MMIC Progress in Japan

Masayoshi Aikawa, Hiroyo Ogawa and Takayuki Sugeta

NTT Radio Communication Systems Laboratories
Nippon Telegraph and Telephone Corporation
Yokosuka-shi, Kanagawa, Japan

ABSTRUCT

In recent years, GaAs monolithic microwave integrated circuits (MMICs) are being actively developed in Japan, and the technology and performance levels are improving at a rapid pace. This article provides an overview of present technological trends in the development of practical GaAs MMICs in Japan.

INTRODUCTION

Monolithic Microwave Integrated Circuits (MMICs) have a number of inherent advantages including small size, light weight, high reliability as well as low cost due to mass producibility. In Japan, MMICs are being developed by several companies with rapid progress in processing based on a background of satisfactory yield and circuit design techniques. There are many potential applications for GaAs MMICs in communication systems and consumer equipment, such as receivers for direct broadcasting satellites (DBS). In this paper, the status of GaAs MMICs technological trends and several current developments in Japan will be described, mainly from the point of view of circuit technology and applications.

RESEARCH AND DEVELOPMENT TRENDS IN JAPAN

Several commercial applications for GaAs MMICs are now envisioned because of recent advances in MMIC manufacturing technologies and circuit design techniques. The purpose of research and development in Japan is mainly at commercial applications, is contrast to the MIMIC Program for military use in the USA. MMIC development is being promoted independently by several companies. A few national R&D projects partly related to MMICs, however, are also active at the present. The major projects are as follows:

(1) Scientific Computer Systems (1982-1990): This project was initiated by the Ministry of International Trade and Industry (MITI) in order to develop the basic technology for high-speed scientific computer systems. The developmnet of GaAs ICs and HEMT devices is pertinant to MMICs.

(2) Future Electron Devices (1981-): This project is part of the research and development project to develop basic techonologies for future industries initiated by MITI. Superlattice devices (1981-1990), hardened ICs for extreme conditions (1981-1985), three-dimensional ICs (1981-1990) are related subjects.

In addition to these projects, several research laboratories of private companies, national laboratories and a couple universities are actively involved in researching devices and circuits as well as materials. In the communication area, NTT has recently developed 30-GHz-band fully implemented MMIC modules for satellite transponders for ETS-VI (Engineering Test Satellite VI), which Japan intends to launch in 1992. NTT has also developed a 26 GHz-band full MMIC receiver for radio systems, which has an uni-planar MMIC structure.

In the consumer area, MMIC low-noise receivers for DBS are being developed, where noise performance is especially important. These MMICs will be described in detail later.

MMIC Components

Low Noise Amplifier

Major electronics manufacturers are engaged in an effort to develop 12-GHz-band MMICs for use in Direct Broadcast Satellite (DBS) receivers. Table I summarizes some examples of low-noise amplifiers for DBS and other applications which have been reported over the past several years. NTT produced a 26-GHz-band low-noise amplifier using an uni-planar technology[1], which will be discussed in next section. The source inductance, which especially degrades the gain performance of FET amplifiers in high frequency bands,

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is reduced by the uni-planar structure. As the source inductance in the uni-planar amplifier is substntially less than that in the microstrip line based amplifier, the uni-planer amplifier is expected to have better RF performance than the microstrip amplifier. The measured noise figure of 3.6dB with a gain of 7.3dB at 26GHz is the best noise figure value for K-band LNAs ever reported. Mitsubishi has developed an extremely low-noise 12-GHz-band MMIC amplifier using HEMTs[2]. The HEMT used in the amplifier has a gate length of 0.5μm and shows a typical noise figure of 1.0dB at 12GHz. The results obtained in Ref.[2] show that HEMT MMICs are promising for low-noise amplification applications.

High Power Amplifier

A couple companies are developing high-power amplifiers operable at Ka-band for satellite communication system application, as shown in Table II. Mitsubishi proposed a new type of 1W power amplifier that operates at 28GHz[3]. The total gate width is 3.2mm and the amplifier delivered 1-dB compression power at 1.1W with a power gain of 4.0dB and a power added efficiency of 10.8% at 28GHz.

Non-linear Circuits

MMIC mixers developed in Japan are mainly associated with 12-GHz band DBS receivers. Table III summarizes some examples of non-linear circuits. NEC reported on a mixer/IF amplifier combination using a dual gate MESFET for DBS applications[4]. Toshiba has integrated Schottky barrier diodes into MMIC mixers[5]. Schottky barrier diode mixers have the advantage of no dc bias circuitry. NTT has been developing several non-linear circuits using the uni-planar technology[1]. These components have been successfully integrated into one module[6].

Frequency Divider

Table I Low-noise amplifiers developed in Japan.

Company	Frequency Band (GHz)	NF (dB)	Gain (dB)	Chip Size (mm)	Device	Year
NTT	22.5-26.5	4.5	10.0	2.2×1.1	MESFET	1986
NTT	18.5-20.5	3.5	3.5	2.0×0.8	MESFET	1986
NEC	20.5-22.2	6.2	7.0	2.75×1.45	MESFET	1981
NEC	11.7-12.7	2.8	16.0	0.9×1.5	MESFET	1983
Toshiba	11.7-12.2	2.8	6.5	1.5×1.5	MESFET	1983
Matsushita	11.7-12.2	2.4	19	1.65×1.3	HEMT	1989
Mitsubishi	11.7-12.2	1.7	15.0	2.3×1.7	HEMT	1988

Table II High-power amplifiers developed in Japan.

Company	Frequency (GHz)	Gain (dB)	1 dB Compression Power(dBm)	Gate Width (mm)	Year
Mitsubishi	28	4	30.4	3.2	1988
Hitachi	28	4	27	3.6	1989
Toshiba	28.5	4.2	28	2.4	1987

Table III Non-linear circuits developed in Japan.

Circuit	Company	Frequency (GHz)	Conversion Loss(dB)	NF (dB)	Year
Mixer	NEC	12	-3.3*	12	1983
	Toshiba	12	-3.5*	9	1983
	NTT	25	5	10	1988
	Matsushita	10.4~10.8	-4*	10.5	1986
Doubler	NTT	11.8	-2.9	—	1987
	NTT	25	2.1	—	1988
Up Converter	NTT	20	6.0	—	1985
VCO	NEC	10.8~10.9	10dBm**	—	1986
	NTT	12~14	-5dBm**	—	1987
	Fujitsu	19.6~19.8	-6dBm**	—	1988
	NTT	5.9~6.5	8~12dBm**	—	1988

* Including IF amplifier gain
** Output Power

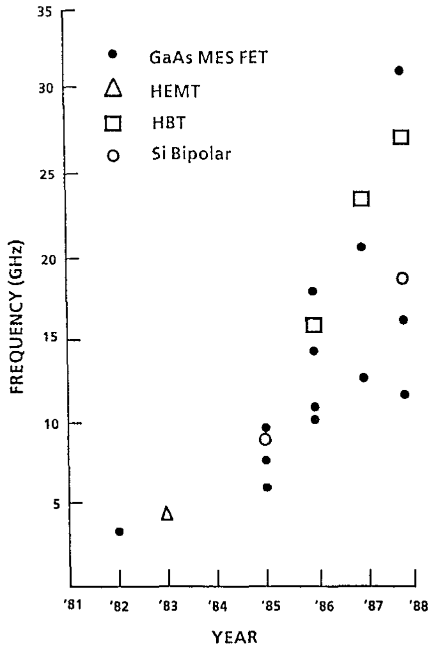

Fig.1. Performance of digital frequency dividers developed in Japan.

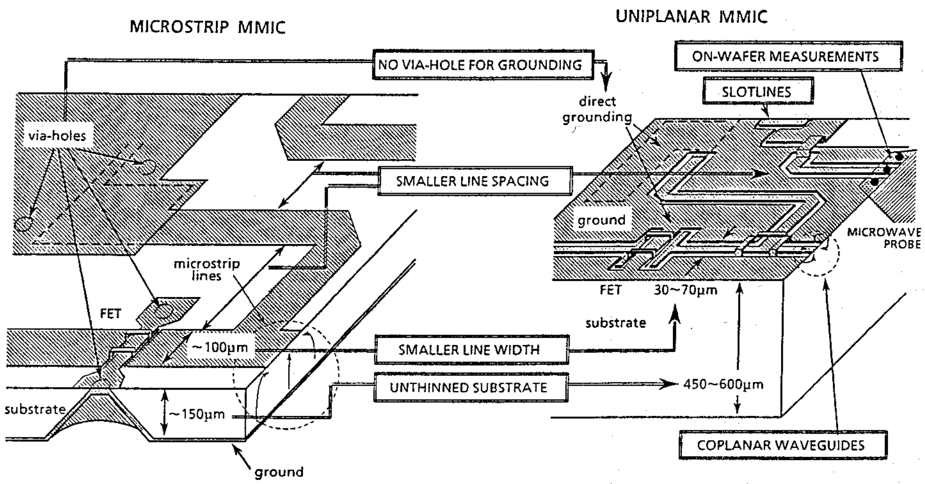

Fig.2. Comparison of microstrip MMIC and uni-planar MMIC.

Stable high frequency performance of local oscillators is required for microwave communication systems. The phase-locked loop (PLL) is a key technology for stabilizations the frequency. Many frequency dividers has been investigated based on various active devices. Figure 1 shows the operating frequency of some of these digital frequency dividers.

MMIC Circuit Technologys

Fundamental MMIC circuit elements are distributed / lumped elements and devices. The distributed elements consist of microsrip lines and coplanar waveguides/slotlines. Microstrip lines have been used as the main transmission line, because the characteristics of microstrip lines are well known and a number of discontinuity problems have been successfully overcome. So far, however, coplanar waveguides or slotlines fabricated on one side of the substrate have not generally been used for MMICs. Two new structures for MMICs have been proposed in Japan, namely, the uni-planar MMIC[1][7] and the Line Unified FET (LUFET) MMIC[8]. A comparison between the microstrip MMIC structure and that of the uni-planar MMIC is shown in Fig.2. Uni-planar MMICs employ coplanar waveguides and slotlines as the main transmission line. They utilize only the top surface of the substrate. The uni-planar circuit structure has the following advantages: (a) the simple balance/unbalance transition circuit can be obtained by a combination of the coplanar waveguide and the slotline. (b) no via-holes for grounding are needed to connect active devices with the ground conductor. (c) the smaller line width and the smaller transmission line spacing reduce the circuit size, and (d) RF performance is easily measured on a wafer.

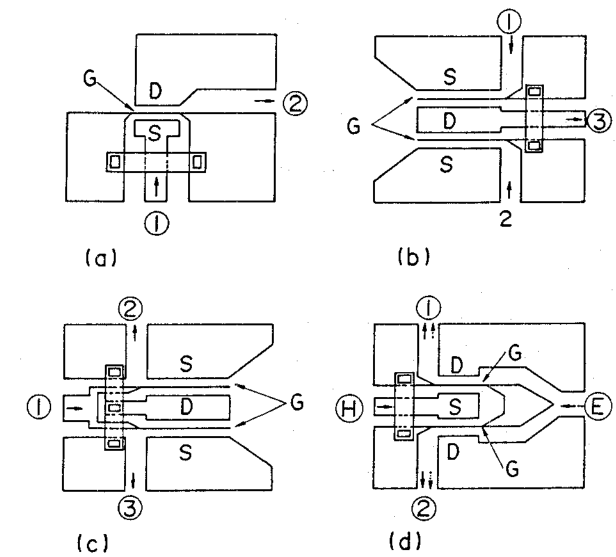

Fig.3. LUFET configurations. (a)Coplanar waveguide-to-slotline transition. (b)Power combiner. (c)Power divider. (d)Magic-T.

Table IV Line-Unified FET MMICs developed in Japan.

Circuit	Band width (GHz)	Loss (dB)	Size (mm)	Year
Magic-T	1-18	5 ± 1	0.3 × 0.5	1988
Divider	0.1-18	1 ± 1.5	1.0 × 1.1	1988
Combiner	4-12	2 ± 2	1.0 × 1.2	1988
Isolator	0.1-12	2.5 ± 1.5	0.8 × 0.8	1989
Mixer	4-12	2-5	0.9 × 1.5	1989
Amplifier	0.1-9	-6.5 ± 1.5	1.0 × 1.3	1988

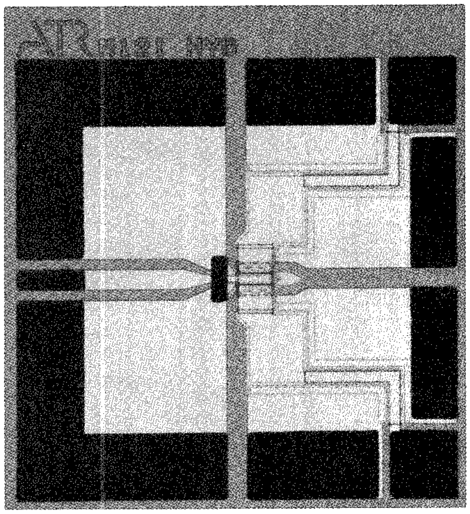

Fig.4. Photograph of LUFET magic-T.

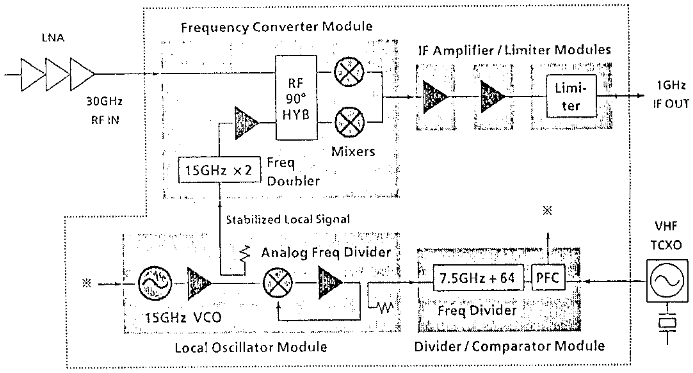

Fig.5. Block diagram of 30-GHz MMIC receiver.

Configurations of the Line-Unified FET MMICs proposed by ATR are shown in Fig.3. The LUFET MMIC has the following features : (a) the electrodes of FETs are unified coplanar waveguides or slotlines; (b) ultrawideband operation due to the absence of frequency-dependent distributed lines can be achieved; and (c) the coplanar waveguides and slotlines can be actively impedance matched with FETs when the FET gates or drains are used for the common electrode. In Fig.3, the electrode relationships among unified coplanar lines are established by airbridges connecting the electrode strips used for the common electrode. A photograph of LUFET MMIC (magic-T) is shown in Fig.4. Table IV summarizes the LUFET MMICs that has been developed in Japan.

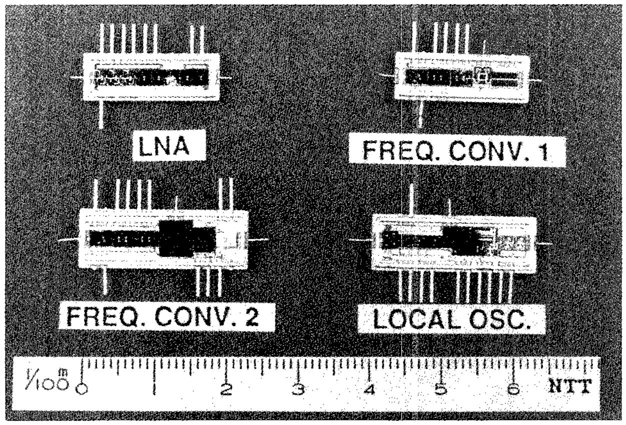

Fig.6(b). Photograph of 30-GHz MMIC module.

Table V Satellite transponder receiver performance.

RF Frequency	27.5~31GHz
I F Frequency	1045 ± 150MHz
Conversion Gain	73dB
LO Phase Noise*	< -80 dBc/Hz
AM/PM Conversion	< 1°/dB
Power Consumption	< 4.8W
Spurious Response	< -70dBm
Ambient Temperature	-10~ + 40°C

* Offset frequency is 1KHz

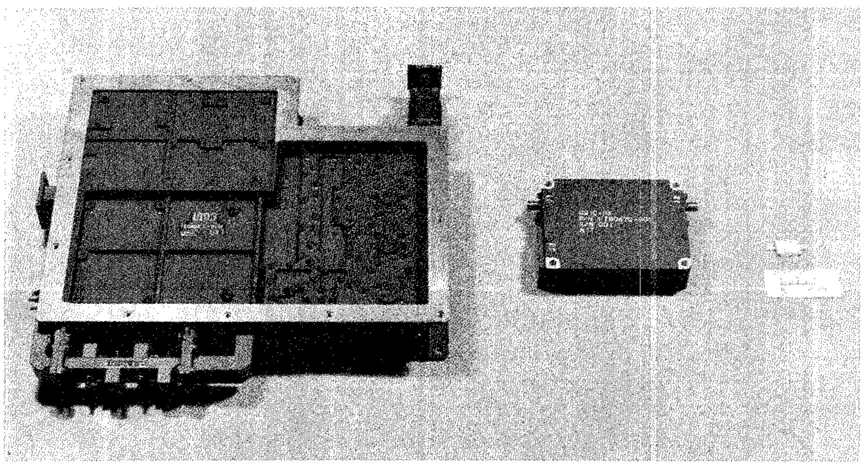

Fig.6(a). Comparison between MIC receiver and MMIC receiver.

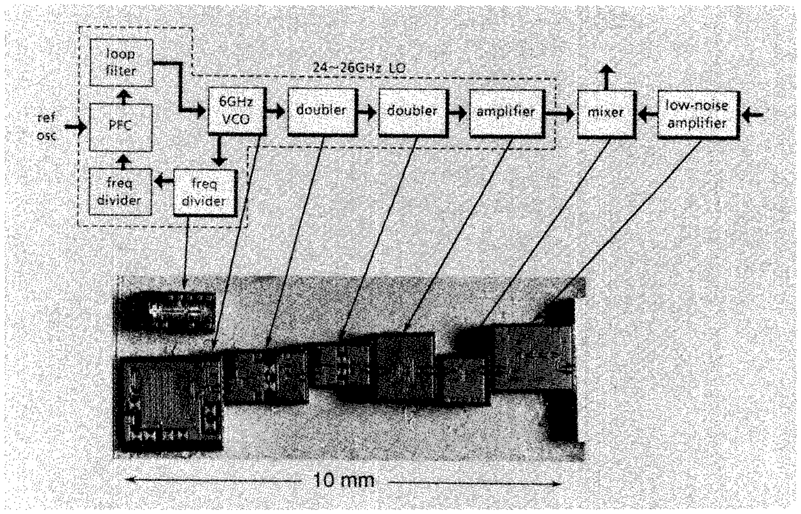

Fig.7. Block diagram of 26-GHz MMIC receiver and MMIC chips.

Table VI Uni-planar receiver performance.

RF Frequency	25~27GHz
LO Frequency	24~26GHz
Noise Figure	8dB
Conversion Gain	2dB
Total Circuit Area	11mm^2

MMIC Subsystems

30-GHz Satellite Transponders

NTT has developed the 30-GHz-band MMIC modules(low-noise amplifier, frequency converters and local oscillators) needed to construct a Ka-band full-MMIC satellite transponder[9]. Figure 5 shows the configuration of the MMIC receiver. Each module contains several MMIC chips in multi-chip form without any external elements or trimming board. An MMIC module includes several MMIC chips. Figure 6 shows photographs of MMIC modules and compares the dimensions of the receiver for CS-3 and ETS-VI satellites. Receiver performance is summarized in Table V.

26-GHz Uni-Planar MMIC Receiver

A fully MMIC 26-GHz-band receiver has been developed at NTT[6]. All monolithic circuits employ the uni-planar configuration described above. Block diagrams of the receiver and MMIC chips used in it are shown in Fig.7. The output frequency is phase-locked by a stable crystal oscillator using a phase-lock loop. The circuit size of each MMIC is reduced by using slotlines, spiral inductors and a closely spaced meander line. The performance of the receiver is summarized in Table VI. Assembled MMICs showed stable receiver performance without any adjustment or external tuning circuits.

12-GHz Broadcast Satellite Converter

Matsushita has developed a 12-GHz MMIC DBS converter[10]. A block diagram of the receiver is shown in Fig.8. A low-noise HEMT amplifier, a local oscillator stabilized by a dielectric resonator, and IF amplifiers are monolithically integrated. Table VII summarizes the performance of the receiver.

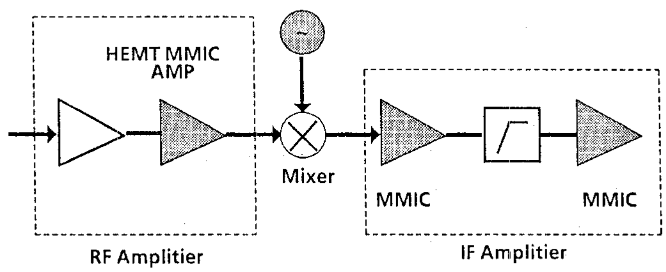

Fig.8. Block diagram of DBS converter.

Table VII DBS converter pereformance.

RF Frequency	11.7~12.2GH
LO Frequency	10.678GHz
NF	<1.35dB
Input VSWR	<2.2
Conversion Gain	55 ± 2.5dB
Image Band Isolation	>32dB

4-GHz One-Chip Frequency Converter

Fujitsu developed a one-chip frequency converter which operates at frequencies up to 4 GHz[11]. The chip integrates feedback amplifiers, a differential amplifier, a double-balanced mixer, a voltage-controlled oscillator, and an IF amplifier on a 1-mm^2 area.

CONCLUSION

This paper reviewed several Japanese national R&D projects related to MMIC development and recent progress in the development of MMICs by Japanese companies. From the technical information provided, it can be projected that (1) a MMIC DBS low-noise converter could be ready for production and available in 1-2 years. (2) MMIC modules (microstrip structure or uni-planar structure) which operate at high frequencies could be achieved in communication systems.

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REFERENCES

[1] M.Muraguchi,et.al., "Uniplanar MMICs and their applications," *IEEE monolithic Circuits Symp. Dig.,* pp.75-77,May 1988.

[2] N.Ayaki, et.al., "A 12GHz-band monolithic HEMT low-noise amplifier," *IEEE GaAs IC Symp Tech Dig.,* pp.105-108,Nov.1988.

[3] M.Kobiki, et.al., "A Ka-band GaAs power MMIC," *IEEE Monolithic Circuits Symp. Dig.,* pp.31-34, June 1985.

[4] K.Honjo, et.al., "X-band low-noise GaAs monolithic frequency converter," *IEEE GaAs IC Symp. Tech. Dig.,* pp.177-180, Oct,1984.

[5] S.Watanabe, et.al., "GaAs monolithic MIC mixer-IF amplifiers for direct broadcast satellite receivers," *IEEE Monolithic Circuits Symp.Dig.,* pp.19-23, May 1984.

[6] T.Hirota, et.al., "A uni-planar MMIC 26-GHz-band receiver," *IEEE GaAs Symp. Tech. Dig.,* pp.185-188, Nov.1988.

[7] T.Hirota, et.al., "Uniplanar MMIC hybrids-A proposed new MMIC structure," *IEEE Trans. Microwave Theory Tech.,* vol.MTT-35, pp.576-581, June 1987

[8] T.Tokumitsu, et.al., "Active isolator, combiner, divider and magic-T as miniaturized function blocks," *IEEE GaAs Symp. Tech. Dig.,* pp.273-276, Nov.1988.

[9] H.Kato, et.al., "A 30 GHz-band full = MMIC receiver for satellite transponders," *IEEE MTT-S International Microwave Symp. Dig.,* PP.565-568, May 1988.

[10] T.Mekata, et.al., "Low noise BS converter using MMICs," *National Conv. Rec. IEIEC, Jap.,* C-681, Mar.1989.

[11] M.Shigaki, et. al.,"One-chip GaAs monolithic frequency converter operable to 4 GHz," *IEEE trans. Microwave Theory Tech.,* vol.MTT-36, pp653-658, Apr.1988.