RECENT ACTIVITIES ON MILLIMETER WAVE INDOOR LAN SYSTEM DEVELOPMENT IN JAPAN (invited)

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ABSTRACT

The necessity for 60 GHz band development in Japan, the features of millimeter wave (MM-wave) indoor LAN, developments needed for its realization, and propagation studies to implement indoor LAN are reviewed. This paper describes a MM-wave minimum delay spread LAN under development in Japan, results of its propagation simulation, absorbable construction materials being considered for the system, and MMIC devices needed for the system.

INTRODUCTION

Recent Activities on Millimeter Wave Development in Japan

The Ministry of Post and Telecommunications (MPT) of Japan estimated that by 2010, the number of the radio terminals in Japan will be between 104-to-130 million.

In order to provide sufficient number of channels for personal use radio terminals, and the wide bandwidth required for the multimedia transmission, the MPT, for many years, has promoted millimeter wave technology development in Japan.

Under the support of the MPT, the MM-wave Sensing System Study and Development Committee, and the MM-wave Indoor Communication System Study Committee conducted studies during 1984-1990 and 1991-1993, respectively. The Promoting Association for MM-waves, organized in 1991 with more than 70 voluntary members of manufactures and users, has worked to promote MM-wave systems development and applications.

In 1992, the Communications Research Laboratory (CRL) of the MPT began a seven year program to develop a system model for MM-wave local area communications systems and the corresponding technologies. In November 1992, the MPT assigned the 59 - 64 GHz band for to-be-developed band, and the 59 - 60 GHz band for experimental systems. This frequency assignment is expected to cause most of the required development efforts to be concentrated in the specified single band, and allow the system developers to be able to purchase devices for that band quickly, and hopefully, at a low cost in the near future.

To date, many MM-wave systems applications have been proposed in Japan [1-3]. Among those systems, the small area communications, or the indoor LAN, and automotive radars are believed to be the most promising systems. This paper will cover indoor LAN system development.

Subjects of the MM-wave Indoor LAN

The most promising features of MM-wave systems applications are: wide frequency bandwidth and ample number of radio channels, small equipment size and weight, and low output power systems using small but very high gain antennas.

To realize indoor MM-wave LAN systems, two major technologies must be resolved. One is the development of 60 GHz devices, and the other is understanding the mechanism of MM-wave indoor propagation.

As for the devices, it is necessary to develop GaAs MMICs and flat antennas, both of which must be manufactured in large quantities and at low cost.

As for the propagation, it is well known that the MM-wave radio propagation is line-of-sight, similar to light waves. Therefore, an indoor communications system suffers from shadowing. In addition, multi-reflected radio waves may generate severe distortion in the received signal, especially for very high bit rate data transmission.

In the following sections, three technical approaches for solving the propagation difficulty, test results of the indoor propagation simulation, a system design for the Minimum Delay Spread (MDS) LAN, absorption characteristics of some construction materials to be used in the MDS LAN, and some excellent data on recent developed MMIC modules operating at 60 GHz are described.

MM-WAVE PROPAGATION

Indoor Propagation Model

One approach to overcome the man-made shadowing is to utilize positively the multi-path signals produced by the walls, furniture, doors, etc. This system was used on an 18 GHz indoor system, where only one among the multi-paths is selected between the transmitter and the receiver by the route diversity system; the delay distortion equalizer is not required [4].

As another approach, the CRL of the MPT in Japan has been studying the propagation characteristics for several kinds of room conditions, emphasizing delay spread mapping using omni-directional antennas which can receive all the multi-path signals, and thereby evading the man-made shadowing [5]. The NTT Radio System laboratory also published similar results for a ray-tracing simulation, with actual measurements emphasizing the delay spread technique [6]. Both groups have released key study results on ways to overcome multi-path distortion in the delay equalizer design.

Minimum Delay Spread LAN

In the other approach to avoid man-made shadowing, vertical transmission is applied in the pico-cellular zone structure, where a hub station antenna is installed on the ceiling, and most of the user station antennas are located in the pico-cell under the hub antenna, as shown in the Fig. 1 [7]. This configuration is worthwhile, since it minimizes the possibility of a person's intrusion into the direct path between hub and user antennas, and it enables to use line-of-sight signals.

While the hub station uses a broad-angle/low-gain antenna, the user terminal antennas are designed for narrow-beam/high-gain antennas, and are pointed directly at the hub antenna in order to reduce the multi-path distortion in the down-link.

To reduce the up-link multi-reflected power much lower than the direct wave signal, some radio absorbable construction materials are partially applied on both the ceiling and the floor. These materials are worthwhile, since it may be possible to omit the adaptive delay equalizers from the hub station receiver, if the technique is successful.

When the absorbable materials of more than 20 dB reflection loss and 10 dB loss are applied to the ceiling and the floor, with 90 % coverage, the distortion is estimated to be -26.8 dB (Table 1), this seems low enough for bi-phase PSK demodulation.

In the most applications, the total interference power is taken as the power sum of interference signals as long as they are not correlated with the desired signal. However, the NTT Radio System Laboratory recently reported the correlated interference signals, produced at multi-reflections, also should be treated the same as un-correlated signals, using a fading simulation system for 4PSK-100Mb/s IF transmission [8]. For example, when a 4PSK-100Mb/s modulation-demodulation system requires a C/N of 17.3 dB, including hardware imperfection of 4 dB, for 10^{-5} bit error rate, the total power of the thermal noise and the undesired interference signals must be -17.3 dB below the desired signal.

The MDS LAN features simplify the MM-wave circuits needed to reduce the route diversity system and delay equalizers, because of lower shadowing produced in this type of system. However, it requires only a small increase in construction cost since absorbers are used. Therefore, according to the cost trade-offs between the circuit simplification and additional small construction cost, this system will be introduced and used in the early stage of MM-wave commercial applications systems in Japan.

SYSTEM PARAMETERS FOR THE MDS LAN

The system parameters for a MDS LAN in a pico-cellular zone of eight meters diameter are shown in Table 2.

We intend to transmit more than 100 Mb/s data in both directions, at 10 mW output power at 60 GHz, using the hub and user antennas of 3 dB and 20 dB gain, respectively. The hub antenna radiates over the eight meter diameter zone, and the user antenna can selectively receive the direct wave transmitted from the specified hub station antenna, by narrowing the beam to about 10 degrees. Using the line-of-sight waves, this system features a fairly low propagation loss, and consequently, the gain of the system is not required to be high.

MEASUREMENTS ON INDOOR PROPAGATION

We have manufactured a 50 - 75 GHz measurement system for indoor vertical transmission as well as traditional horizontal transmission, both in the frequency domain and in the time domain converted from frequency domain measurement. The main features of this system are shown in Table 3, the photograph of the system is shown in Fig. 2 [9].

Transmitting and receiving antennas are mounted on separate wooden supports: elevation angle of the beam direction can be adjusted from -90 to +90 degrees in one degree steps, and the antenna heights can be also adjusted, respectively.

Fig. 3 shows the measurement configuration of the indoor vertical propagation, setting the TX antenna downward (-90 deg.) at about 180 cm high, and RX antenna upward (+90 deg.) at 50 cm high above the floor. From the measurement, it is found that there are four different dominant paths shown in the figure; (1) direct wave between TX and RX, (2) and (3) reflected waves at ceiling and concrete deck behind the ceiling, respectively transmitted as the TX antenna sidelobes, and (4) double reflection of the normal beam.

Fig. 4 (a) and (b) show the time domain data corresponding to the configurations of Fig. 3, and to the absorber conditions laid on the floor.

The measured peaks of Fig. 4 are consistent with the time delay and power loss calculated from the configuration, and the reflection loss value. Comparing data at peak 4, with and without absorber sheet laid under the hub antenna, the small size (30 cm square) absorber reduces the reflected power effectively by around 20 dB.

These measurements show how effectively absorber materials can be used to reduce reflected powers.

From the measurements of horizontal propagation shown in Figs. 5 and 6, the received power at the peaks from 1 to 4 varies 0 to -50 dB. This measurement is simulating the traditional horizontal propagation LAN, and it shows that the receiving dynamic range is required to be 50 decibels or more. On the contrary, the receiving level varies only about 10 dB for the TX-RX distance in the MDS LAN, since the signal at peak 1 is the principal signal.

Such high level and nearly constant receiving signal power allows the MM-wave band receiving circuits of the MDS LAN to be realized in a very simple way, i.e., small antennas, medium power amplifiers, moderate noise figures, etc.

RADIO ABSORPTION OF CONSTRUCTION MATERIALS

Studies of the absorbing characteristics of construction materials have been carried out in Japan as well as in European countries, for the use of some absorbing materials in the wireless LAN system.

We developed a reflection loss measuring system shown in Figs. 7 and 8. However, all the electrical units are the same as the measuring system shown in Fig. 2, but the arc type wooden support is designed to hold the antennas independently directed at the center of the test material, according to a specified incidental angle. Some sample data of the construction materials over 50 - 75 GHz frequency band are shown in Fig. 9. Of two ceiling materials, (a) a rock-wool acoustic plate has almost no absorbing characteristic, while (b) a pulp cement board has about 10 dB loss; (c) a synthetic fiber carpet tile to be currently used for floor has also no absorption, but (d) a fireproof cement excelsior board for wall-use shows about 20 dB loss.

Considering the wide range of possibilities of size, weight, cost and color for actual use, however, it is necessary to continue the study of various materials for absorbers.

60 GHz MMIC DEVICES

In order to realize the MDS LAN, all MM-wave active devices must be manufactured at low cost and in large quantities. MMICs are considered the best solution to meet these requirements. Following are sample results that our laboratories have developed for 60 GHz application systems.

The photograph, in Fig. 10, shows a MM-wave band oscillator MMIC chip, which oscillates in 55 GHz directly, and is stabilized by the dielectric resonator. The direct oscillation contributes to the hardware minimization and the high stability provides high quality transmission On this chip, frequency stability of -1.9 ppm/°C, and the phase noise of -88 dBc/Hz at 100 kHz off carrier are obtained. Its circuit schematics and the frequency spectrum are shown in Figs. 11 and 12 [10].

Fig. 13 shows the photograph of the MMIC receiver module chip, which is composed of a four stage LNA, an active gate mixer, a 60 GHz local oscillator, and a buffer amplifier on one chip. This MMIC features a larger scale integration which contributes to minimize the receiver size, and an image rejection frequency converter which removes the filtering circuit of the mixer. The obtained noise figure and the conversion gain are 4.8 dB and 20 dB, respectively. Its circuit diagram and the data of conversion gain and NF are shown in Figs. 14 and 15 [11].

CONCLUSION

The MPT of Japan has promoted the MM-wave development, by organizing committees and associations, and assigning a special frequency band at 60 GHz for experimental work.

This paper describes a very high speed MDS LAN configuration featuring a simple and low cost system, reducing the multi-reflected waves and man-made shadowing. Early work has produced propagation simulation results, effectiveness of the MDS LAN, and the possibility of using absorbable construction materials. The author's group will develop bread-board models and conduct system tests in 1995, using MMICs now under development.

The performances of the bread-board models and system test data will be disclosed in the future.

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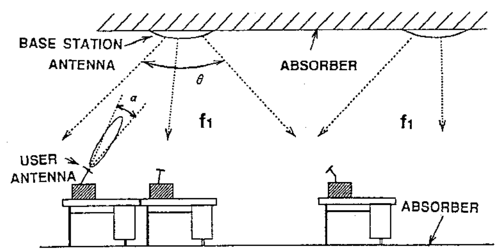


Fig.1 System Configuration of Minimum Delay Spread LAN

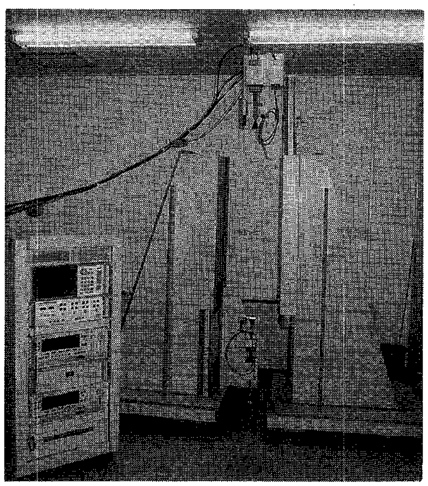


Fig.2 Photograph of Indoor Propagation Measurement System

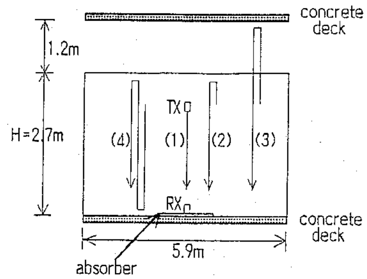
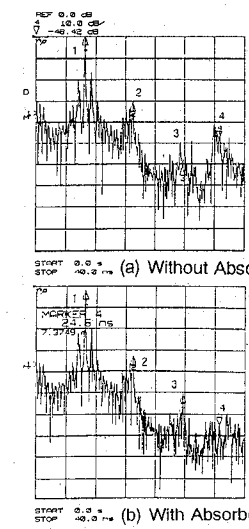


Fig.3 Measurement Configuration of Indoor Vertical Propagation



(a) Without Absorber

(b) With Absorber

Fig.4 Time Domain Data of Indoor Vertical Propagation

Table 1 Estimated Undesired Power Level

ITEM	LOSS(dB)
P_d (Direct received power)	0
P_{LP} (Propagation Loss of 3 times of distance)	10
P_{LC} (Reflection Loss on ceiling of 90% covered with 20 dB absorber)	9.6
P_{LF} (Reflection loss on floor of 90% covered with 10 dB absorber)	7.2
$P_d - P_u = P_{LP} + P_{LC} + P_{LF}$	26.8

Table 2 System Parameters of MDS LAN

Information	100 Mb/s digital signal
Information direction	bi-lateral
Zone diameter	8 meter
Ceiling height	3 meter
Frequency	59 - 60 GHz
Modulation	FSK
Output power	10 mW
Noise figure	8 dB
Antenna (base station)	3 dBi
Antenna (user unit)	20 dBi
Received signal	-49 dBm
Noise level	-79.9 dBm
Interference level	-75.8 dBm

Table 3 Main Features of Propagation and Reflection Loss Measuring System

Frequency	50 - 75 GHz
Max. output power	+3 dBm
Sensitivity	-84 dBm
Dynamic range	70 dB
Antennas [TX,RX]	horn antenna (23.5 dB typical)
Time resolution	better than 0.1 nsec
Numerical processing	FFT

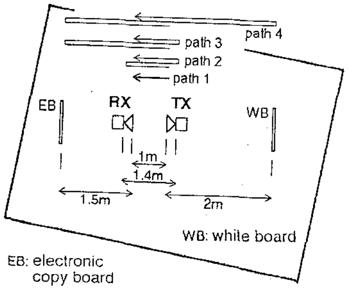


Fig.5 Measurement Configuration of Indoor Horizontal Propagation

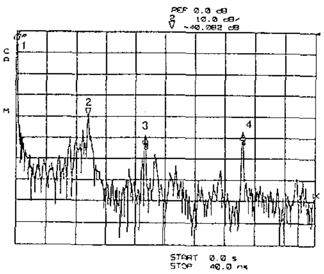


Fig.6 Time Domain Data of Indoor Horizontal Propagation

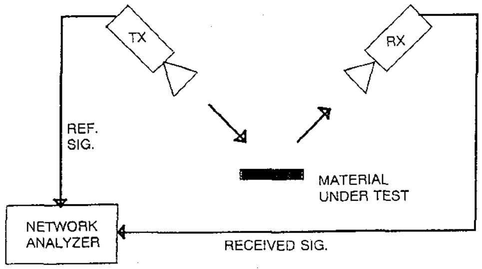


Fig.7 Block Diagram of Reflection Loss Measuring System

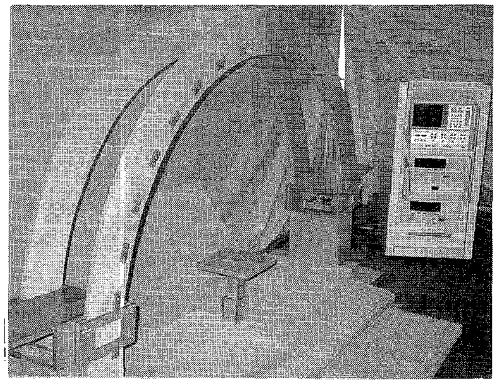
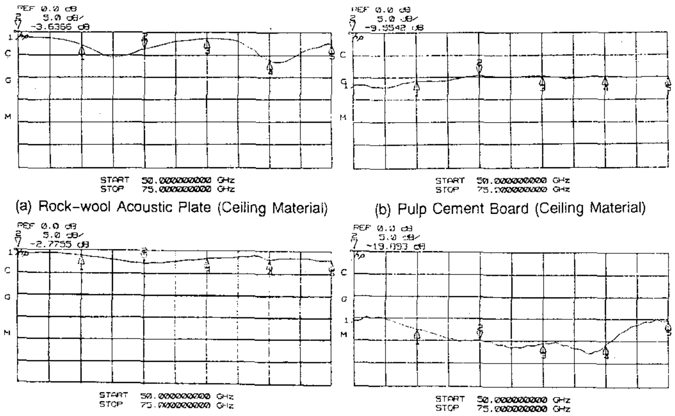


Fig.8 Photograph of Reflection Loss Measuring System



(a) Rock-wool Acoustic Plate (Ceiling Material) (b) Pulp Cement Board (Ceiling Material)

(c) Synthetic Fiber Carpet Tile (Floor Material) (d) Fireproof Cement excelsior Board (wall Material)

Fig.9 Sample Reflection Loss of Materials

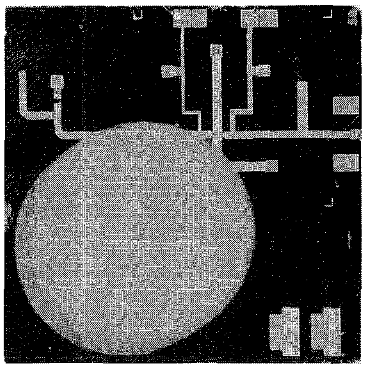


Fig.10 Photograph of DRO MMIC

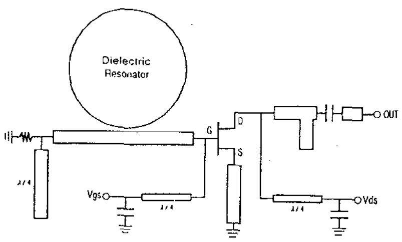


Fig.11 Circuit Schematic of DRO MMIC

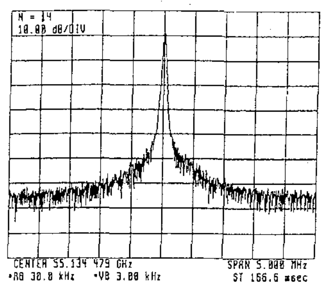


Fig.12 Oscillation Spectrum of DRO MMIC

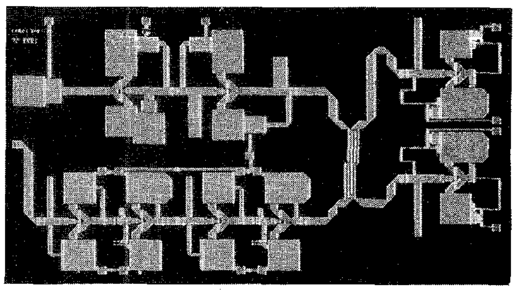


Fig.13 Photograph of Receiver Module MMIC

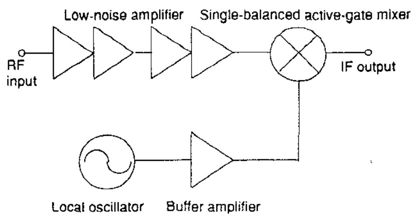


Fig.14 Receiver Circuit Diagram

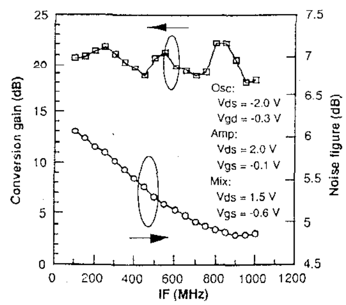


Fig.15 Receiver Conversion Gain and Noise Figure