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A 30 GHZ-BAND FULL-MMIC RECEIVER FOR SATELLITE TRANSPONDERS

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ABSTRACT

30GHz-band MMIC modules (low noise amplifier, frequency converters and local oscillator) needed to construct a Ka-band full-MMIC satellite transponder have been developed. A receiver bread-board model has been assembled using MMIC modules and total performances have been evaluated Test results indicate successful performance as a satellite receiver system.

1. INTRODUCTION

Satellite transponders are required to be extremely lightweight and highly reliable as well as to have excellent electrical performances. Monolithic microwave IC's (MMIC's) have great potential for fulfilling these requirements.

Many papers on MMIC developments have been published, however, most papers have been concerned with the basic functional circuits, especially in the Ka-band. Moreover, no examples of applying MMIC's to the satellite transponders have been reported.

The key MMIC chips for Ka-band receivers have already been reported by the authors [Ref. 1]. After then, MMIC's size, power consumption and electrical performance have been improved and the MMIC modules using these MMIC chips and a 30 GHz band full-MMIC receiver bread-board model have been developed.

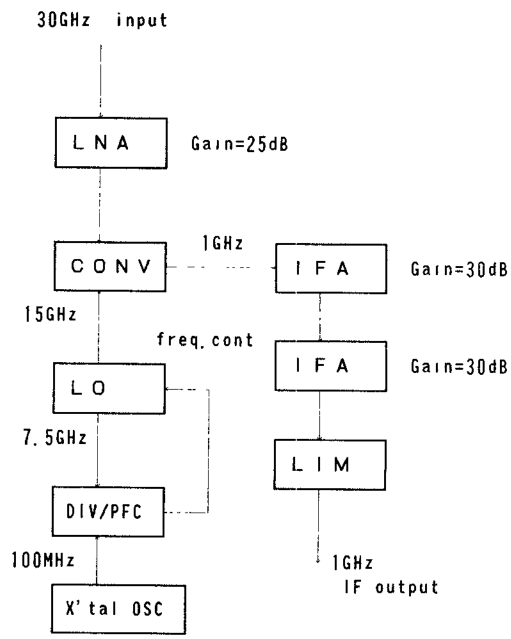
This paper describes the newly developed MMIC modules and presents total system performances of a Ka-band receiver bread board model incorporating MMIC modules.

2. RECEIVER CONFIGURATION

Two different receiver configurations (an image rejection type (IR type) and a non image-rejection type (NIR type)) have been developed. The configuration of the IR type full MMIC receivers is shown in Fig. 1. The configuration of the NIR type receiver is same as that of the IR type except for an external filter for image suppression between a low noise amplifier and a mixer. The IR type is used for receivers incorporating the low noise amplifier and the mixer in one housing The NIR type is used in the case that the low noise amplifier is installed separately from the receivers.

To realize the full MMIC receiver, it is necessary to solve some critical problems associated with MMIC implementation First problem is removal of narrow-band filters. This is because that the filters occupy large area on IC chips and limit usable frequency range. Second problem is to suppress the phase noise of MMIC oscillators MMIC oscillators have fairly noisy spectrum due to its low Q characteristics. These problems have been solved by developing the phase shift type image rejection mixer and by employing high speed phase lock technology in the local oscillator, respectively.

To make the MMIC's easy to handle, full MMIC modules containing several MMIC chips in multi-chip form without any external elements or trimming board, have been developed. An MMIC module includes one to six MMIC chips. The receiver presented here is composed of seven MMIC modules and fully implemented by MMICs except for a X'tal oscillator.



LNA : low noise amplifier module
CONV: frequency converter module
LO: local oscillator module
IFA: IF amplifier module
LIM: limiter module
DIV/PFC: digital frequency divider / phase frequency comparater

Fig. 1 Full MMIC Receiver Configuration

3. LOW NOISE AMPLIFIER MODULE

The configuration of a low noise amplifier module is shown in Fig. 2. A low noise amplifier module contains four chips of two-stage amplifiers employing 0.3 μm gate length 150 μm gate width GaAs FETs with via holes. Input and output ports of each MMIC chip are directly connected to adjoining chips. Lumped constant MIM capacitors are used as matching elements to achieve small size circuits. MIM capacitors have much deviation in capacitance owing to fabricated insulator thickness deviation. Therefore, this 30 GHz amplifier design employs a novel circuit configuration which can compensate for the capacitance variation of the MIM capacitors. Measured frequency response is shown in Fig. 4. Typical gain of 27 dB and noise figure of 8.2dB have been obtained in the 29 to 31 GHz range.

An appearance of the module is shown in Fig. 3. The size of the module is 18.9x6.7x3.5 mm^3. Power consumption is 0.4W.

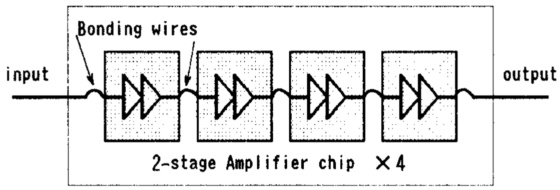
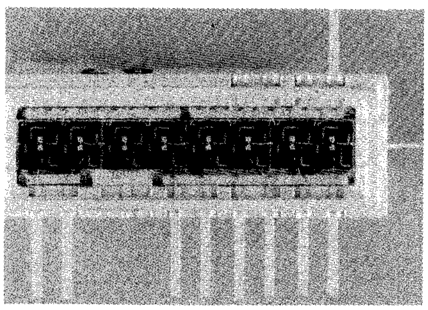


Fig. 2 Configuration of 30GHz Amplifier Module



(18.9×6.6 ×3.5 mm^3)

Fig. 3 30GHz Amplifier Module

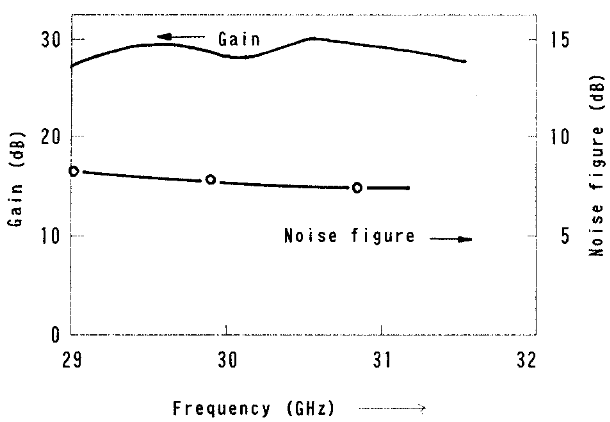


Fig. 4 30GHz Amplifier Characteristicsistics

4. FREQUENCY CONVERTER MODULES

Two different configurations of frequency converter modules have been developed, the image rejection type (IR type) and non image-rejection type (NIR type). Input, local and IF frequency bands are 30GHz, 15GHz and 1GHz, respectively.

4.1 Image-rejection Frequency Converter Module

The configuration of an IR type frequency converter module is shown in Fig. 5. The module contains five chips (a diode mixer, an IF phase shifter, a 30GHz frequency doubler and two 30GHz local amplifiers). An FET type doubler is employed because of its broad band characteristics. The 30 GHz local amplifiers are two-stage amplifiers using 0.5 μm gate length 300 μm gate width FETs. The mixer is phase shifting type which is able to suppress the image receiving without a filter. It requires 90 degree phase shift networks in local and IF circuits. In this circuit, a unique wide-band phase shifter using active elements has been developed.[Fig. 7] It consists of two FET-CR phase shifters with constant-amplitude characteristics. Two input IF signals are combined under a constant phase difference of 90 degrees. This active phase-shift network includes no distributed constant elements. Almost constant phase-frequency characteristics have been obtained in the 0.5-1.5GHz IF range within ±5 degree phase deviation. Main characteristics of IR frequency converter module are as shown in Fig. 8. A typical conversion loss of 10 dB and a image rejection ratio of more than 18 dB have been obtained.

An appearance of the module is shown in Fig. 6. The size of the module is 23.3x8.4x4.1 mm^3. Power consumption is 0.73W.

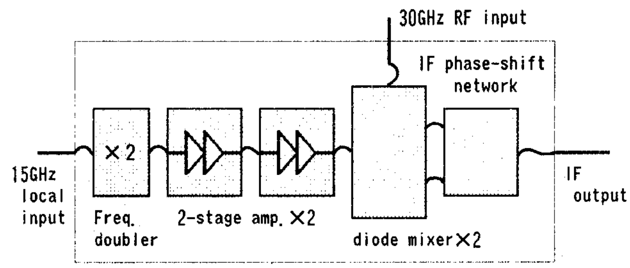
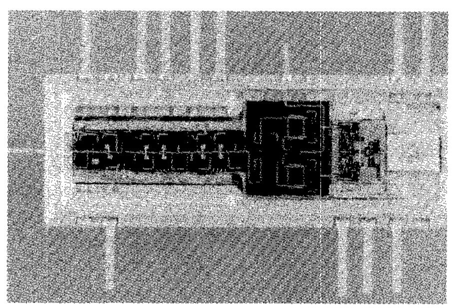


Fig. 5 Configuration of IR-type Frequency Converter Module



(23.3×8.4 ×4.1 mm^3)

Fig. 6 IR-type Frequency Converter Module

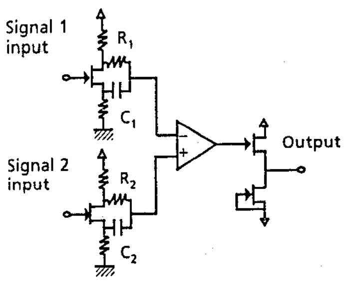


Fig. 7 Active IF Phase-shift Network

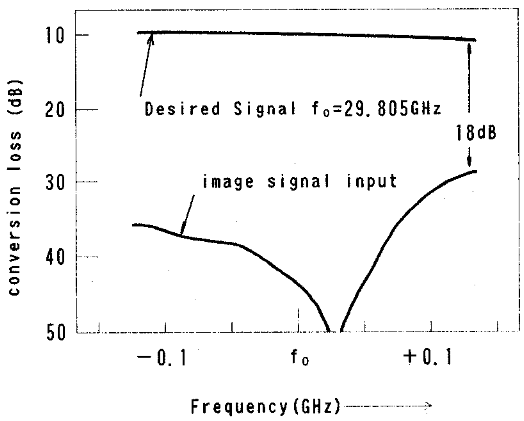


Fig. 8 Characteristics of IR-type Frequency Converter Module

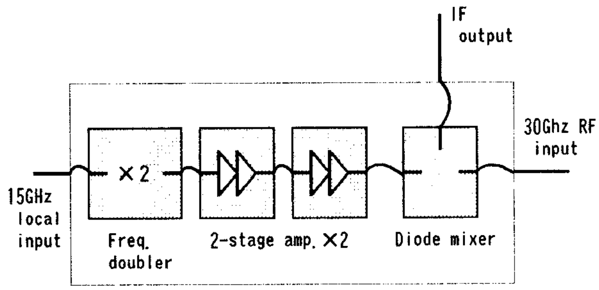
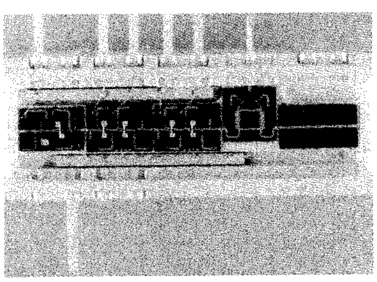


Fig. 9 Configuration of NIR-type Frequency Converter Module



(18.9×6.6 ×3.5 mm^3)

Fig. 10 NIR-type Frequency Converter Module

4.2 Non Image-rejection Frequency Converter Module

The configuration of an NIR type frequency converter module is shown in Fig. 9. The module includes four MMIC chips (a single balanced mixer, a 30 GHz doubler and two 30GHz amplifiers). The configuration of the local circuit is identical to the above mentioned IR frequency converter.

An appearance of the module is shown in Fig. 10. The size of the module is 18.9x6.7x3.5mm^3. Power consumption is 0.65W.

5. LOCAL OSCILLATOR MODULE

The configuration of a local oscillator module is shown in Fig. 11. The local oscillator module forms 15 GHz band phase locked oscillator with a 1/64 digital frequency divider / phase frequency comparator. It contains six MMIC chips (a 15 GHz voltage controlled oscillator (VCO), a 15 / 7.5 GHz Miller type analog frequency divider [Ref. 2], a 7.5 GHz amplifier, two 15GHz amplifiers and a passive power divider). The voltage controlled oscillator is varactor tuned full-MMIC type without an external resonator. It employs common-drain source-follower FET circuit to obtain wide tuning range and low pulling figure. The chip includes a unique dumping circuit in bias network to suppress undesirable out-of-band parasitic oscillations [Ref. 3].

The analog type frequency divider converts the frequency of VCO output (15 GHz band) to digital frequency divider input (7.5GHz band) . The principle feature of the circuit is lower power consumption at high frequency than digital frequency dividers.

The ouput frequencies of the module are smoothly tunable from 14.2 GHz to 16.0 GHz (7.1 GHz to 8.0 GHz at divided port) as shown in Fig. 13.

An appearance of the module is shown in Fig. 12. The size of the module is 23x8x3.5 mm^3. Power consumption is 0.96W.

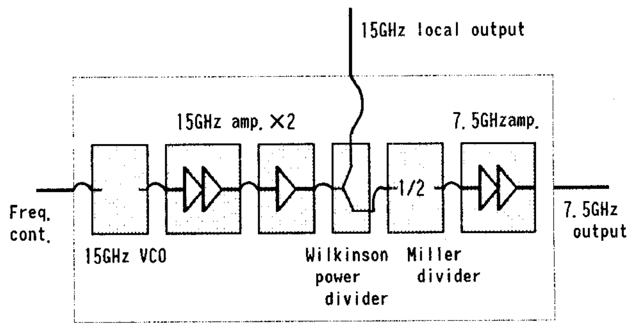
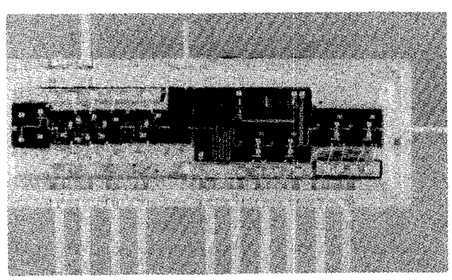


Fig. 11 Configuration of Local Oscillator Module



(23.0×8.0 ×3.0 mm^3)

Fig. 12 Local Oscillator Module

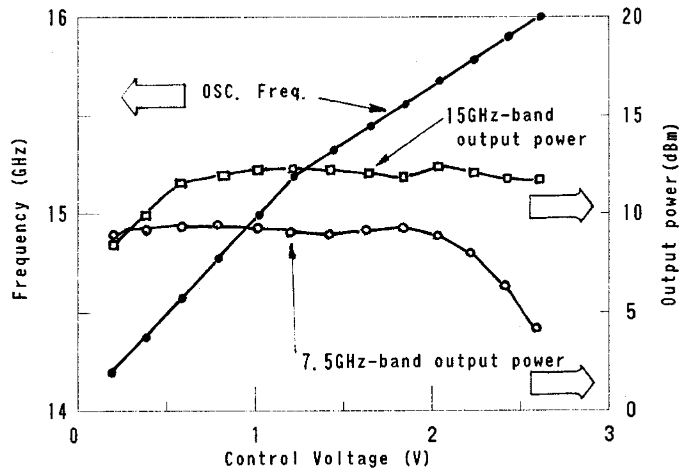
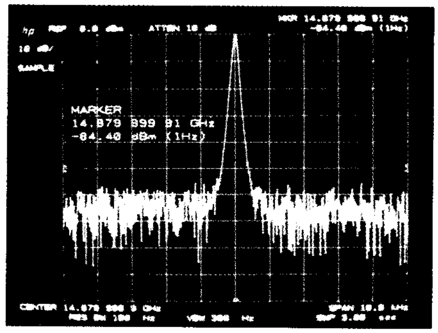
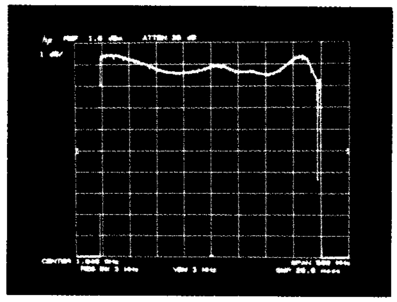


Fig. 13 Tuning Characteristics of Local Oscillator Module



center freq. : 14.88GHz
H : 100Hz/div
V : 10dB/div

Fig. 14 Measured Local Oscillator Specectrum



Input signal: 30.805GHz ±200MHz
center freq. : 1.045GHz
H : 50MHz/div
V : 1dB/div

Fig. 15 Measured Frequency Response of Receiver Bread-board

6. RECEIVER PERFORMANCE

A 30 GHz full MMIC receiver bread-board model has been assembled using the MMIC modules described in the previous sections plus two 1GHz amplifiers, a limiter [Ref.4] and a 7.5 GHz digital frequency divider [Ref.5] which were developed at NTT laboratories.

Various tests, such as temperature test and electro-magnetic compatibility test etc., were carried out and it has been confirmed that all the measured data were satisfactory as a satellite receiver system.

6.1 Local oscillator phase noise

The MMIC VCO has a fairly blunt or noisy spectrum due to its low-Q property. The noise comes from quick fluctuation in the oscillation frequency. Such quick fluctuation can be suppressed by a high speed and high gain phase locked technology. The measured phase locked local oscillator output spectrum is shown in Fig. 14. It exhibits no spurious output. The SSB phase noise density less than -80 dB / Hz at 1kHz offset has been obtained.

6.2 Transmission Characteristics

Frequency response of the bread-board from 30GHz input to 1 GHz output port is shown in Fig. 15. A sufficiently flat response less than ±1 dB was obtained. Moreover, undesirable spurious oscillation was not found in the output spectrum at all.

7. CONCLUSIONS

30 GHz band MMIC modules for Ka-band satellite transponders have been successfully developed. A bread-board model of a 30 GHz receiver has been manufactured using newly developed MMIC modules, and total system performances was evaluated. Essential transponder design requirements including high image ratio and high stability / low noise local oscillator without using high-Q filters, have been satisfied.

The full MMIC receiver modules presented here is being equipped for the transponders on the ETS-VI satellite that Japan intends to launch in 1992.

ACKNOWLEDGMENTS

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References

[1] T.Ohira et.al.,"Development of key monolithic circuits to Ka-band full MMIC receivers" IEEE 1987 Microwave and Millimeter-wave Monolithic Circuits Symposium, pp.69-74, June 8-9, 1987

[2] R.L.Miller,"Fractional-frequency Generators utilizing Regenerative Modulation",Proc. IRE, vol. 27, pp.446-456, July 1939.

[3] T.Ohira et.al.,"MMIC 14GHz VCO and Miller frequency divider for low-noise local oscillators", IEEE Trans. Microwave Theory Tech., vol. MTT-35, pp.657-662, July 1987.

[4] H.Kikuchi et.al.,"1GHz Band High Gain Monolithic amplifiers and limiting amplifiers", to be submitted.

[5] H.Ichino et.al.,"An 8.6 GHz Si Bipolar Dynamic Frequency 1/64 divider", to be submitted.