown in Fig. 1, the receiver downconverter module is composed of a low noise amplifier block, a mixer block driven from a local oscillator module, IF

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amplifier block, and a DC block. The low noise amplifier block consists of a waveguide isolator, a waveguide-to-microstrip transition, a two –stage single-ended LNA amplifier and a two-stage balanced amplifier. The mixer block consists of a Ka-band drop-in isolator, an image rejection filter, a mixer, K-band drop-in isolator, and a spurious rejection filter. IF amplifier block consists of two of a two-stage balanced amplifier, a balanced HEMT attenuator, a two-stage balanced amplifier with medium power performance, a K-band drop-in isolator and a microstrip-to-waveguide transistion. The DC block consists of a 9-pin D-sub connector, a DC regulation circuit, LNA bias circuit, IFAMP bias CKT, and temperature compensation circuit.

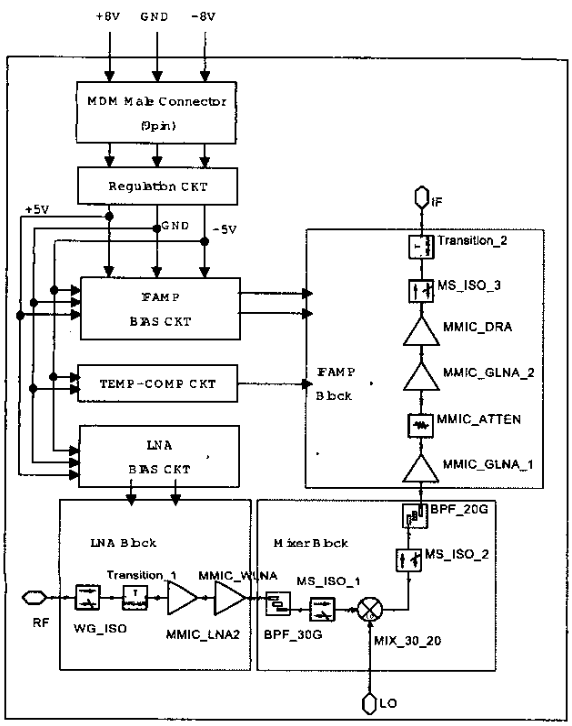

Fig. 1. Block Diagram of the Ka-band Receiver-Downconverter Module

LNA Block

The waveguide isolator has insertion loss of 0.1dB, isolation of 30dB, and return loss of 30dB. The waveguide-to-microstrip transition had been realized with insertion loss of less than 0.3dB that should be tuned additionally to improve the NF performance of the receiver downconverter module [1].

The 1st LNA and the 2nd LNA are MMIC chips fabricated in 0.15um GaAs PHEMT process. The 1st LNA has a single-ended structure, NF of less than 1.7dB and gain of more than 17dB at the operating frequency range. Fig. 2 shows the measured data of the chip. The 2nd LNA has balanced structure and NF of less than 2.5dB, gain of more than 17dB, and return loss about 20dB at its input and output port.

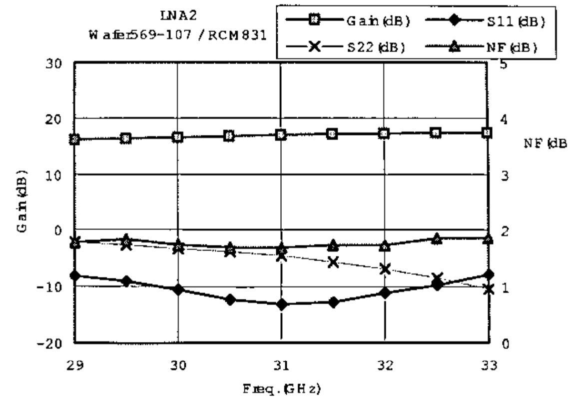

Fig. 2. Test Result of the Ka-band LNA MMIC

Mixer Block

Drop-in isolators for Ka-band and K-band have insertion loss of less than 0.8dB and isolation of more than 20dB in the operating frequency range.

The image rejection filter and the spurious rejection filter had been fabricated on 10mil-thick Alumina substrate using a thin-film technology. The image rejection filter has insertion loss of about 1dB in the pass band and rejection of more than 50dB at 21GHz. The spurious rejection filter had been designed to decrease the 2nd LO signal of 19.6GHz and has insertion loss of about 2dB in the pass band and rejection of about 40dB at the 2nd LO frequency. Fig. 3 shows the simulation result of the spurious rejection filter.

The mixer is a MMIC chip fabricated in a 0.15um GaAs process and has a doubly balanced diode mixer structure. It has the conversion loss of about 8dB and the isolation of more than 20dB between each port.[2]

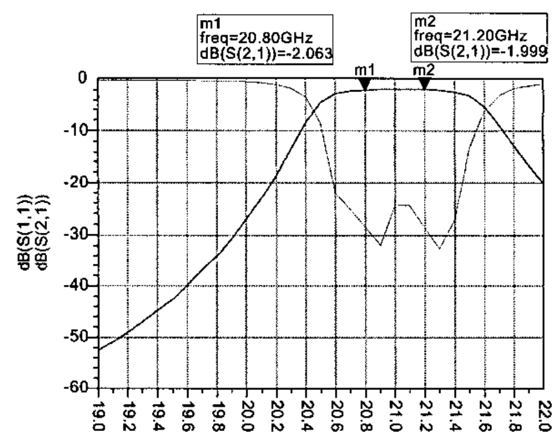

Fig. 3. Simulation result of the spurious rejection filter

IFAMP Block

Amplifiers and attenuator in the IFAMP block are MMIC chips fabricated in a 0.15um GaAs PHEMT process. The 1st and the 2nd amplifiers are the same amplifier operating at 20GHz frequency band and it has NF of less than 1.6dB and gain of more than 17dB in the operating frequency range. It is a two-stage amplifier with a balanced structure.[3]

The 3rd amplifier has a medium power output performance of 23dBm-P1dB to meet the IMD requirement of the module. Its gain is about 16dB and the return loss is about 20dB.[4]

In the IFAMP block, a variable attenuator MMIC chips has been used to control the entire gain of the module and compensate the gain variation caused by the temperature variation. It has a balanced structure composed of four HEMT which should be controlled by gate voltage. Its controllable attenuation range is 2dB to 32dB. [4]

The microstrip-to-waveguide transition designed for output connection of the module has insertion loss of 0.3dB and return loss more than 20dB in a test fixture manufactured to measure the performance.

DC Block

DC regulation circuit converts the primary DC input of +8V and –8V to the output of +5V and –5V with the circuit for pre-injection of negative voltage and DC regulation about 0.3% load regulation performance.

LNA bias circuit and IFAMP bias circuit provide DC bias for the amplifiers in the LNA Block and IFAMP Block, respectively.

Temperature compensation circuit has been designed to supply DC bias to the attenuator MMIC chips to meet the module gain requirement at room temperature and to compensate the gain variation over the temperature range.

The board for the CKT's had been fabricated using thick-film technology on 25mil-thcik Alumina substrate and the discrete components has been assembled on the substrates with soldering technology.

Performance Analysis

The analysis results of the module related NF and IMD are summarized in Table 2. The NF of about 2.2dB and C/I3 of about 58dBc would be obtained without an additional tuning. To comply with the NF value of 2.3dB at 65°C, additional tuning should be needed in the front area of the module because the NF value would be increased by 0.4dB according to temperature variation from 25°C to 65°C. The other performance requirements would be satisfied by considering the gain performances of amplifiers and the performance of the sub-components.

Table 2. Performance analysis results

Block	N.F. (dB)	Gain (dB)	Cum. N.F. (dB)	Cum. Gain (dB)	Signal Level (dBm)	IMD (dBc)
Input		0		0	-59	
Isolator	0.1	-0.1	0.1	-0.1	-59.1	-318
Transition	0.3	-0.3	0.4	-0.4	-59.4	-313
LNA2	1.7	17	2.1	16.6	-42.4	-105
W LNA	2.5	17	2.15	33.6	-25.4	-76.5
Filter30G	1	-1	2.15	32.6	-26.4	-76.5
Isolator	0.9	-0.9	2.15	31.7	-27.3	-76.5
Mixer	8	-8	2.16	23.7	-35.3	-76.3
Isolator	0.8	-0.8	2.16	22.9	-36.1	-76.3
Filter20G	2	-2	2.17	20.9	-38.1	-76.3
G LNA	1.6	17	2.18	37.9	-21.1	-68
Attenuater	14.8	-14.8	2.19	23.1	-35.9	-67.9
G LNA	1.6	17	2.19	40.1	-18.9	-61.8
DRA	5	16	2.19	56.1	-2.9	-57.6
Isolator	0.8	-0.8	2.19	55.3	-3.7	-57.6
Transition	0.3	-0.3	2.19	55	-4	-57.6

III. Manufacturing and Test Results

Each MMIC chip used in the Ka-band receiver-downconverter module has been assembled on carrier metal before fixed in the module. The carrier shape and housing shape have been designed with small size to avoid housing resonance. The lowest resonant frequency simulated using structure analysis software was about 35GHz.

In the housing design, metal wall has been made for isolation of the side to assemble RF components from the side to the assembled DC components and the DC connection was provided through EMI filters.

Every components used in manufacturing the module have been qualified to be applicable in space environment. The assembly process and performance test was accomplished on the basis of the rules related to the production of space components.

An Additional tuning has been done to improve the NF performance of the module on the substrate in the input waveguide-to-microstrip transition at the alignment test step. It has produced the effect of decreasing the NF value by 0.2dB. In addition, the improvement of NF value of 0.1dB has been obtained by tuning DC bias for the 1st LNA amplifier. The NF performance measured over temperature range is shown in Fig. 5 and the NF value at 65°C was measured with about 2.3dB.

The module gain at room temperature is 55.0~55.3dB and the gain variation over the temperature range of -15°C to +65°C was measured with 1.5dB. The test result for the gain performance is shown in Fig. 6.

The IMD performance of 57dBc was measured and the value meets the requirement value of 56dBc as in the Fig. 7. The 2nd LO rejection of 33dBc was achieved as in the Fig. 8.

The other performances have been measured to comply with the requirement value in Table 1.

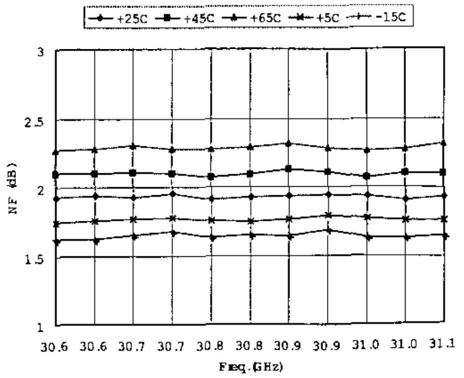

Fig. 5. NF performance over temperature range

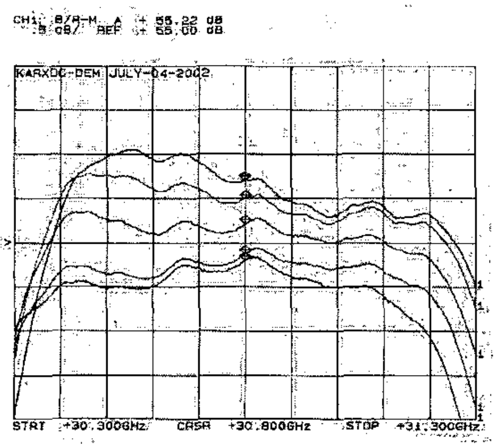

Fig. 6. Gain performance over temperature range

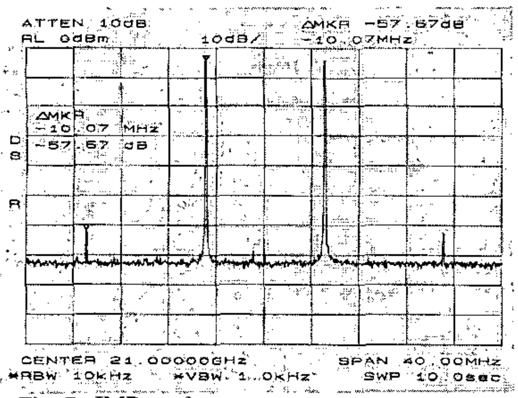

Fig. 7. IMD performance over temperature range

IV. CONCLUSIONS

In this paper, the design, manufacturing, and test results of a Ka-band receiver-downconverter for satellite transponder have been described. The module has been designed with MMIC amplifiers, a MMIC attenuator, and a MMIC mixer. The developed module has NF value of 2.3dB at 65□C, 55dB gain at room temperature, and IMD performance of more than 57dBc. The results show the best performance of the receiver-downconverter module operating at Ka-band frequency up to date. It's a box module with the weight of 240g and the size of 93mmX84mmX26mm.

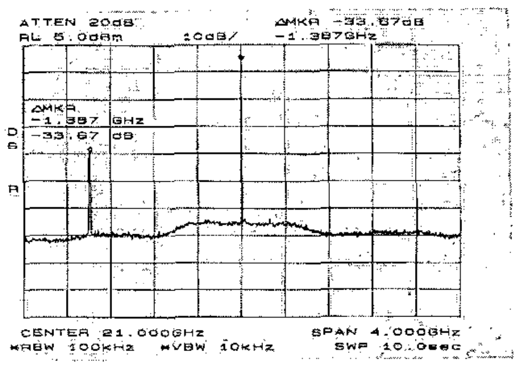

Fig. 8. 2[nd] LO rejection performance

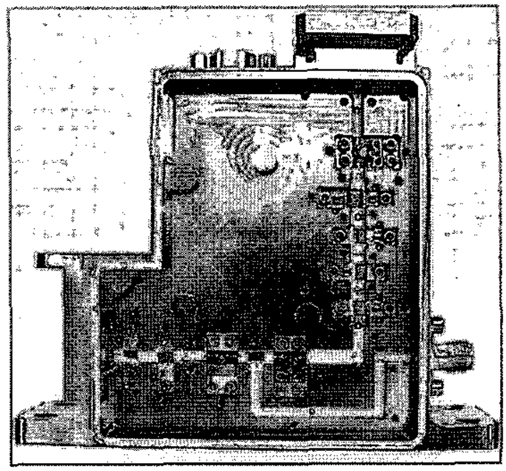

Fig. 9. Picture of the Ka-band Receiver-Downconverter Module

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