MILLIMETER-WAVE PACKAGING AND MODULE TECHNOLOGY DEVELOPMENTS IN JAPAN

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ABSTRACT

This paper presents an overview of recent trends in millimeter-wave packaging and module technology development in Japan. For commercial millimeter-wave applications such as wireless radio links, wireless LANs, automotive radars and so on, packaging and module technologies with high performance and productivity are required. Ceramic-base packages up to W-band, flip-chip bonding and packaging of CPW MMICs for low cost and high reproducible assembling, and extremely compact multi-layer HTCC transmitter/receiver MCMs for 60GHz band communications, have been developed.

INTRODUCTION

Commercial millimeter-wave applications such as wireless radio links, wireless LANs, automotive radars and so on are increasing. MMICs for those systems are in the stage of mass production. Therefore, packaging and module technologies with low cost, high reproducibility and productivity as well as high performance become important issues for system applications. Conventional metal packages with waveguide ports have been used for millimeter-wave modules assembling MMICs with wire bondings as Itoh et al (1), Ohata et al (2) and Yakuwa et al (3). As for advanced technologies satisfying those requirements, many activities are being conducted on millimeter-wave MMIC packaging, assembling and module tecnologies in Japan. This paper reviews recent trends in these technologies. Ceramic-base packages up to W-band, flip-chip bonding and packaging for low cost and high reproducible assembling of MMICs, and very compact MCMs, are described.

MILLIMETER-WAVE PACKAGE

Several types of ceramic-base millimeter-wave package have been developed by Kyocera Corp.. A metal wall package operable at 94GHz-band has been developed improving the RF-feed-through in the ceramic layers as Tomie et al (4). Figure 1 shows its structure and Fig.2 shows plan views and cross sections of the conventional RF-feed-through and improved one. The reflection occurs at the interface of the microstrip line and stripline in the feed-through due to drastic change in the transmission mode. To minimize this mode change influence, the feed-through structure is improved by thinning the bottom layer substrate to suppress higher transmission modes, reducing the feed-through width, and setting up ground patterns alongside the signal line in the stripline area. The insertion loss of a feed-through with two interconnection substrates is about 1dB from 90GHz and 100GHz as shown in Fig.3.

The other type of millimeter-wave package is made of laminated ceramics with a couple of electromagnetic coupling feed-through as shown in Fig.4 as Koriyama et al (5). A microstrip line on the lower alumina layer, which will connect to the device, is coupled with the input and output microstrip lines on the upper alumina layer through slots formed in the grounded plane. This package has low loss and is suitable for surface mount. Figure 5 shows transmission characteristics of a through line of the package with a couple of electromagnetic coupling feed-through designed for 76GHz. The insertion loss of one feed-through is estimated to be 0.4dB.

FLIP-CHIP BONDING TECHNOLOGY

The flip-chip bonding has advantages of low cost and low loss interconnect with high reproducibility. NEC Corp. has developed 60/76GHz CPW MMICs and high reliability flip-chip bonding technology as Maruhashi et al (6) and Ito et al (7). For precise MMIC design, proximity effects between the MMIC and substrate have to be analyzed. Figure 6 shows changes in the characteristic impedance and the electrical wavelength of the CPW in the MMIC with the air-gap between the MMIC and substrate by the 3D electromagnetic simulation. The electrical characteristics of the CPW does not significantly change if the air-gap is larger than 20μm. Thermo-compression bonding using Au stud bumps formed on an alumina substrate at 300°C and 100gf/bump pressure realizes 19±1.5μm air-gap, high die shear strength of 57gf/bump and high reliability of no failure over 1500 cycles for temperature stress test between 125°C and -55°C as shown in Fig.7. A flipped 60GHz-band 3-stage LNA exhibits 19.5±1.0dB gain @55-61GHz and 3.6dB NF @58GHz, which is no significant change from the performance of chip itself as proven in Fig.8.

Fujitsu Labs. Ltd. has also developed flip-chip bonding and packaging technologies of CPW MMICs for 76GHz automotive radars as Ohashi et al (8). Plated Au pillars on the MMIC are thermally bonded to Sn pad on an alumina substrate. The substrate has microstrip lines on one side, connected to CPW lines for MMIC flip-chip bonding on the other side via through holes as shown in Fig.9. As the ground plane of the microstrip line and that of the CPW are identical, there is no discontinuity of the ground plane outside of the package to the MMIC interface. Figure 10 shows the characteristics of this package with a flipped MMIC through line. A loss of the package feed-through is estimated to be 0.5dB@76GHz. An assembled MMIC, for example, a doubler chip consisting of a 38GHz amplifier, a 90 degree hybrid coupler and 38/76GHz frequency doublers presents two 76GHz outputs of 0dBm as input to output characteristics shown in Fig.11.

MULTI-CHIP MODULE TECHNOLOGY

Highly integrated, very compact transmitter/receiver multi-chip modules (MCMs) employing AlN multi-layer HTCC structure for 60GHz-band wireless LAN systems have been realized by NEC Corp. and Communication Res. Lab. as Mizoe et al (9). Figures 12 and 13 show the layer structure and cross sectional view of the MCM, which is composed of four conductive layers and three AlN dielectric layers. A V-band RF interface is realized by a waveguide/microstrip-line transformer designed by the 3D electromagnetic analysis. The waveguide is formed by inner-side wall-metalized WR15 holes. Figures 14 and 15 show photographs and block diagrams of 60GHz transmitter and receiver modules, respectively. These modules are highly integrated in the extremely compact size of 21 x 16 x 3.05 mm^3 by making full use of 3D multi-layer RF/DC patterns. Figure 16 shows the performance of the transmitter module. The module exhibits 16.1dBm output power, 15.0 dB conversion gain @61.6GHz. Figure 17 shows the performance of the receiver module. The module exhibits 5.25dB NF, 31dB conversion gain and 18dB image rejection ratio @59.5GHz.

As millimeter-wave modules easy to be used, a cost effective module composed of a small flat antenna and RF MMICs mounted in a hermetically sealed package has been proposed by Fujitsu Quantum Devices Ltd., Olympus Optical Co., Ltd. and Communication Res. Lab. as Hirachi et al (10). A planar dielectric integrated circuit (PDIC) module composed of a circuit substrate built on a dielectric substrate for a TE_{010} mode dielectric resonator has also been proposed and a 30GHz packaged DRO has been realized by Murata Mfg. Co., Ltd. as Kato et al (11).

SUMMARY

As for advanced millimeter-wave packaging and module technologies for low cost and high productivity as well as high performance, ceramic-base packages up to W-band, flip-chip bonding and packaging of CPW MMICs, and highly integrated compact multi-layer HTCC transmitter/receiver MCMs have been developed in Japan. These technologies are very promising for the commercial use of millimeter-wave systems.

ACKNOWLEDGEMENT

The author wish to thank to researchers and engineers contributing to these developments.

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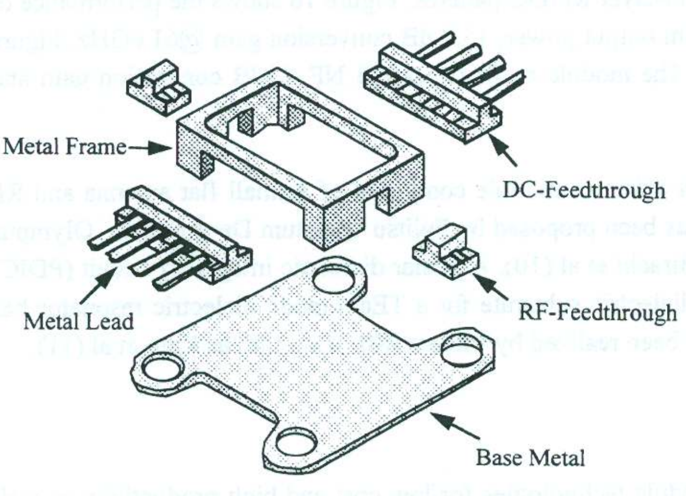


Fig.1 Structure of 94GHz metal wall package.

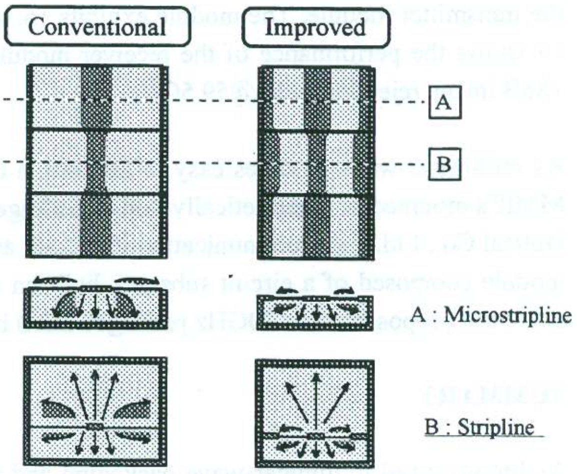


Fig.2 RF feed-through improvement for 94GHz metal wall package.

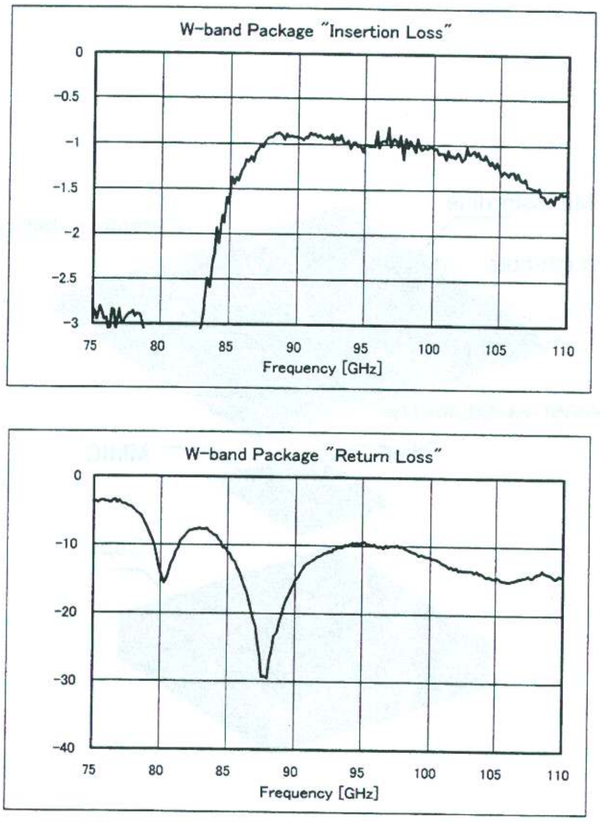


Fig.3 Characteristics of a feed-through for 94GHz metal wall package.

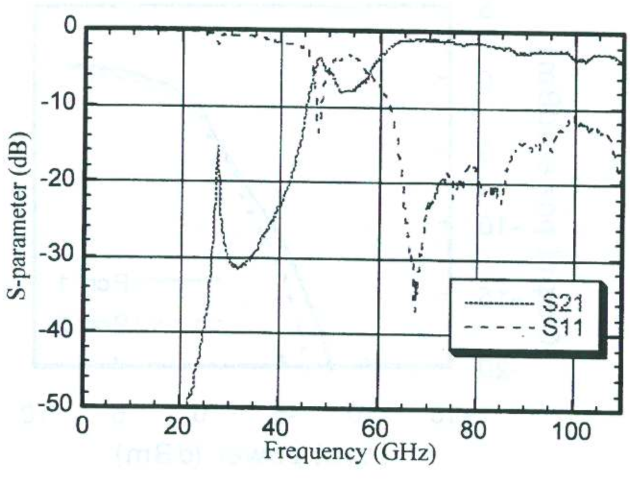


Fig.5 Characteristics of a couple of feed-through for 76GHz electromagnetic coupling sample.

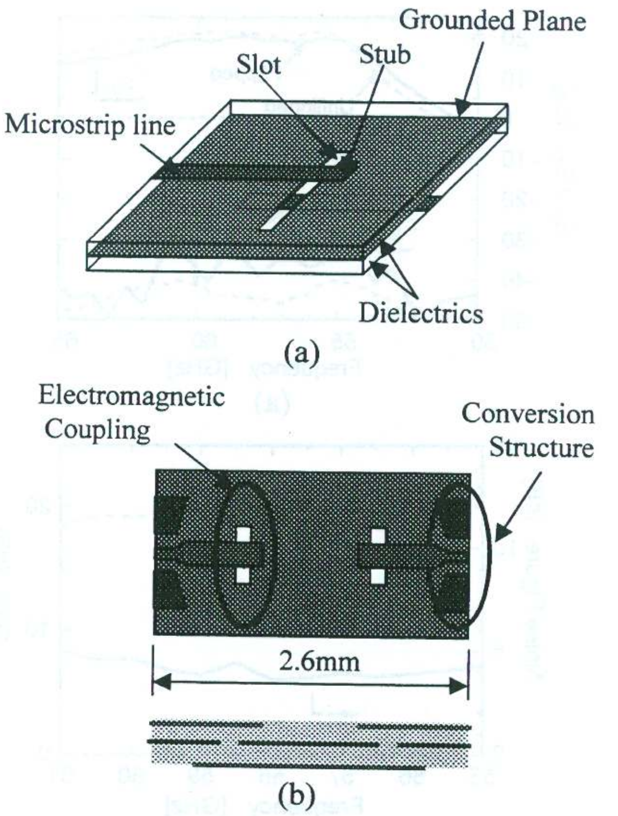


Fig.4 Schematic of electromagnetic coupling(a) and package sample designed for 76GHz(b)

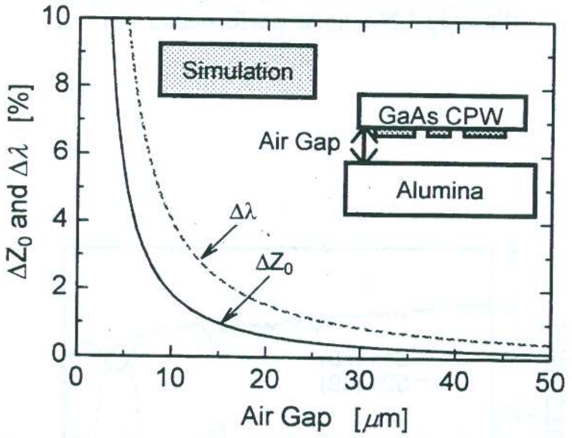


Fig.6 Changes of characteristic impedance Z_0 and electrical length λ for MMIC CPW vs. air gap.

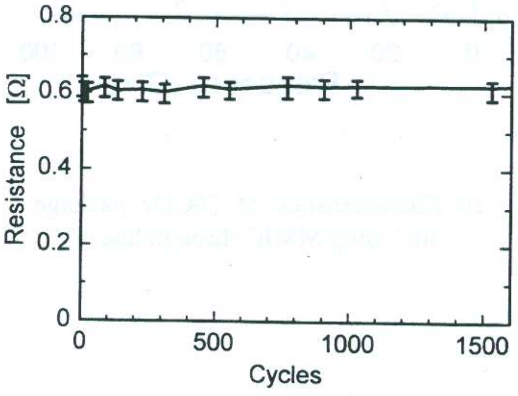
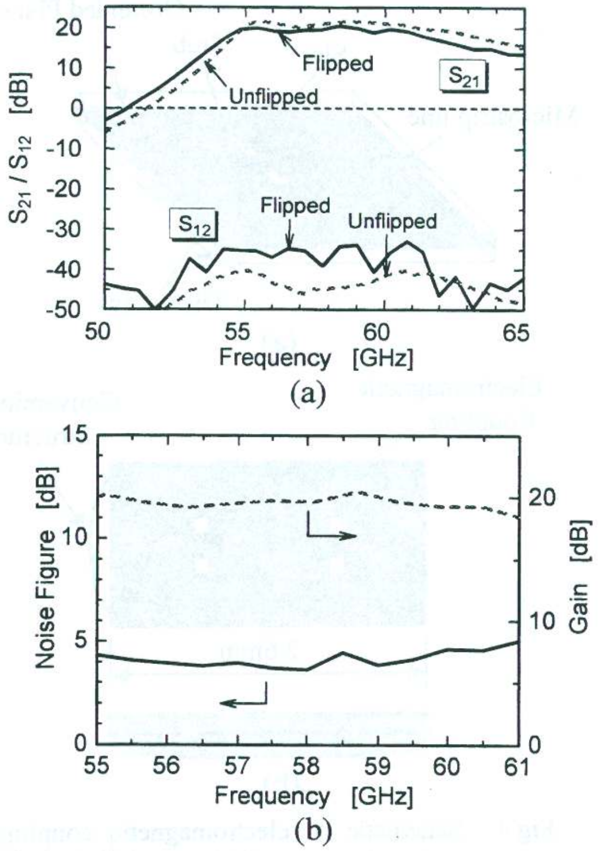


Fig.7 Resistance of 6-bump series interconnects under thermal cycle test.



(a)

(b)

Fig.8 Change in small signal characteristics of 60GHz LNA with flip-chip bonding (a) and flip-chip LNA noise performance (b).

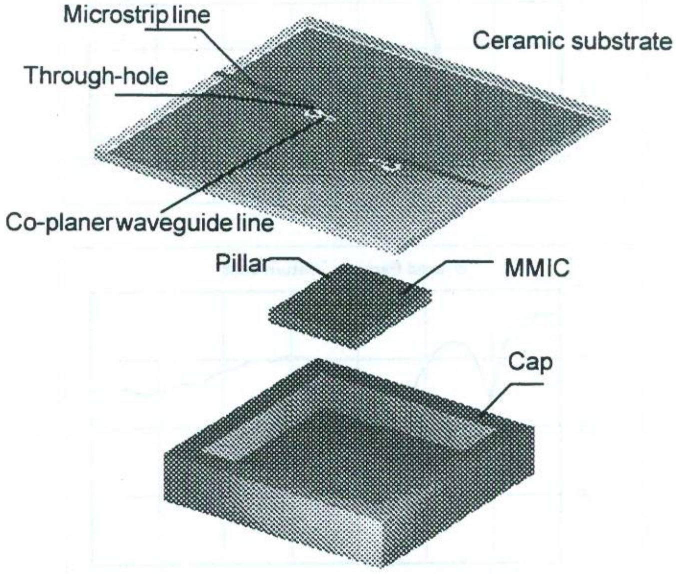


Fig.9 Structure of package for 76GHz flip-chip MMIC

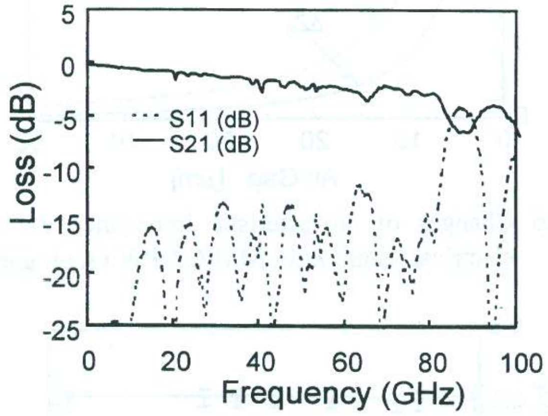


Fig.10 Characteristics of 76GHz package including MMIC through line.

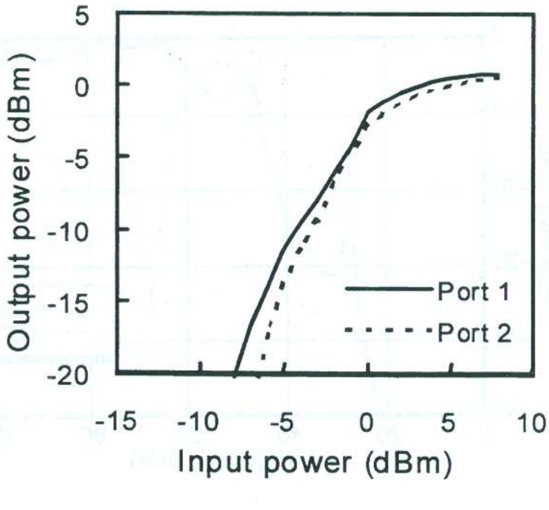


Fig.11 Input/output characteristics of 38/76GHz doublers

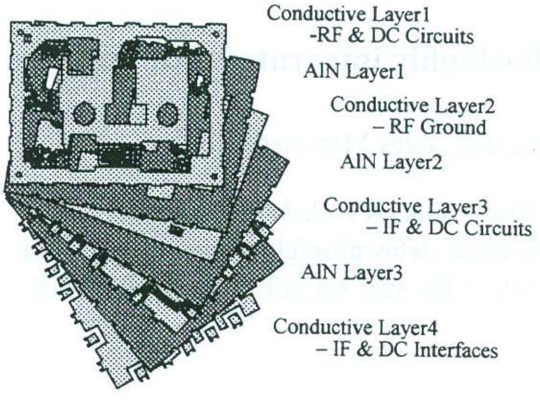


Fig.12 Multi-layer HTCC-MCM structure.

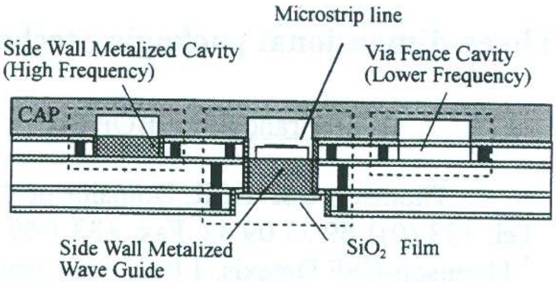


Fig.13 Cross sectional view of MCM

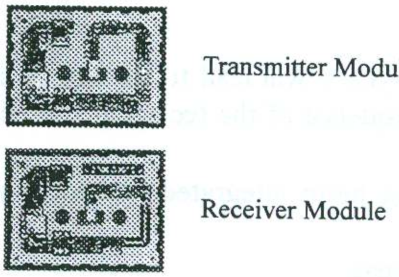


Fig.14 Transmitter / Receiver Module.
(21 x 16 x 1.05 mm^3)

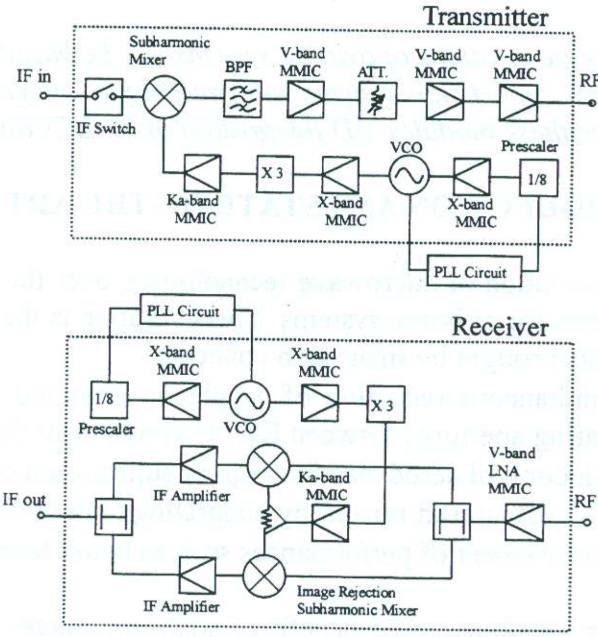


Fig.15 Transmitter/receiver MCM block diagram

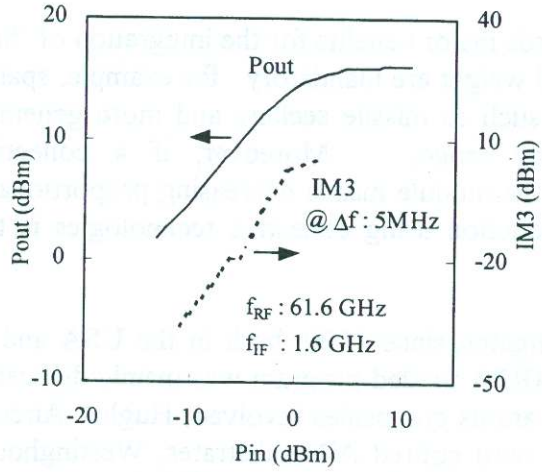


Fig.6 RF Performance of Transmitter

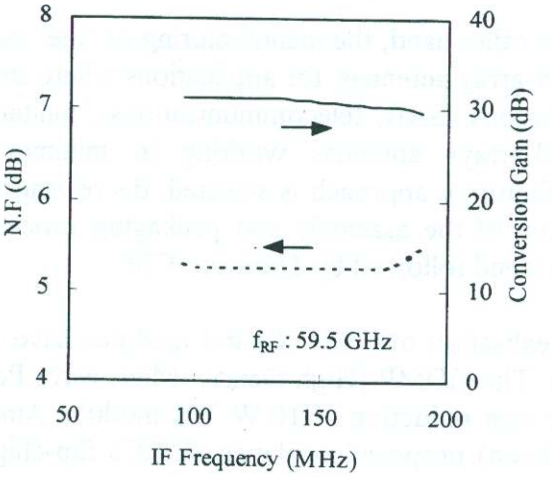


Fig.17 RF Performance of Receiver