RECEIVING PART OF SATELLITE BORNE MILLIMETER WAVE TRANSPONDER

Kenichi Tsukamoto and Risao Hayashi
Radio Research Laboratories — Ministry of Posts and Telecommunications
2—1, Nukui-Kitamachi 4—chome,
Koganei-shi, Tokyo, 184 Japan

Abstract

Engineering models for the receiving part of the satellite borne millimeter wave transponder were developed, and sufficient results were obtained in their overall characteristics for application to the Japanese Experimental Communication Satellite (ECS).

This paper presents the development process and characteristics of these engineering models.

Summary

Introduction

As one of the most important national space programs, the Experimental Communication Satellite (ECS) will be launched into the geostationary orbit (about 145° E) from Tanegashima launching site in 1978 by means of a N-type rocket under development in Japan.

The important mission objectives of this satellite program are to gain the technology for establishing a stationary orbit spin-stabilized satellite system and to conduct various satellite telecommunication and millimeter wave propagation experiments.

The satellite has two communication transponders, C-band (6/4 GHz) and millimeter wave (30/35 GHz or 35/32 GHz), and the latter is a double frequency conversion type whose intermediate frequency is chosen as 4 GHz with the purpose of making cross-strap circuit configurations between two transponders.

The Radio Research Laboratories has taken charge of the development of the millimeter wave transponder, and several engineering models of the receiving part have been made. After some preliminary investigations on bread board models, three types of engineering models were manufactured as the first step to the frequency scheme of 30.2 GHz and 3.95 GHz for input and intermediate frequencies respectively.

The first is the crystal local oscillator type where a crystal-controlled oscillator signal (120 MHz) is frequency-multiplied up to 26 GHz and applied to the receiving mixer. The second is the Gunn local oscillator type where the local signal is obtained directly from a Gunn diode oscillator.

The third is the parametric amplifier type (PA type) where a PA operating at room temperature is used as the low noise pre-IF amplifier.

In addition, a millimeter wave parametric amplifier was manufactured as a RF pre-amplifier.

The former two engineering models—crystal local type and Gunn local type—were manufactured with prospective overall characteristics, and manufactured again with more strict specifications.

Input, local and intermediate frequencies of these final step engineering models are 34.7 GHz, 30.75 GHz and 3.95 GHz respectively with available communication bandwidth of about 300 MHz. Their overall gain is about 25 dB and noise figure is less than 12.5 dB. Requirements for DC power consumption of less than 4.5W and for total weight of less than 2.5Kg were satisfied in these types.

With regard to the PA type, a light weight and small size engineering model was developed with fairly excellent low noise characteristics, but the requirements for DC power consumption and gain stability could not be met.

In the following sections, the PA type as well as the other two types will be discussed, because the parametric amplifier will become an important satellite borne device in future.

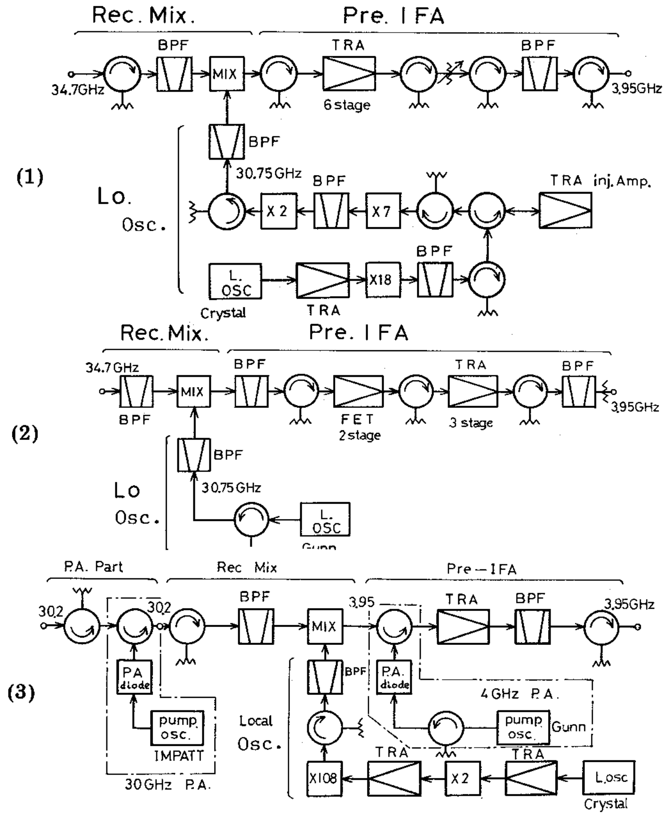


Figure 1. Block diagrams of three types of engineering model: (1) Crystal local type, (2) Gunn local type, (3) Parametric amplifier type (PA type) and 30 GHz PA

Composition

Figure 1 shows the block diagrams of the crystal local type, the Gunn local type and the PA type respectively.

Crystal local type: A fifth overtone crystal oscillator signal (122 MHz) is frequency-multiplied up to 30.75 GHz and fed to the receiving mixer. The local signal is power-amplified in the 2 GHz stage by means of an injection-locked transistor amplifier.

Bipolar transistors are used in the pre-IFA. The appearance of this type is shown in photo 1-(1).

Gunn local type: 30.75 GHz local signal is directly obtained by a Gunn diode oscillator which is frequency-stablized by a high Q cavity loading, and fed to the receiving mixer. Low noise FETs and bipolar transistors are used in the pre-IFA.

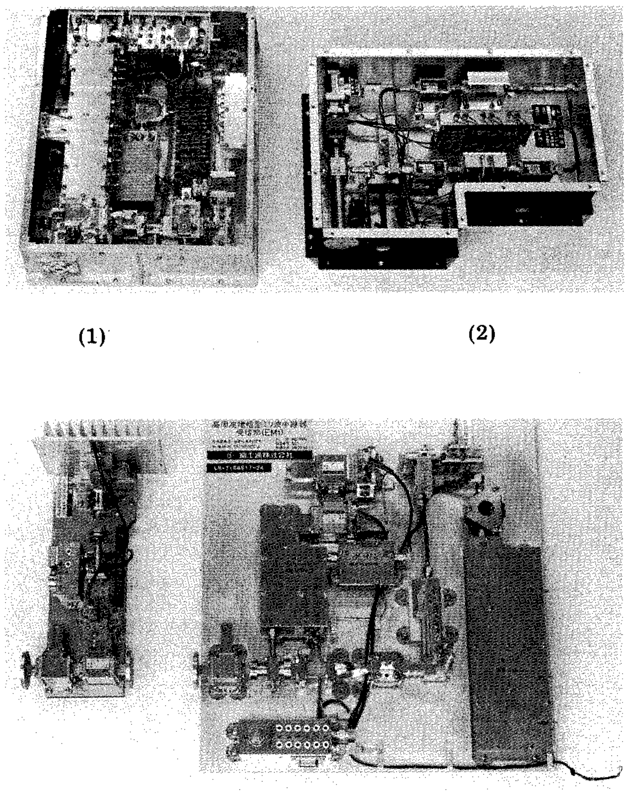
The appearance of this type is shown in photo 1-(2).

PA type: A non-degenerated parametric amplifier with 20.16 GHz pumping a signal generated by a Gunn diode oscillator is used at room temperature as the 4 GHz pre-IFA.

The local signal for the down converter is produced by almost the same circuit configuration as that of the crystal local type except the injection-lock amplifier.

The appearances of this type and the 30 GHz PA are shown in photos 1-(3) and 1-(4).

From the view point of realizing compact size and light weight, the single ended mixer, with the construction of band pass filters direct coupling in both of the input and local oscillator sides, is used in the down converter in each of these types.



(1) (2)

(4) (3)

Photo 1. Appearances of three types of engineering models: (1) Crystal local type, (2) Gunn local type, (3) Parametric amplifier type, (4) 30 GHz PA.

<u>Characteristics</u>

Table 1 shows the summary of characteristics of the above three types of engineering models. The frequency stability of the Gunn local oscillator is about $1.5 \sim 3 \times 10^{-5}$ in ambient temperature ranging from -10° C to 55° C. This high stability is obtained by a high Q cavity ($Q_0 \cong 1200$) loading.

The cavity for frequency-adjustment is made of brass, and the difference in their coefficients of thermal expansion between these two metals is utilized to compensate the resonance frequency fluctuations caused by ambient temperature variations.

The noise figure of the PA type has been improved to as low as 6.5 dB with the 30 GHz PA attached as indicated in Figure 1-(1), but the power consumption is rather high as compared with the other two types.

The power is almost consumed in the Gunn diode oscillator for pumping in the PA type.

Figure 2 shows the characteristics of gain and noise figure vs frequency for the finally manufactured two types. Two sets of engineering models (No. 1 and No. 2) were made in the same manufacturing process for each type to investigate how identical characteristics could be obtained.

As is evident from Figure 2, more similar characteristics could be obtained in the crystal local type as compared with those of the Gunn local type, but the noise figure of latter type (11.1 dB) is better by about 1.5 dB than that of the former type.

In the Gunn local type, a good conversion loss (5.6 dB) and a good noise figure of pre-IFA (4.25 dB) were obtained by using a specially developed GaAs mixer diode and Schottky barrier gate FETs (f_c = 50 GHz, G_{max} = 19.7 dB at 4 GHz, NF = 2.9 dB) respectively.

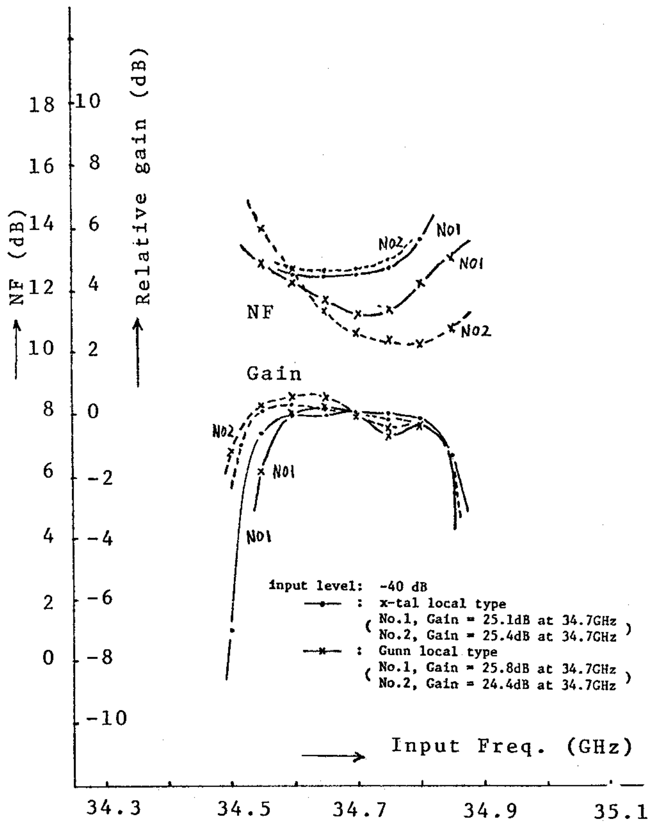


Figure 2. Characteristics of gain and noise figure (NF) vs Freq. at room temperature.

		Crystal LO. Type 1)	Gunn LO Type 2)	P.A. Type 5)
Recv. freq. (center)	(GHz)	34.7	34.7	30.2
IF freq. (center)	(GHz)	3.95	3.95	3.95
Lo. OSC. freq.	(GHz)	30.75	30.75	26.25
freq. stability 3)		$1. \times 10^{-5}$	$1.5 – 3 \times 10^{-5}$	$1. \times 10^{-5}$
Lo. OSC. output	(dBm)	5	9	7
Gain	(dB)	25.4	25.8	30
Gain linearity 4)	(dBm)	-25	-35	-34
Band width	(MHz)	326	335	300
Noise Figure	(dB)	12.55	11.1	6.5
Input VSWR		1.12	1.28	1.1
Output VSWR		1.04	1.21	1.07
Required D.C. power	(W)	4.47	3.6	21.3
Weight	(kgr)	2.2	2.35	2.5

1) 122 MHz crystal osc. and freq. multiplication
2) Gunn osc. with high Q cavity
3) -10°C–+55°C
4) 1 dB compression input level
5) 30 GHz PA is attached to PA type.

Table 1. Characteristics of mm-wave transponder (Receiving part).

The DC consumption power and weight of the Gunn local oscillator circuit are 1.2W and 210gr respectively and they are very small as compared with those of crystal local type (2.9W, 600 gr).

The characteristics of the parametric amplifiers are shown in Table 2. Since the characteristics of the parametric amplifier are susceptible to influence of pumping level and its frequency, it is necessary to stabilize the pumping source sufficiently, and their circuits become unavoidably complicated and heavy. In addition, the pumping source of parametric amplifier works usually at rather low efficiency because very high frequency is required for pumping (for example, 1~4% at 75 GHz IMPATT).

Therefore, it is necessary to develop further high efficient pumping sources before parametric amplifiers become actually applicable to satellite borne millimeter wave transponders.

		4GHz P.A.	30GHz P.A.
Signal freq.	(GHz)	3.95	30.2
Pump. freq.	(GHz)	20.16	75.12
Idling freq.	(GHz)	16.21	44.92
Gain	(dB)	12	9
Band Width (3dB)	(MHz)	360	600
Noise Figure	(dB)	2.2	3.6
Linearity 1)	(dBm)	-25	-4
Circuit type			
1) P.A.		non-degenerated-MIC	non-degenerated-wave guide
2) Pump source		free running 2)	free running 3)
Weight	(gr)	470 4)	479.6 5)
Req. D.C. power	(W)	10.43	8.3
Device elements			
1) Varactor		VAP103 N19 (Varian)	DVE 6347H (Alpha varactor)
2) Pump source		GD518D (NEC-Gunn)	4405H (Hughes-IMPATT)

1) 1 dB compression input level.
2) PIN diode control ALC (output power variation 0.4 dbm/50°C, freq. stability $2 \times 10^{-3}/20^{\circ}C$)
3) Freq. stability $2.7 \times 10^{-3}/20^{\circ}C$
4) Pumping cct 278.3 gr.
5) Pumping cct 235.0 gr.

Table 2. Characteristics of parametric amplifiers

The noise figure of parametric amplifier pumped by the IMPATT oscillator (Qext—100) was measured to be nearly equal to that of klystron oscillator. In limited test results, it could be said that the noise of the pumping source would not so much affect the noise figure of the parametric amplifier.

Environmental Tests

The summary of the environmental test results are shown in Table 3. In addition to the thermal vacuum and vibration tests, the finally manufactured two types of engineering models have passed safely the storage tests (6 hours at -30°C and at 60°C) and humidity tests (24 hours at 92% relative humidity at room temperature).

Conclusion

Two types of engineering models for receiving part, the crystal local type and Gunn local type, have been completed with fairly satisfactory characteristics, and these two types have successfully passed the specified environmental tests. Any unexpected change was not recognized throughout these tests in their electrical and mechanical characteristics.

Acknowledgement

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TEST ITEMS				CRYSTAL LOCAL NO. 1	CRYSTAL LOCAL NO. 2	GUNN LOCAL NO. 1	GUNN LOCAL NO. 2
GAIN VARIATION (dB)	NON-ACTIVE T	VIBRATION	SINE	~0.1	~0	~0.1	~0.6
			RANDUM	~0.1	~0.1	~0.3	~0
	ACTIVE T	THERMAL		1.3	1.0	1.6	1.0
		VACUUM		~0.1	~0.1	~0.1	~0.1
NF VARIATION (dB)	NON-ACTIVE T	VIBRATION	SINE	~0.15	~0.05	~0.4	~0.3
			RANDUM	~0.1	~0.05	~0.1	~0.5
	ACTIVE T	THERMAL		1.5	1.3	1.7	1.1
		VACUUM		~0.05	~0.05	~0.15	~0.2
LOCAL FREQUENCY FLUCTUATION ($\times 10^{-5}$)	NON-ACTIVE T	VIBRATION	SINE	–	8.5×10^{-2}	3.2	1.9
			RANDUM.	–	10^{-3}	3.21	1.8
	ACTIVE T	THERMAL		8.7×10^{-1}	1.1	3	1.5
		VACUUM		1.4×10^{-1}	2.8×10^{-1}	1.3	0.35
CONSUMPTION POWER VARIATION (W)	NON-ACTIVE T	VIBRATION	SINE	–	–	–	–
			RANDUM	–	–	–	–
	ACTIVE T	THERMAL		~0.7	~0.6	~0.4	~0.5
		VACUUM					

TEST LEVEL DIAGRAM

Table 3. Environmental Test Results