A Compact Ka-band 156 Mbps Transceiver for a Wireless LAN System Using PTFE/FR-4 Laminated MCMs

Kazuaki Takahashi, Suguru Fujita, Masugi Inoue*, Gang Wu* and Hiroyuki Yabuki

Mobile Network Research Lab., Matsushita Electric Industrial, Co., Ltd.,
3-10-1 Higashimita Tama-ku, Kawasaki 214-8501, JAPAN, E-mail: kazuaki@mrit.mei.co.jp
*Communications Research Lab., Independent Administrative Institution, JAPAN

***Abstract* - A millimeter-wave radio access system has a number of features that makes it appealing as one approach to broadband communications. However, for a millimeter-wave system to come into wide use, it must be miniaturized and the associated costs reduced. We have succeeded in realizing a compact 156 Mbps radio transceiver with a 38 GHz band optimizing RF architecture. We also adopted newly developed three-dimensional laminated MCMs using low cost plastic materials. It was confirmed in the initial experiments that this millimeter-wave wireless LAN equipment can cover a sufficient service area for broadband telecommunications in an indoor environment.**

I. INTRODUCTION

There has been increasing commercial demand for millimeter-wave radio systems and various concepts have been proposed in attempts to realize these systems. The wireless local area network (W-LAN) system is one of the more promising applications capable of providing broadband access above 100 Mbps for an indoor environment. In order to come into wide use, radio equipment should be cost-effective and small in size.

Optimization of RF system architecture suitable for millimeter-wave can achieve high-performance while at the same time allowing the miniaturizing of the radio. In considering the modulation circuits, modulation complexity must be effectively dealt with if compact and cost-effective radio is to become a reality. A linear modulation such as QPSK or QAM is very effective from the viewpoint frequency efficiency, although it is also true that linear modulation needs more complex and higher linearity devices than non-linear modulation such as ASK, FSK or MSK. Because of the existence of broadband frequency resources in the millimeter-wave band, it is possible to use nonlinear modulation. Above 100 Mbps direct modulators able to employ a dielectric resonated voltage controlled oscillator (DR-VCO) for MSK have been reported [1]-[2]. A significant downsizing of the radio equipment should be achieved by not only a DR-VCO but also by integrating the oscillator into a single module with the other circuit, which could be a base-band or bias circuit. A high-performance multi-chip-module (MCM) can be realized by utilizing multilayer ceramics (HTCC or LTCC) technology [3]. However, large-scale ceramics are not suitable due to substrate cost and mechanical reliability.

In this paper, we propose RF architecture suitable for a millimeter-wave W-LAN system in order to downsize the radio equipment. Additionally, a low-cost three-dimensional MCM structure using a PTFE/FR-4 laminated substrate was proposed. This structure can be integrated into a single module with all the radio functions including DR-VCO and base-band circuits. A 156 Mbps GMSK transceiver was successfully developed in a compact MCM incorporating the base-band circuits. These techniques resulted in very compact W-LAN device occupying a volume of less than 1000 cc. Furthermore the effectiveness of the developed W-LAN system was proven in an indoor test.

II. WIRELESS LAN SYSTEM ARCHITECTURE

A link budget was calculated listed in table 1. This W-LAN system provides a point to multipoint (P-MP) service, which consists of an access point (AP) and multiple stations (STs). Required antenna gain and transmitting power were calculated assuming a 20 m maximum distance. Ignoring rainfall attenuation, we optimized the link budget based on the condition that the equipment was to be used in an indoor environment. A TX power of 10 mW and a 25 dBi antenna gain product for TX and RX allows the maintenance of a good C/N margin of more than 4 dB. In order to realize P-MP service, the ST transmitting power should be adjusted to be lower than -50 dBc when the ST is not communicating with the AP. This is because leakage of the ST transmitter signal may interfere when another ST is transmitting a signal.

Radio specifications of the Ka-band wireless LAN system are listed in table 2. Frequency division duplex and reservation-based slotted idle signal multiple access (RS-ISMA [4]-[7]) were employed. In order to avoid multi-path fading, narrow beam width was adopted for the ST antenna, and circular polarization also has the advantage of being able to suppress reflected signal. On

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the other hand, the AP antenna was widened in order to maintain a wide service area. In order to realize a compact transceiver, the most important obstacle to overcome is circuit simplification. We employed the following RF architectures to realize a compact radio.

- Direct frequency modulation to the VCO can simplify the transmitter circuit.
- Adopting single conversion for the receiver can also simplify the receiver circuits.
- Employing an individual antenna configuration for TX and RX removes the need for an expensive antenna duplexer.
- Laminated MCM structure enabled us to reduce significantly the number of mechanical components and interconnect loss.

Table 1 Link budget design result

Modulation	GMSK (BbT=0.5)
RF Frequency	38 GHz
Service area	distance 2 to 20 m
Data Rate (Air)	156 Mbps
Required Bit Error Rate	1×10^{-7}
Noise Bandwidth	200 MHz
Receiver Noise Figure	8 dB
Transmit Power	10 dBm
Antenna Gain Products	25 dBi
Free Space Attenuation	70.1 to 90.1dB
Received C/N	27.9 dB
Required C/N	18.5 dB
C/N Margin (static error 5 dB)	4.4 dB

Table 2 Radio Specification of Wireless LAN

Radio Frequency	Down-Link: 37.75 GHz Up-Link: 38.75 GHz
Access/Duplex	RS-ISMA / FDD
Antenna Gain	AP : 5 dBi ST : 20 dBi
Beam Width	AP : > 60deg ST : >10deg
Polarization	Right-handed Circular Polarization

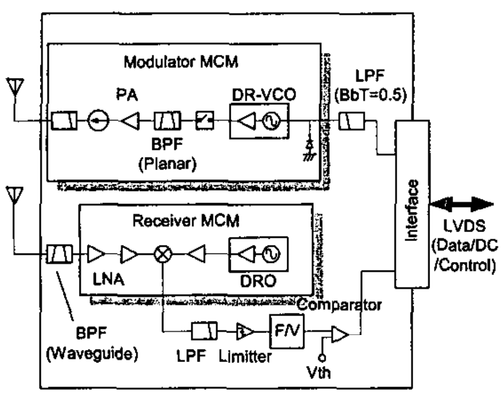


Figure 1 Block diagram of the Ka-band W-LAN Radio.

Figure 1 shows proposed W-LAN block diagram. This W-LAN consists of two Ka-band MCMs, and interface to MAC board installed on the PC was employed low-voltage differential signal (LVDS).

III. PTFE/FR-4 LAMINATED MCMS

A. Three-Dimensional Laminated MCM Structure

The structure of the new three-dimensional laminated MCM is shown in figure 2. The multilayer substrate consists of PTFE / woven-fiber-glass (TACONIC, U.S.) and glass epoxy (FR-4, Sumitomo Bakelite, JAPAN). On the topmost layer of the PTFE and the prepreg, there are square ca vities for the MMICs. This structure can minimize the bonding wire length to less than 250 μm since the cavity depth can closely approximate the MMIC thickness of 100 μm when 5 mil (127 μm) PTFE and 50 μm prepreg are used. Accordingly, interconnect loss can be reduced to less than 0.2 dB at 38 GHz. This laminated MCM can be easily integrated with other functional circuits such as a planar filter, intermediate frequency (IF) circuits and bias circuits. We evaluated a test sample MCM on which a Ka-band amplifier MMIC was mounted. Measured results are shown in figure 3 and compared with the extracted measured data excluding bonding wire effects, which was calculated form on-wafer measured data and measured 50 Ω lines on the MCM. This results means that interconnect loss of the bonding wire of less than 0.1 dB was obtained. In terms of production cost, this structure is promising since this laminated structure is based on a general printed circuited board (PCB) fabrication process.

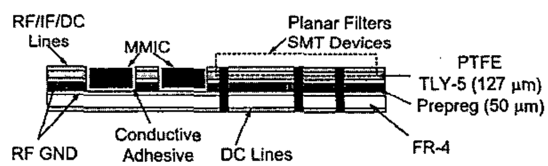


Figure 2 Three-dimensional laminated MCM

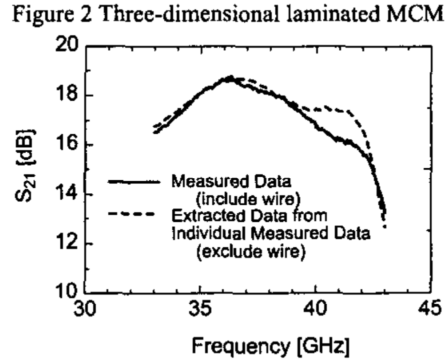


Figure 3 Fabricated Ka-band amplifier.

B. 156Mbps MSK Modem and Transceiver

We adopted a direct MSK modulator employing a 19 GHz band VCO and a frequency multiplier. A dielectric resonator was adopted to improve frequency stability. Figure 4 shows a fabricated transmitter assembled on the laminated MCM structure. Built-in planar filters were fabricated on the MCM substrate on which four MMIC dies, an isolator and bias circuits were assembled together. For the band limitation, a 5^{th}-order Bessel filter as an approximate gaussian filter was used employing an LC network. The base-band signal, which passed the filter, is added to the modulation port of the VCO, and the frequency modulation signal is obtained. Measured occupied bandwidth was 163.3 MHz as shown in figure 5.

For the receiver section, a dielectric resonated oscillator (DRO) was also employed to produce a local signal. As shown in figure 6, a small deviation of about 0.5 dB or less was obtained in the desired IF band (500 MHz ± 100 MHz). Single conversion was employed to simplify the circuit. The IF frequency was 500 MHz, and a waveguide RF filter was employed to suppress the image frequency and transmitter interference signal. In order to realize broadband demodulation up to 156 Mbps, an analog discriminator was employed as a frequency detector. Measured bit error rate (BER) as a function of input level is shown in figure 7 and compared with the theoretical GMSK value. The transceiver obtained –59 dBm input sensitivity to meet the required BER of less than 1×10^{-7} with a 2-dB degradation from the theoretical value.

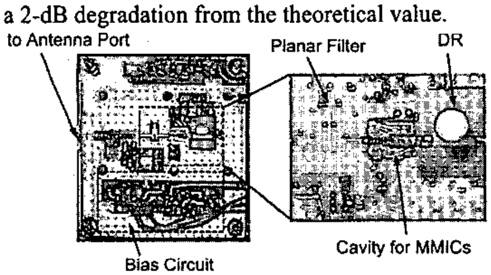


Figure 4. 156 Mbps GMSK transmitter fabricated on a laminated MCM.

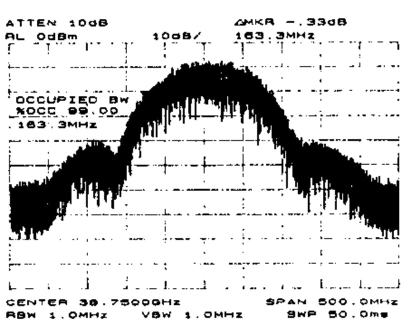


Figure 5 GMSK output spectrum

We fabricated a very compact W-LAN device at 38 GHz, as shown in figure 8. Both the AP and ST have an almost identical architecture. The device occupies an overall volume of 880 cc excluding the TX and RX antennas. Two different STs were developed in order to accommodate two types of installation situation, partition top and desktop.

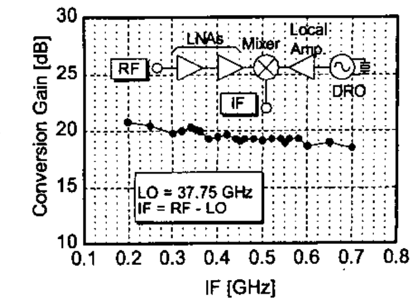


Figure 6 Frequency characteristics of the RX MCM

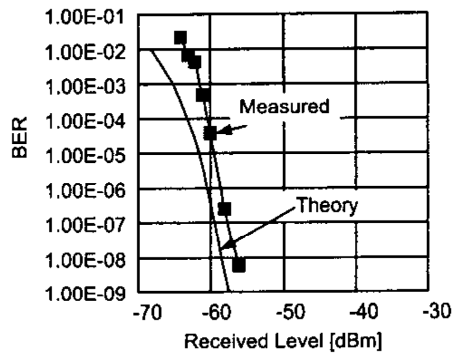
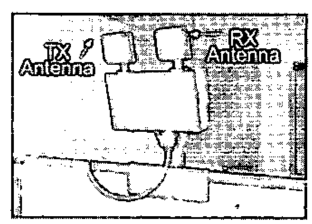
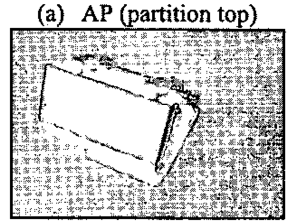


Figure 7 BER test results.



(a) AP (partition top)



(b) ST (desktop)

Figure 8 Photograph of the developed 38-GHz W-LAN

IV. W-LAN System Performance

The relation between RSSI and BER was measured by using a pairing between an AP and an ST to examine the effect of the multi-path environment. Figure 9 shows the installed equipment used in the multi-path effect test. Figure 10 and 11 shows the measured distribution of the RSSI and BER results, respectively. RSSI shows a smooth distribution where the voltage decreases as the distance increases. Only two BER dip points were observed at a distance of around 8 m. This means that there was a multi-path effect due to multiple reflections. At the same time, a BER of less than $1x10^{-5}$ was achieved throughout almost the entire service area. This raw BER level would result in excellent throughput quality if FEC or ARQ techniques were to be introduced.

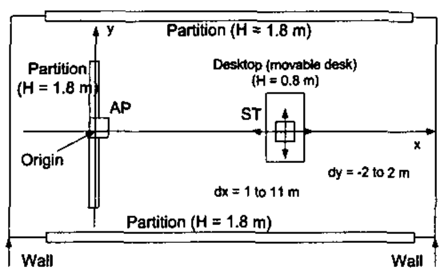


Figure 9. Equipment layout for multi-path environment

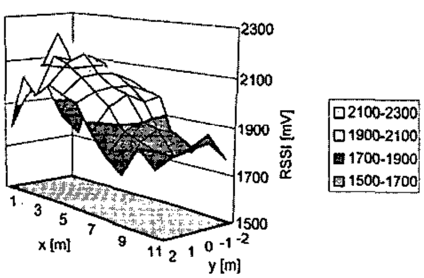


Figure 10. Measured RSSI voltage distribution in the multi-path environment

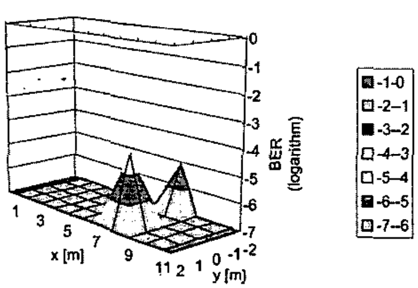


Figure 11. Measured BER distribution in the multi-path environment.

V. Conclusion

The optimization of RF architecture facilitated the downsizing of wireless LAN equipment. Additionally, a new PTEF/FR-4 laminated MCM structure was proposed as RF device concept. A compact Ka-band 156 Mbps transceiver using DR-VCO was then successfully developed and demonstrated on the proposed MCM structure. This laminated MCM realized to integrate with various functional circuits to obtain a compact radio.

A 156 Mbps transceiver obtained –59 dBm input sensitivity to meet the required BER of less than $1x10^{-7}$ with a 2-dB degradation from the theoretical value. The developed W-LAN equipment obtained a very compact volume of 880 cc excluding the TX and RX antennas. Furthermore, the wireless LAN system thus developed was evaluated in an actual indoor test. . The test results confirmed that this W-LAN system could provide an excellent service quality with handover and little multi-path effect, though still having a very simple configuration.

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