Wideband Millimeter Wave/Optical Network Applications in Japan

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Abstract

This paper describes work on wideband millimeter-wave/optical network applications in Japan, especially projects being pursued at ATR. Results of fundamental transmission experiments demonstrate the feasibility of digital signal transmission at 118 Mbps with a BER of less than 10^{-6}. In addition, an advanced system considered suitable for future high-speed mobile communications is proposed. This system employs an intelligent multibeam antenna and the direction of each sharp beam can be controlled adaptively. An optical signal processing array antenna is found to be suitable for this system, and several key technologies for system construction are described.

Introduction

A rapid increase in the number of people using mobile/personal communication systems in Japan has pushed the capacity of all channels to their limit, and the problem will become even more severe with the implementation of high-speed data and/or video transmission services. Therefore, there is an urgent need to develop the millimeter-wave (MMW) band and utilize its large bandwidth.

This paper describes wideband MMW fiber optic technologies being developed in Japan for subcarrier transmission systems to be used in future mobile systems, especially projects being carried out at ATR [1]. Other related research in Japan, [2],[3],[4],[5],[6] is also introduced. In addition, construction of a wideband millimeter-wave/optical network for future high-speed mobile communications is described, and experimental results are shown. Results of fundamental transmission experiments are presented to demonstrate the feasibility of digital signal transmission at 118 Mbps with a BER of less than 10^{-6}, and prove the validity of the system concept.

However, some problems still need to be addressed. In this system, due to large propagation losses, a large transmission power is required to cover the wide area of the cell zone. In addition, the effect of multipath becomes serious when the signal bandwidth is wide. To cope with these problems, we propose an advanced millimeter-wave/optical network which employs an intelligent multibeam antenna where the direction of each sharp beam can be controlled adaptively. An intelligent antenna which enables the beam control is one of the key components in this system.

For this purpose, we earlier proposed an optical signal processing array antenna which can simplify the circuit configuration when the element number is increased[7],[8]. After some system evaluations, this antenna was found to be suitable for the above advanced system[9]. Several key technologies needed to construct subcarrier transmission systems are also described.

Research on Millimeter wave optical network systems in Japan

In Japan, several organizations have been researching millimeter wave optical networks. At ATR, we have proposed MMW over fiber for the first time that transmits a MMW signal over a fiber optic link[10] and have constructed a demonstration system. The details are given in the next section.

Osaka University has proposed a new optical transmission scheme for MMW signals using a time division multiplexing (TDM) technique[2],[3]. In the proposed system, MMW signals received by several antennas are sampled (bandpass sampling) and transformed to pulse trains of the TDM format, which then modulate the LD. After transmitted over the fiber, these signals are detected, divided into individual signals and demodulated. The main feature of this method is that it is free from intermodulations, and direct modulation of the LD is possible because the speed of the sampled signal is much lower than that of the MMW signal. Their main interest is routing technology for optical network systems based on theoretical considerations[4].

CRL (Communications Research Laboratory) in Japan has proposed the first intelligent antenna for millimeter-wave/optical network systems. They have also studied adaptive distributed antennas whose effectiveness has been confirmed theoretically[5].

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Millimeter wave optical network system developed at ATR

Figure 1 shows a fundamental block diagram of an MMW fiber-optic link developed at ATR. This system distributes MMW signals from a control station (CS) to a base station (BS) over a fiber. At the base station, the optical signals are translated to MMW signals. This means that no frequency conversion is required at the BS. This configuration allows us to achieve simple, small, and low-cost radio base stations because there is no need for frequency converters.

The standard frequency for applications of MMW in Japan is 60 GHz. However, 43.65 GHz is used in the experiment due to restrictions of the characteristics in the optical modulator. The

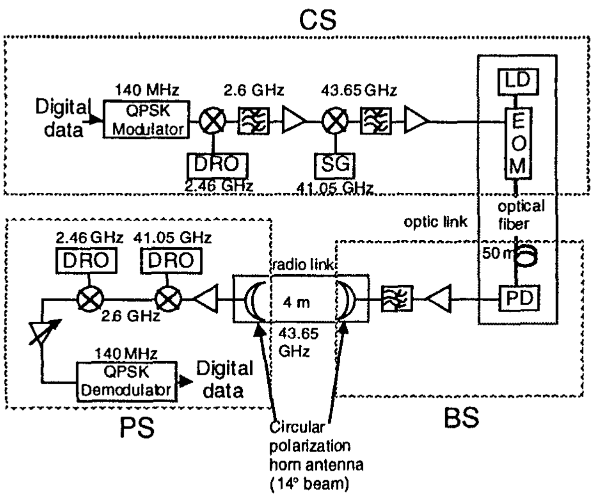

Fig. 1 Block diagram of a MMW fiber-optic link

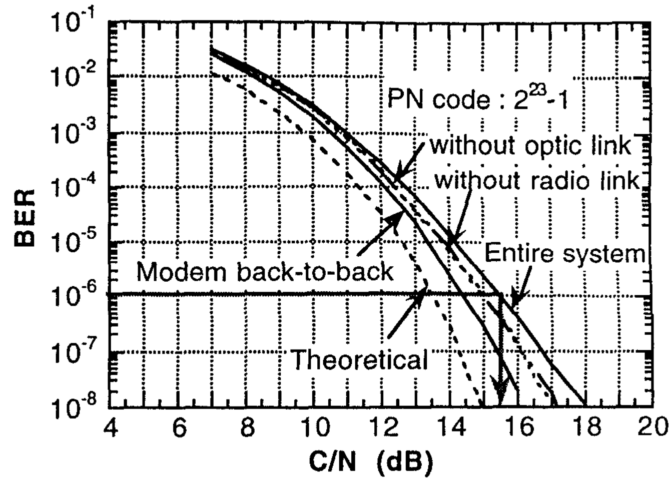

Fig. 2 Measured BER characteristics of the system shown in Fig. 1

transmission rate of the signals is 118 Mbps and QPSK modulation is employed. A short radio path (4 m) and narrow beamwidth (14 degree) Horn antennas are employed to obtain the BER transmission characteristics, and to avoid other effects such as multipath propagation.

Figure 2 shows the system's measured BER characteristics. The measured C/N, which achieves a BER of 10^{-6}, was 15.5 dB. This means degradation in the BER characteristics from the modem back to back was about 1 dB. The characteristics were obtained without an optic link and without a radio link. They were almost identical to the total system's BER characteristics. From these results, the feasibility of digital signal transmission at 118 Mbps with a BER of less than 10^{-6} was confirmed.

In order to prove the system concept, a demonstration system was constructed, having one control station, two radio base stations, and two personal mobile stations as shown in Fig. 3. For the broadband signal source, a moving picture was used. Since

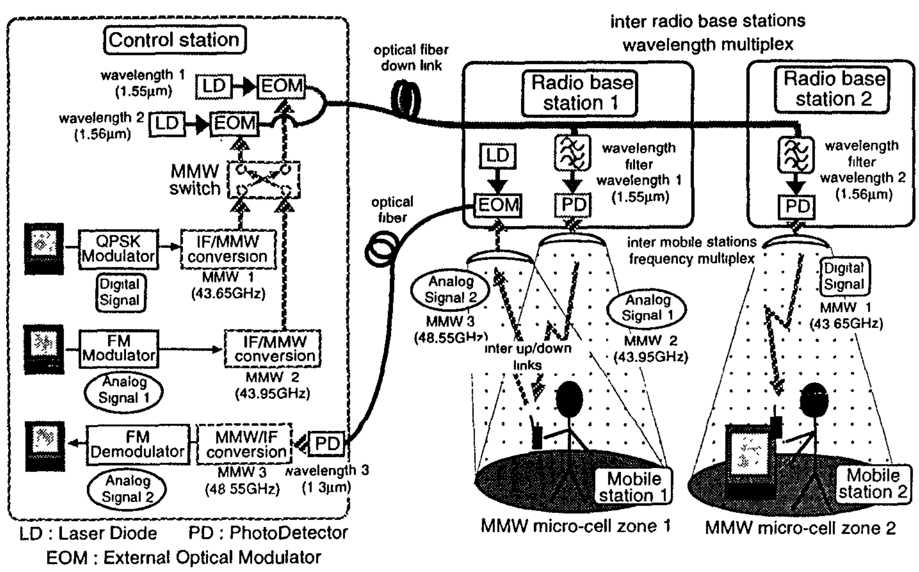

Fig. 3 Block diagram of demonstration system

an MMW fiber-optic link can transmit any modulation scheme, an FM analog video signal and a QPSK digital signal were transmitted simultaneously.

The experimental results showed that the analog video signal could be transmitted more than 50 meters with good image quality [11], and that the digital transmission characteristics were identical to those in Fig. 2. It was demonstrated that the moving picture could be tramsmitted with good quality, and the system concept was proved. Figure 4 shows a view of the experimental equipment.

Fig. 4 A view of the experimental equipment

Key components for building a millimeter wave optical network

The key components in this system are an optical modulator and a detector. To build the system shown in Fig. 1, a millimeter-wave optical modulator [11] and a millimeter-wave high-speed PIN detector [13] were employed. These components are comercially available. Figure 5 shows the frequency characteristics of the EOM which was used to build the system. The characteristics were measured by a two-tone method[14]. Although there are some dips between 40 GHz and 50 GHz (due to the imperfectness of the coaxial to coplanar transition), this modulator is applicable to this system because the response is not deteriorated around 43.65 GHz. Recently, these characteristics have been improved. As a millimeter-wave optical modulator capable of being operated at higher frequency bands, a ridged type one has been reported[15].

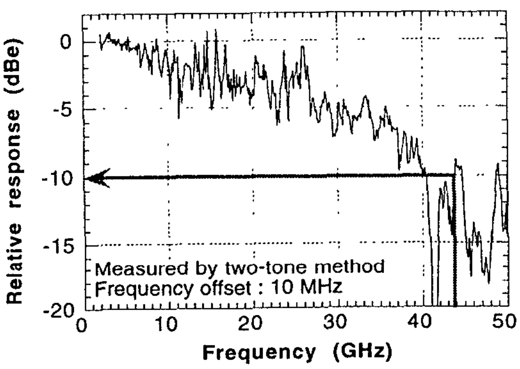

Fig. 5 Frequency characteristics of EOM used to build the system

Specified frequency bands in the millimeter-wave band are being allocated for millimeter-wave subcarrier systems. Accordingly, components employed for this system should have a high responsivity at the specified frequency bands. Based on this concept, several components have been developed. A millimeter-wave transimpedance amplifier was developed to provide a higher response than that of the unit detector at the specified frequency band [16]. Figure 6 shows its results. The receiver gives more than 15 dB improvement over the MSM photodetector itself in the frequency range of between 45 GHz and 50 GHz.

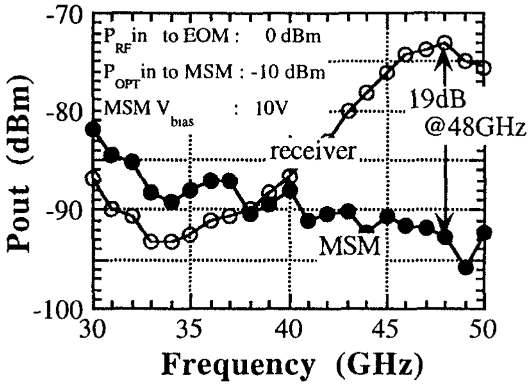

Fig. 6 Frequency responses of the OEIC receiver and the MSM photodetector

A millimeter wave optical network employing optical signal processing array antenna for a multibeam system

Figure 7 shows our image of a future advanced millimeter-wave/optical network that employs an intelligent multibeam antenna and where the direction of each sharp beam can be controlled adaptively to follow the movement of a portable terminal. The feature of this system is that the wide area of the cell zone can be covered and the effect of multipath can be avoided. In addition, this system can be adaptively controlled for traffic changes.

The fundamental system parameter is evaluated in this section to clarify the system image. Figure 8 shows the received power

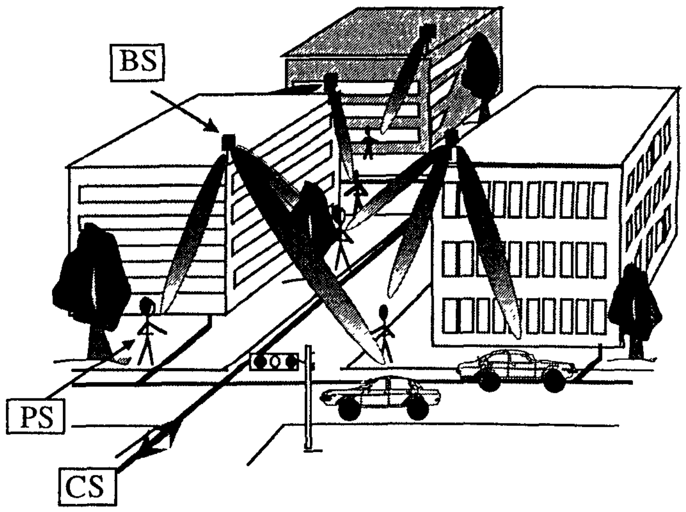

Fig.7 Future image of millimeter-wave fiber optic link system

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versus propagation distance characteristics assuming a 10 dBm transmitting power at 60 GHz. From this figure, it can be seen that to propagate more than 100 m, a total antenna gain of more than 30 dB is required.

In this system, we are considering that the BS should have an intelligent high gain antenna with a sharp beamwidth, and the PS should have a simple low gain antenna with a wide beamwidth, so that the PS can see the BS. The gain of a single patch antenna at 60 GHz has been calculated to be 7 dB[9]. However, when

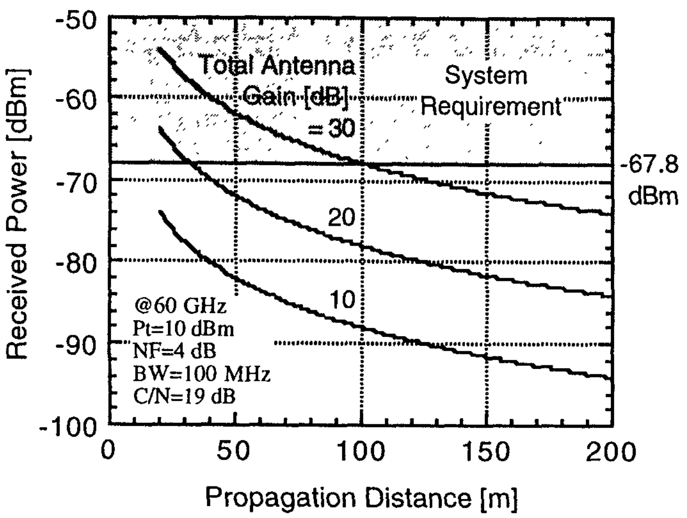

Fig. 8 Received power vs. propagation distance characteristics as total antenna gain parameter

the loss of the feeder and that of the substrate are considered, it has been estimated to be around 5 dB.

In this case, the gain of the BS antenna should be 25 dB. More than 100 elements are required to achieve the gain if we consider the case all array elements are to be uniformly excited.

An optical signal processing array antenna can control the phase gradients of microwave signals for many multibeam input signals[7],[8]. As a result, this antenna is suitable for the proposed system shown in Fig. 7 because it can simplify the circuit configuration compared with the conventional one using microwave phase shifters[17].

By applying this antenna to a future millimeter-wave fiber optic link system capable of transmitting wideband signals adaptively and following traffic changes can be constructed.

Conclusion

Work on wideband millimeter-wave/optical network applications in Japan, especially those being pursued at ATR, have been introduced. Results of fundamental transmission experiments have shown the feasibility of wideband digital signal transmission. In addition, an advanced system, which is considered to be suitable for future high-speed mobile communications, has been proposed. It employs an intelligent multibeam antenna and the direction of each sharp beam can be controlled adaptively. An optical signal processing array antenna was found to be suitable for this system.

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