Small-size 72-GHz-band Transceiver Modules Utilizing IF Self-heterodyne Transmission Technology

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Abstract **— A 72-GHz-band transceiver is developed for millimeter-wave short-range wireless access systems. To eliminate an oscillator for a receiver and to avoid the degradation of the signal quality due to the phase noise of a transmitter oscillator, we employ novel IF self-heterodyne transmission scheme. For multi-chip modules (MCMs), coplanar devices are mounted in multi-layer LTCC packages. At an IF frequency of 4.4 GHz and an RF frequency of 72.4-GHz, an output power of 6.6 dBm at 1-dB gain compression point is obtained for the transmitter. For two-tone RF signals of 71.8 and 72.4 GHz, the receiver provides an IF output power of –50 dBm at a total input power of –40 dBm. The total size of the transmitter, receiver and DC power supply/control boards is 89 mm × 83 mm.**

I. Introduction

The increasing demands for high-speed data transmissions facilitate realization of broadband wireless systems. Recently, the millimeter-wave ad-hoc wireless access system[1] has been proposed, in which high-speed data exchange is possible among digital equipments in the picocell networks. We used 60-GHz-band transceivers for system feasibility study in the first trial. Our research scope also includes 72-GHz-band usage to exploit new frequency resources.

The cost issue is quite severe to be considered for millimeter-wave modules implemented in such systems. Our first approach for cost reduction is to employ self-heterodyne technique[2], in which RF modulation signals and a local oscillation signal are transmitted simultaneously. Using this technique, the received IF signal is free from degradation due to oscillator phase noise in the transmitter. In this scheme, low phase-noise characteristics are not required for the oscillator in the TX and the oscillator in the RX can be eliminated. The second approach is to employ flip-chip modules with multi-layer ceramic packages[3][4], resulting in high productivity.

In this work, we develop a small-size 72-GHz-band transceiver adopting the self-heterodyne transmission scheme. The transmitter and receiver modules are fabricated using coplanar devices (MMICs and filtes) and multi-layer low-temperature co-fired ceramic (LTCC) substrates as packages. The total size including the transmitter, receiver and DC power supply/control boards is 89 mm × 83 mm.

II. IF Self- Heterodyne Transceiver

The block diagram of the transceiver is shown in Fig.1. A novel self-heterodyne configuration is employed, in which the local-carrier-added DSB signal is generated for an IF band. The 1st IF signal(~600 MHz) from a baseband circuit is up-converted to the 2nd IF signal with a center frequency of 4.4 GHz. The 2nd IF frequency covers a double-side-band (DSB) signal and an intentionally added local signal from the oscillator. At this stage, power levels of the DSB signal and the local signal are adjusted to be same to obtain an optimal C/N at the RX for a given value of the transmission power[2]. This adjustment done in the

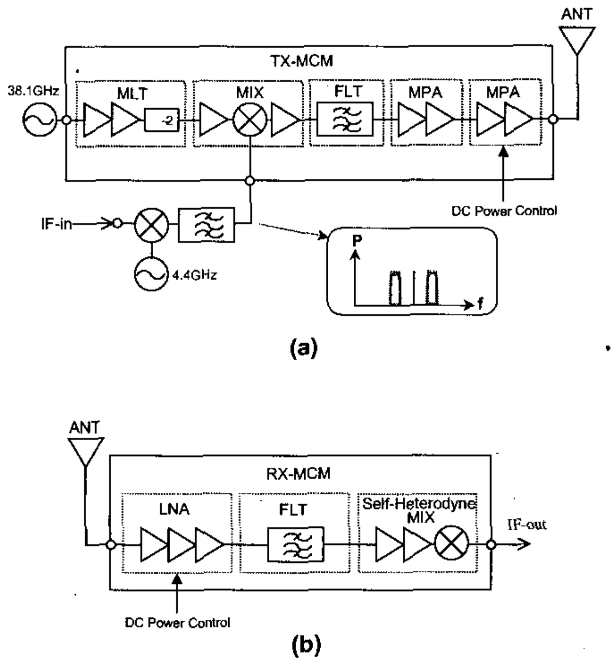

Fig. 1. Transceiver block diagram. (a)TX-MCM, (b) RX-MCM.

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IF stage facilitate a simple millimeter-wave circuit compared to the case for the original self-heterodyne scheme at RF frequency[2]. Then, in the transmitter, the 2nd IF signal is up-converted again to an RF signal with a center frequency of 71.8 GHz. In the receiver, the received signal is amplified and down-converted directly to the 1st IF signal using a square-law detector. Thus, no local oscillator is required in this receiver. Furthermore, the frequency of the down-converted 1st IF signal is exactly same as that before transmission and oscillator phase noise does not affect the quality of the IF signal due to coherent nature of the local and DSB signals at the 2nd IF frequency. A local frequency of 38.1 GHz is selected since we can use an oscillator already developed for 76-GHz automotive radar applications as a local source to be frequency-multiplied.

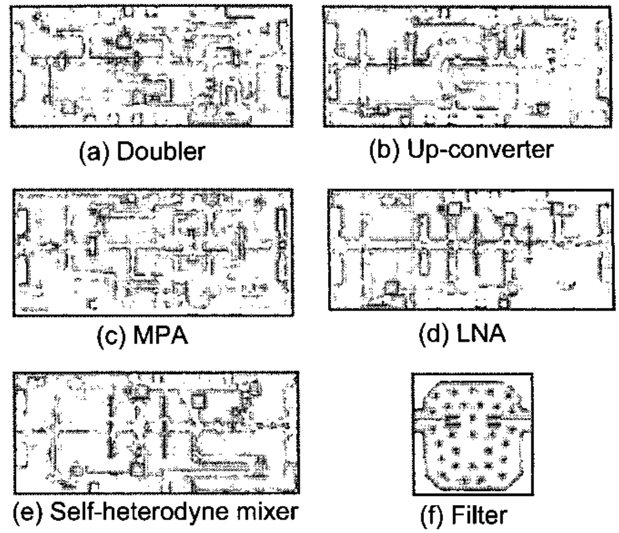

Fig. 2. MMIC and Filter chipset. Each MMIC size is 2.5 mm × 1.15 mm and Filter size is 3.4 mm × 3.5 mm.

III. MMIC AND FILTER CHIPSET

For compactness and cost reduction of the millimeter-wave devices, we employ coplanar-type MMICs and multi-layer LTCC substrates[4] for 72-GHz-band multi-chip modules (MCMs). Figure 2 shows photographs of the fabricated MMICs and the filter. For the transmitter MCM (TX-MCM), three MMICs were developed. For the 38-to-76-GHz frequency doubler with a 38-GHz two-stage driver amplifier, the output power of −1 dBm was measured at an input power of 2 dBm. The up-converter consists of a source-injection mixer with input/output buffer amplifiers and exhibited an output power of −1 dBm at an RF frequency of 72 GHz and an IF frequency of 4.4 GHz. The two-stage MPA has FET gate-widths of 150 μm in the first stage and 300 μm in the second stage. The power performance at 3.3-V operation is shown in Fig. 3. The 72-GHz output power was 10.2 dBm at 1-dB gain compression point with a linear gain of 11.5 dB. For the receiver MCM (RX-MCM), two MMICs were developed. A three-stage LNA provided the 18-dB gain from 70 to 75 GHz. A self-heterodyne mixer (square-law detector) utilized gate-source junction of an FET, with a two-stage preamplifier. All MMICs were fabricated based on 0.15-μm AlGaAs/InGaAs heterojunction FET technology.

The dielectric waveguide filters with coplanar I/O[5] were implemented in the TX- and RX-MCMs. Figure 4 shows performance of the filter. An insertion loss of 1 dB with a center frequency of 72.4 GHz was obtained. The 3-dB bandwidth was 4.0 GHz. To suppress a local leakage from up-converter, an attenuation pole was incorporated at 76.2 GHz using cross-coupling technique for the filter.

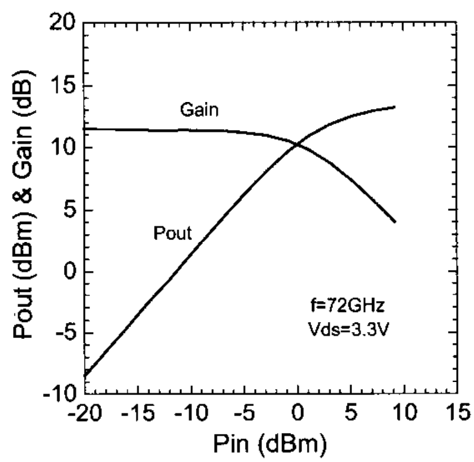

Fig. 3. Power performance of MPA at 3.3V operation.

A schematic cross-sectional view of the MCM is shown in Fig. 5. A multi-layer LTCC substrate is used as packaging structure. Signal and bias lines, ball grid array (BGA) pads for baseband, and coplanar waveguide to waveguide transition are completed after co-firing in the multi-layer ceramic fabrication process. Coplanar devices, i.e. MMICs and filters are mounted in the cavities formed on the substrate using flip-chip bonding technique to achieve highly repeatable interconnection. The LTCC

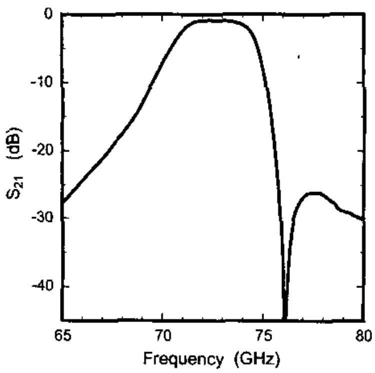

Fig. 4. Filter performance.

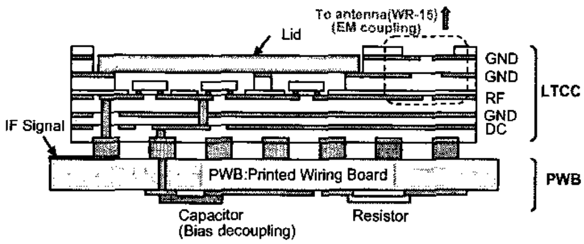

Fig. 5. Schematic cross-sectional view of LTCC modules.

substrates are directly mounted on the printed wiring boards using BGA technique. Figure 6 shows TX- and RX-MCMs on the transmitter and receiver boards with a DC power supply/control board. The sizes of the transmitter and receiver boards are 41 mm × 77 mm and 38 mm × 77 mm, respectively. The total size for sum of three boards is 89 mm x 83 mm.

IV MODULE PERFORMANCE

The fabricated MCMs were tested using WR-15 waveguide interface put on the antenna port of the LTCC substrates. Including coplanar waveguide to waveguide transition, loss from the nearest MMIC to WR-15 waveguide interface was about 3 dB at 72 GHz. All data shown in the following include this value.

Figure 7 shows the RF output power as a function of 4.4-GHz IF input power for the TX-MCM. At an IF power of 1.6 dBm, the 72.4-GHz RF power was 8.0 dBm. An RF output power at 1-dB gain compression point was 6.6 dBm. The power of 76.2-GHz local leakage was suppressed to -24 dBm by the dielectric filter in the transmitter. DC Power dissipation was about 1 W for the TX-MCM.

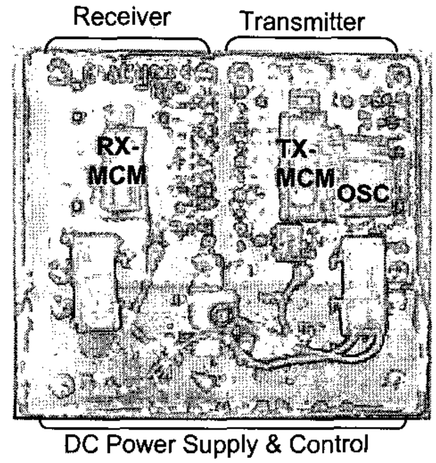

Fig. 6. TX- and RX-MCMs on the transmitter and receiver boards with a DC power supply/control board.

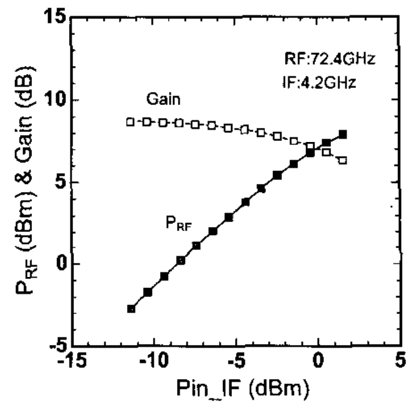

Fig. 7. Power performance of TX-MCM.

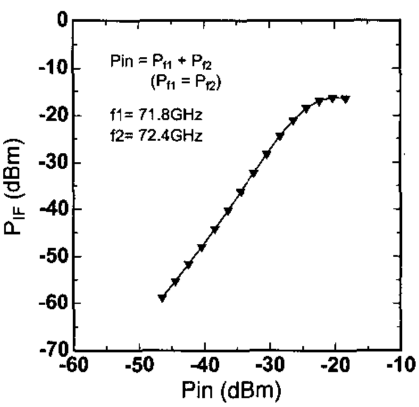

Fig. 8. IF output power as a function of two-tone input power for RX-MCM.

Figure 8 shows the IF output power as a function of total input power for the RX-MCM. In the evaluation step, two CW signals with powers of Pf1 and Pf2 were employed, instead of a local-carrier-added DSB. In this case that Pf1=Pf2, the IF output power was increased with increasing total input power with at a slop of 2 for a linear region. This is particular nature for the self-heterodyne receiver[2]. An IF output power of –50 dBm was measured at a total input power –40 dBm. DC Power dissipation was about 0.1 W for the RX-MCM.

V. CONCLUSION

A 72-GHz-band transceiver was developed for a millimeter-wave ad-hoc wireless access system. We employed IF self-heterodyne transmission scheme and LTCC module structure for cost reduction. For the TX-MCM, an output power of 6.6 dBm was achieved at a 1-dB gain compression point. For the RX-MCM, an IF output power of –50 dBm was obtained when a two-tone RF signal with a total power of –40 dBm was input. The total size of transmitter, receiver and DC power supply/control boards is 89 mm × 83 mm.

These modules will be implemented and evaluated in the millimeter-wave ad hoc wireless access system.

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REFERENCES

[1] K. Hamaguchi, Y. Shoji, H. Ogawa, A. Akeyama, E. Kawakami, K. Yoshida, T. Hirose, M. Kuzuhara, and K. Sakamoto, "Millimeter-wave ad hoc wireless access systems - (1) Overview of system development-," *The 4th Topical Symposium on Millimeter Waves (TSMMW2002), Technical Digest*, pp.127-129, March, 2002.

[2] Y. Shoji, K. Hamaguchi, H. Ogawa, "Millimeter-wave remote self-heterodyne system for extremely stable and low-cost broad-band signal transmission," *IEEE Trans. on Microwave Theory Technique*, vol. 50, pp.1458 -1468, June. 2002.

[3] K. Maruhashi, M. Ito, L. Descros, K. Ikuina, N. Senba, N. Takahashi, and K. Ohata, "Low-cost 60 GHz-band antenna-integrated transmitter/receiver modules utilizing multi-layer low-temperature co-fired ceramic technology," *2000 Int. Solid-State Circuits Conf. Dig.*, pp. 324-325, Feb. 2000.

[4] K. Maruhashi, M. Ito, K. Ikuina, T. Hashiguchi, J. Matsuda, W. Domon, S. Iwanaga, N. Takahashi, T. Ishihara, Y. Yoshida, I. Izumi, and K. Ohata,"60GHz-band flip-chip MMIC modules for IEEE1394 wireless adapter", *European Microwave Conference*, Vol.1, pp.407- 410, London, Sep., 2001.

[5] M. Ito, K. Maruhashi, K. Ikuina, T. Hashiguchi, S. Iwanaga, and K. Ohata, "60-GHz-band dielectric waveguide filters with cross-coupling for flip-chip modules," *2002 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1789-1792, May 2002.