Millimeter-Wave Broadband Transceivers

By Keiichi OHATA,* Kenichi MARUHASHI,* Masaharu ITO* and Toshio NISHIUMI†

ABSTRACT Millimeter-wave broadband transceivers with data rates as high as 1.5Gbps have been developed on the unlicensed 60GHz-band. A direct ASK modulation and demodulation scheme is adopted for the 60GHz-band transceiver. The Traveling Wave Switch (TWSW) as an ASK modulator and an integrated HJFET data driver realizes ultra fast 60GHz-band modulation. To enable a highly producible and compact transceiver module, CPW MMICs and planar filters are flip-chip mounted in TX and RX LTCC MCMs, which are assembled on printed wiring boards using BGA connection. 1.25Gbps full duplex wireless Gigabit Ethernet transceivers having a function to convert a 1000BASE-SX optical fiber link seamlessly to a wireless link, a 1.485Gbps uncompressed HDTV wireless transmission system and so on have been commercialized.

KEYWORDS **Millimeter-wave, Wireless link, ASK, CPW (Coplanar Waveguide) MMIC, MCM, Gigabit Ethernet, HDTV**

1. INTRODUCTION

Demands for high-speed multimedia data communications, such as a huge data file transmission and real-time high definition TV signal streaming, are markedly increasing, e.g., Gigabit Ethernet networks are now beginning to be widely used. Wireless transmission with 1Gbps and greater data rates are very attractive. However, the speed of conventional wireless LAN systems (IEEE802.11b/g, 11a etc.) is limited to less than 100Mbps. The very wide unlicensed 60GHz-band (59 - 66GHz in Japan) is suitable for ultra high speed wireless communications with data rates above 100Mbps, especially, of 1Gbps and higher, 10dBm (10mW) transmitting power, a 2.5GHz occupied bandwidth defined as 99% power occupancy for one transmitter, 500ppm carrier frequency tolerance and an antenna usage with up to 47dBi gain are permitted on this unlicensed band. Therefore, wireless links with various data rates and transmission ranges can be realized. An S400 (400Mbps) wireless 1394 adapter was demonstrated for the first time by the authors[1]. An MMIC chipset for 1Gbps wireless links was reported[2]. However, low cost highly producible module technologies are required for the commercial use of 60GHz-band systems. We have proposed a low-cost multi-chip module (MCM) concept based on the multilayer Low-Temperature Co-Fired Ceramic (LTCC) technologies[3], and fabricated 60GHz-band Coplanar Waveguide (CPW) MMICs, planar filters and MCMs [4-8]. Utilizing these technologies, we have developed 60GHz-band broadband wireless transceivers with a data rate as high as 1.5Gbps[9,10], as well as commercial products for wireless Gigabit Ethernet links and a 1.485Gbps HD SDI (High Definition Serial Data Interface) wireless transmission system for uncompressed HDTV.

2. TRANSCEIVER CONFIGURATION

The transceiver block diagram is shown in **Fig. 1**,

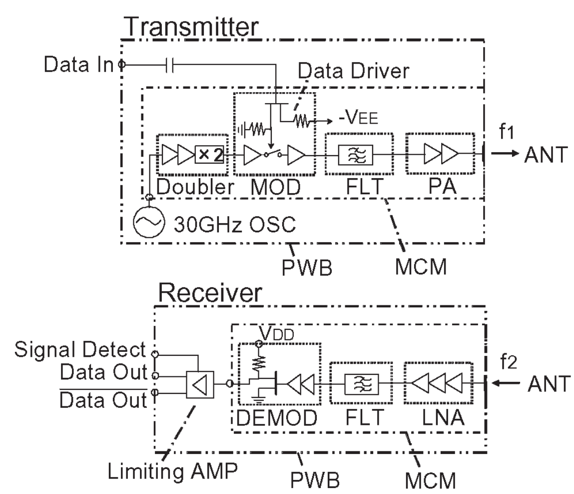

Fig. 1 60GHz-band ASK transceiver block diagram.

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adopting a direct ASK modulation and demodulation scheme for a simple configuration with a high data rate. The transmitter consists of a 30GHz-band oscillator, a 30 to 60GHz band frequency doubler, an ASK modulator, a bandpass filter and a power amplifier. Higher than 1.5Gbps ASK modulation can be realized using a Traveling Wave Switch (TWSW) with low insertion loss and high isolation[11] as described in Section 3.1. For the oscillator, a free running one with a phase noise of about –80dBc/Hz at 1MHz off-carrier can be used. However, for the unlicensed 60GHz-band in Japan, a DRO is adopted to meet with the permitted frequency tolerance of 500ppm. The receiver consists of a low noise amplifier, a bandpass filter, a demodulator (detector) and a post limiting amplifier enabling the output signal to be converted to the pseudo ECL (PECL) level. A pair of separate carrier frequencies of f1 and f2 about 3GHz apart is adopted for the duplex link in order to attain the requisite isolation between the transmitter and receiver.

The cross sectional structure of the millimeter-wave transceiver module is shown in **Fig. 2**. The features of our highly producible transceiver module are

(a) Coplanar MMICs and planar filters.
(b) Flip-chip mounted multilayer LTCC MCM.
(c) Antenna/MCM/PWB 3D compact transceiver module using Ball Grid Array (BGA) connection.

The MMICs are designed and fabricated based on 0.15μm AlGaAs/InGaAs HJFET technologies with high fmax of 240GHz.

3. HIGH SPEED ASK MOD/DEMOD

3.1 ASK Modulator

A schematic diagram of the circuit for the ASK modulator MMIC is shown in **Fig. 3**. A traveling wave switch is used for the modulation. For the HJFET pinched-off with –1.5V gate voltage, the switch is in the on-state as a low-loss transmission line. When the HJFET is turned on under the condition of 0V gate voltage, the switch is in the off-state as a very high-loss transmission line. The input impedance of the switch is so high that it is easy to be driven at high speeds. The data driver consists of only one HJFET, which acts as the pull down circuit for the data output at the HJFET drain to be negative, converting the input PECL data to the signal level for the switch on/off (–1.5/0V). The monolithic integration of the data driver with the switch avoids degradation of high speed operation due to parasitic capacitances in the case of hybrid configuration.

3.2 ASK Demodulator

Figure 4 shows a schematic diagram of the circuit for an ASK direct demodulator. The MMIC consists of a 2-stage low noise pre-amplifier and a detector. The detector comprises an HJFET biased in the nonlinear region. The ASK modulated 60GHz-band signal input to the gate is directly detected as an output voltage of the load resistor inferred from the drain current change. This scheme has advantages of high-speed capability and high sensitivity due to its small input gate capacitance and high gain amplification by the HJFET.

4. MMIC AND FILTER CHIPSET

Figure 5 shows 60GHz band CPW MMIC chipset. A doubler chip shows a higher than 0dB conversion gain for input frequencies from 29 to 32GHz. A

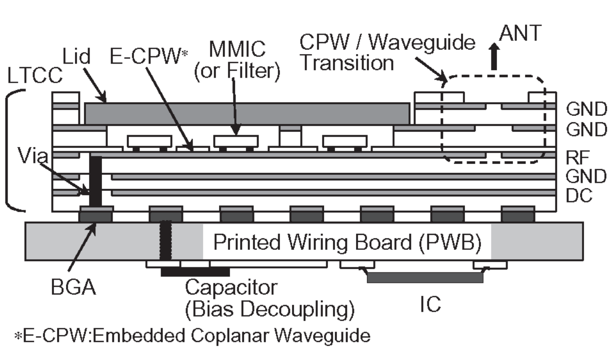

Fig. 2 Transceiver module cross sectional structure.

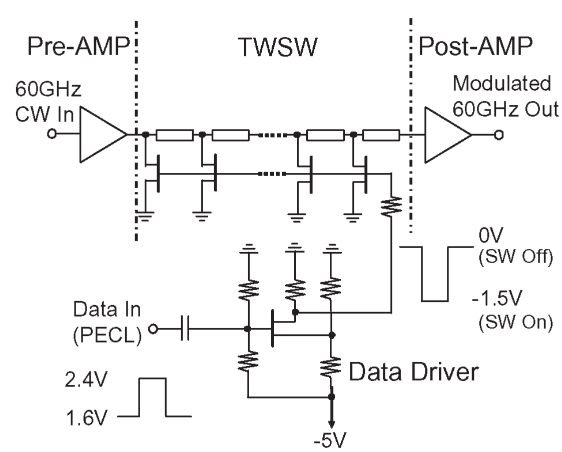

Fig. 3 A schematic diagram of the circuit for the ASK modulator MMIC.

modulator chip has a higher than 4dB gain with a high on/off ratio of 28dB from 59 to 64GHz. The on/off ratio has a high of 28dB. A 2-stage medium power amplifier chip[3] exhibits 12dB linear gain and a 14dBm saturated output power from 59 to 64GHz. A 3-stage low noise amplifier chip shows a higher than 18dB gain from 59 to 64GHz. A demodulator chip has a higher than 10mV output for an input power of higher than –30dBm. The chip size of all MMICs is 2.5×1.15 mm^2. A flip-chip bandpass filter has also been developed. This is of the planar dielectric waveguide type as shown in **Fig. 6**, having resonators formed by metalized front/backside surfaces and through holes in the alumina substrate with CPW input and output ports. The filter chip with 3 resonators is shown in **Fig. 7**. Cross coupling between the first and third resonators is introduced to enable steep attenuation characteristics of small size[8]. The filter in the receiver exhibits a 3dB bandwidth of 3GHz with 3dB insertion loss. The transmitter filter was designed for a narrower bandwidth having a 10dB bandwidth of 2.5GHz with a 2dB insertion loss. The chip size is 3.4×3.5mm^2.

5. TRANSCEIVER PERFORMANCE

Fabricated transmitter and receiver MCMs are shown in **Fig. 8**. **Figure 9** shows frequency response for the transmitter output power together with the filter response. 30GHz-band 0dBm CW signal is input to the doubler chip in the transmitter MCM by an RF probe. The peak output power for the ASK modulated 60GHz-band signal is plotted versus frequency. This is for f1 of 60.5GHz. The frequency response reflects that of the filter in the transmitter MCM, and is effective for reducing the bandwidth of the ASK modulated 60GHz-band signal. The output power is

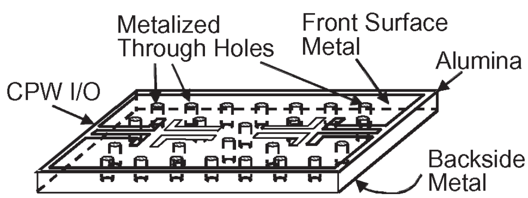

Fig. 6 Planar dielectric waveguide filter schematic.

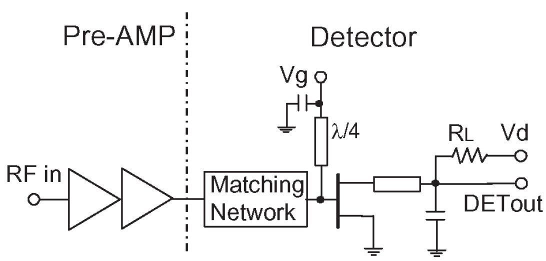

Fig. 4 A schematic diagram of the circuit for an ASK direct demodulator.

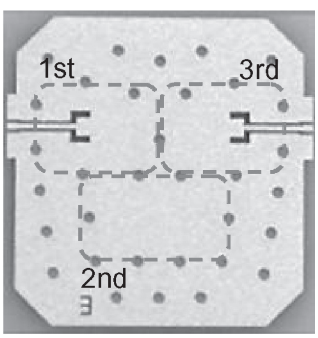

Fig. 7 Planar filter chip with 3 resonators. Broken lines indicate resonator arrange.

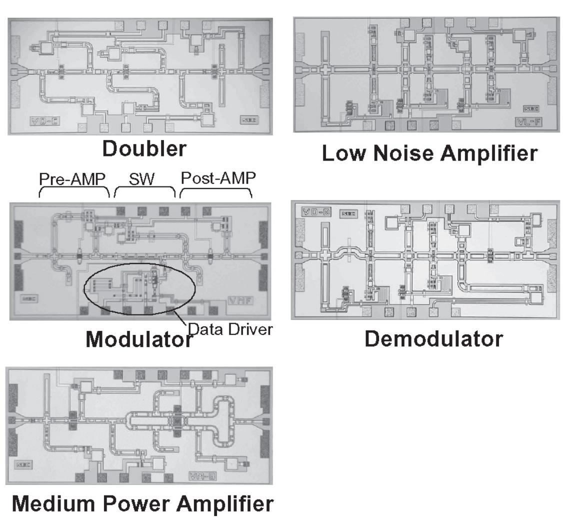

Fig. 5 CPW MMIC Chipset.

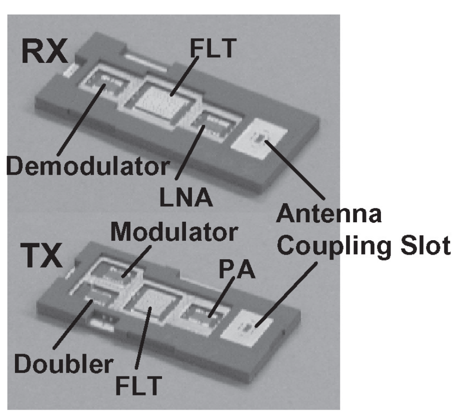

Fig. 8 Transmitter and receiver MCMs.

10.4dBm. The output spectrum of the transmitter for a 1.25Gbps random signal input is shown in **Fig. 10**. The occupied bandwidth defined as 99% power occupancy is 1.28GHz.

The receiver performance is shown in **Fig. 11**. The bit error rate (BER) is plotted against the received power at 1.25Gbps data rate. The minimum received power for less than 10^{-9} BER is –46dBm. **Figure 12** shows the eye pattern of a 1.485Gbps demodulated signal for HD-SDI at –40dBm received power. Good eye opening can be seen indicating error free signal demodulation.

6. BROADBAND WIRELESS LINKS

Several types of broadband wireless link product have been developed by adopting the 60GHz-band ASK transceiver. Wireless Gigabit Ethernet link has a function of a media converter to connect a fiber link to a full duplex wireless link seamlessly with 1.25Gbps data rate for both directions. **Figure 13** shows the wireless Gigabit Ethernet link configuration. The data input and output interface is a

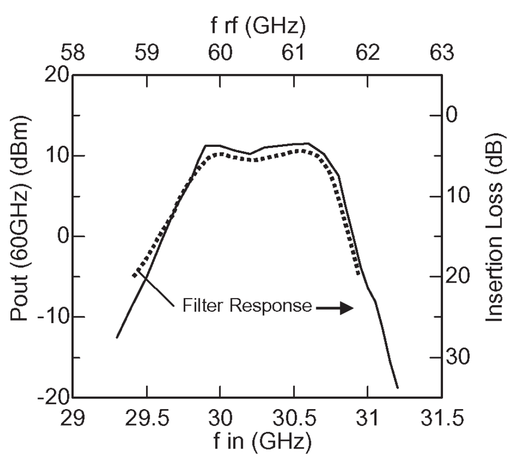

Fig. 9 Frequency response of peak output power for TX MCM.

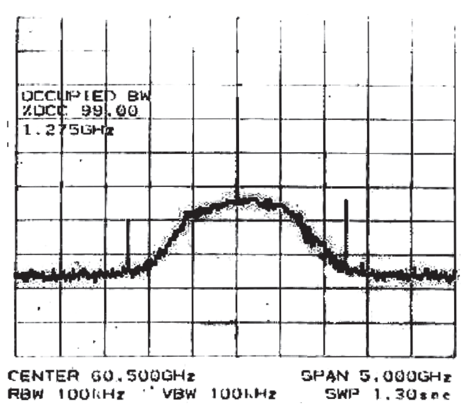

Fig. 10 Transmitter output spectrum for 1.25Gbps random signal input (V:10dB/div).

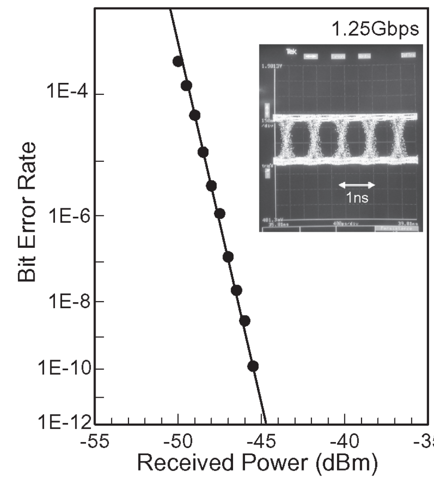

Fig. 11 Bit error rate performance and eye pattern power at a 1.25Gbps data rate.

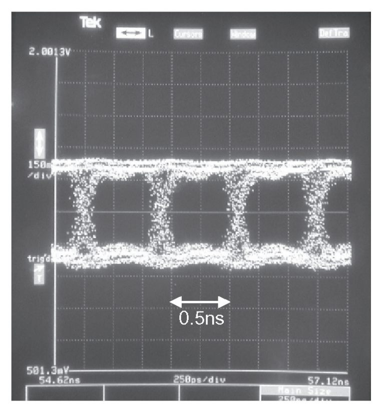

Fig. 12 Eye pattern of 1.485Gbps received signal.

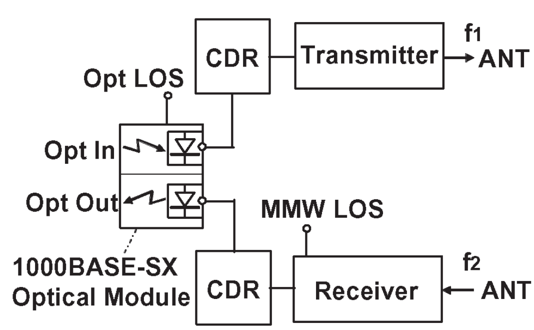

Fig. 13 Wireless Gigabit Ethernet link configuration.

Table I Millimeter-wave broadband transceiver products.

Wireless Link Type	Fast Ethernet			Gigabit Ethernet		HDTV
	Indoor		Outdoor	Indoor	Outdoor	Outdoor
Antenna Gain (dBi)	18	25	36	25	36	36
Transmission Range (m)	12	60	300	25	200	200
Data Rate	10/100Mbps Full-Duplex			1.25Gbps Full-Duplex		1.485Gbps
Data Interface	10BASE-T/100BASE-TX			1000BASE-SX		HD-SDI
Power Dissipation (W)	≤7		≤12	≤10	≤15	≤10
Weight (kg)	0.25	0.6	7	0.6	7	7

Photo 1 Wireless Gigabit Ethernet link product (a) for indoor use. Size: 200×50×140 mm^3.

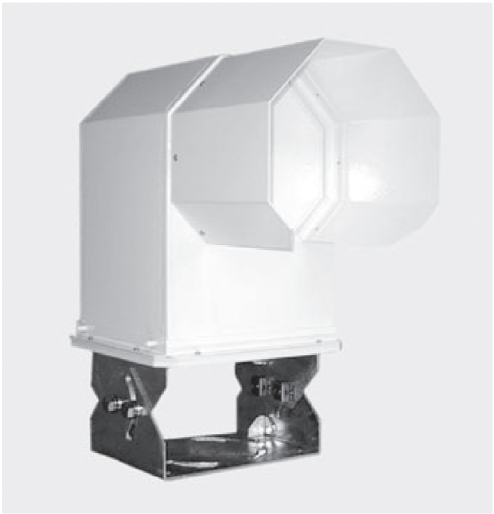

Photo 2 Wireless Gigabit Ethernet link product (b) for outdoor use. Size: 280×272×365 mm^3.

1000BASE-SX optical transceiver module. The transmitted data from the optical module is input to the millimeter-wave transmitter after waveform reshaping via the clock and data recovery circuit (CDR). The received data from the millimeter-wave receiver is input to the optical transmitter after waveform reshaping via the CDR.

Two types of the wireless Gigabit Ethernet link product have been developed with different kinds of antenna. One, featuring a compact size and a short transmission range of 25m is for indoor use and adopts a flat array antenna with 25dBi gain. Its appearance is shown in **Photo 1**. Another is for outdoor use and features the long transmission range of 200m using a 36dBi gain parabolic antenna. Its appearance is shown in **Photo 2**. The wireless Gigabit Ethernet link has advantages over the fiber link, such as instantaneous installation and transparency through the wall except for that made with the metal. It is suitable for high speed links between buildings and for links from the station to movable terminals in trains and cars.

The other outstanding wireless transmission system is for a 1.485Gbps HD-SDI uncompressed HDTV signal. This system adopts a unidirectional link for outdoor use and features the long transmission range of 200m. HD SDI signals are directly input/output to/from a millimeter-wave transceiver, without an encoder or decoder and show advantages over the conventional wireless transmission system for compressed HDTV owing to the extremely high quality and very little delay. The product view is the same as for Photo 2. **Table I** summarizes millimeter-wave broadband transceiver products commercialized by NEC Engineering, Ltd.

7. CONCLUSION

Millimeter-wave broadband transceivers with a data rate of as high as 1.5Gbps have been developed for the unlicensed 60GHz-band. A direct ASK modulation and demodulation scheme is adopted for the 60GHz-band transceiver utilizing the TWSW as an ASK modulator and an HJFET detector. CPW MMICs and planar dielectric waveguide filters have been developed. These are flip-chip mounted in TX and RX LTCC MCMs, which are assembled on printed wiring boards using BGA connection. A compact highly producible transceiver module is thus realized. Several types of 1.25Gbps full duplex wireless Gigabit Ethernet link, 1.485Gbps uncompressed HDTV wireless transmission system and so on for indoor and outdoor usage have been commercialized in order to take advantage of the easy usage of ultra high speed and broadband wireless links.

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REFERENCES

[1] K. Ohata, K. Maruhashi, et al., “A 500Mbps 60GHz-band Transceiver for IEEE 1394 Wireless Home Networks,” *30th European Microwave Conf. Proc.*, **1**, pp. 289-292, Oct. 2000.

[2] K. Fujii, M. Adamski, et al., “A 60GHz MMIC Chipset for 1-Gbit/s Wireless Links,” *2002 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1725-1728, June 2002.

[3] K. Maruhashi, M. Ito, et al., “Low-cost Antenna-integrated 60GHz-band Transmitter/Receiver Modules Utilizing Multi-layer Low-temperature Co-fired Ceramic Technology,” *2000 IEEE Int. Solid-State Circuits Conf. Dig.*, pp. 324-325, Feb. 2000.

[4] K. Maruhashi, M. Ito, and K. Ohata, “A 60GHz-band Coplanar-MMIC Chipset for 500Mbps ASK Transceivers,” *22nd GaAs IC Symp. Dig.*, pp. 179-182, Nov. 2000.

[5] K. Maruhashi, M. Ito, et al., “60GHz-Band Flip-Chip MMIC Modules for IEEE1394 Wireless Adapters,” *31th European Microwave Conf. Proc.*, **1**, pp. 407-410, Sept. 2001.

[6] K. Ohata, K. Maruhashi, et al., “Wireless 1.25Gb/s Transceiver Module at 60GHz-Band,” *2002 IEEE Int. Solid-State Circuits Conf. Dig.*, pp. 298-299, Feb. 2002.

[7] M. Ito, K. Maruhashi, et al., “A 60GHz-band Planar Dielectric Waveguide Filter for Flip-chip Modules,” *2001 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1597-1600, May 2001.

[8] M. Ito, K. Maruhashi, et al., “60GHz-band Dielectric Waveguide Filters with Cross-coupling for Flip-chip Modules,” *2002 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1789-1792, June 2002.

[9] K. Ohata, K. Maruhashi, et al., “1.25Gbps Wireless Gigabit Ethernet Link at 60GHz-Band,” *2003 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 373-376, June 2003.

[10] K. Ohata, “Developments of Gigabit Wireless Links in Japan,” *25th GaAs IC Symp. Dig.*, pp. 85-88, Nov. 2003.

[11] H. Mizutani and Y. Takayama, “DC-110 GHz MMIC Traveling Wave Switch,” *IEEE Trans. Microwave Theory Tech.*, **48**, 5, pp. 840-845, May 2000.

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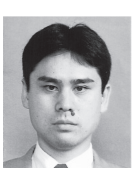

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