Fiber Optic Millimeter-Wave Subcarrier Transmission Links for Personal Radio Communication Systems

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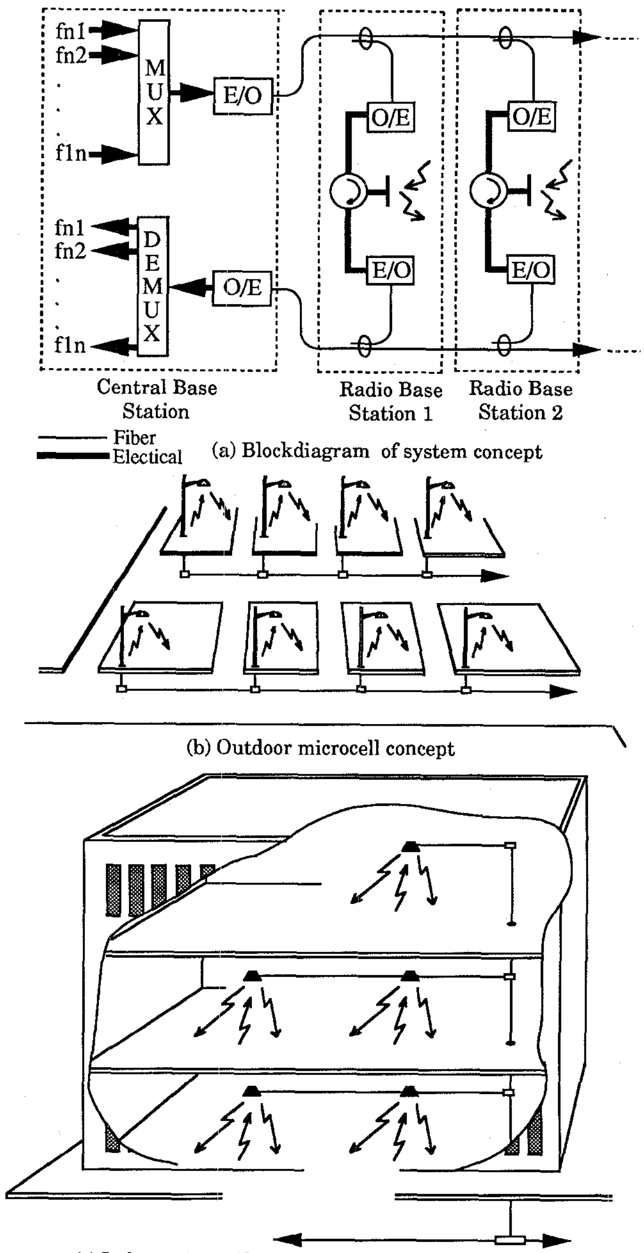
Abstract
This paper proposes two configurations of fiber optic links for use in millimeter-wave subcarrier transmission for personal radio communication systems. The system concepts for millimeter-wave personal communication systems are first described and the advantages of millimeter-wave frequencies are discussed. The combination of direct modulation and indirect (external) modulation techniques are utilized to transmit millimeter-wave signals. The fiber optic link is experimentally investigated. The 25-GHz band FM transmitter/receiver and 70-MHz QPSK MODEM are connected to the fiber optic link. These signals are simultaneously transmitted and excellent performance is observed.

INTRODUCTION

Fiber optic microcellular radio systems have been investigated for mobile and personal communications[1]-[5]. Since the microcellular systems consist of very small sized cells a few hundred meters in diameter, a large number of radio base stations is required for radio signal distribution. It is thus very important to fabricate a cost-effective, compact radio base station, i.e. a transmitter/receiver module composed of an E/O, an O/E, and amplifiers. Such systems utilize UHF-band subcarrier frequencies (radio frequencies) which are transmitted via optical fiber and propagated in the microcell. Commercially available optical devices are successfully utilized to demonstrate fiber optic microcellular mobile systems. However, broadband distribution such as video signals through radio frequencies could not be realized by the above system configuration.

In this paper, millimeter-wave subcarrier transmissions by fiber optic links are investigated to provide broadband signals to a large number of personal telephone terminals. The broadband video distribution networks are first demonstrated using subcarrier multiplexing techniques[6]-[8]. The basic system concept is shown in Fig.1. A large number of modulated millimeter-wave subcarriers is combined by power combiners. The optical power is intensity modulated by the composite signal and transmitted over a single-mode fiber, and divided by an optical power splitter at each radio base station. The divided optical signal is directly detected by a wide-band pin photodiode and amplified by millimeter-wave integrated amplifiers. The millimeter-wave frequencies are radiated into the microcell zone. The radio base stations receive radio frequencies from portable telephones and transmit optical signals to the central base station. Fiber-optic millimeter-wave subcarrier transmission links give the following advantages to the microcellular systems:

1. Millimeter-waves are essentially broadband frequencies which can transmit a large number of video subcarriers. For example, an FM-modulated 4.2-MHz NTSC video signal requires a 36-MHz bandwidth[9]. If the channel separation is 40



(a) Blockdiagram of system concept

(b) Outdoor microcell concept

(c) Indoor microcell zone concept

Fig.1. System concept of fiber optic millimeter-wave subcarrier transmission links

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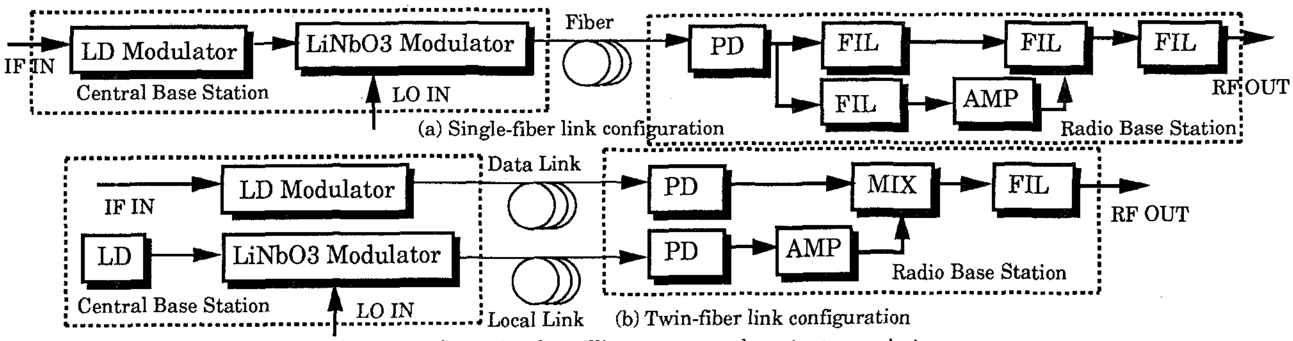


Fig.2. Fiber optic configuration for millimeter-wave subcarrier transmission

MHz[7] and 100 channels are transmitted, the required radio frequency band is approximately 3.6 GHz. The relative bandwidth becomes 0.06 if the center radio frequency is 60 GHz.

2. Millimeter-waves are absorbed by oxygeon and water molecules[10]. The absorption together with rainfall attenuation can be exploited to decrease the frequency interference between microcell zones.

3. The system control functions such as frequency allocation and a modulation/demodulation scheme can be housed in the central base station. This makes it possible to simplify the radio base station configuration.

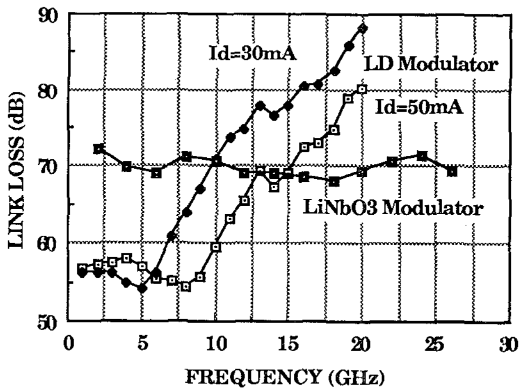
4. Fibers can run inside buildings to provide indoor microcells, as shown in Fig.1(c). Thus millimeter-wave signals could be propagated almost the everywhere personal activities exist.

LINK CONFIGURATION

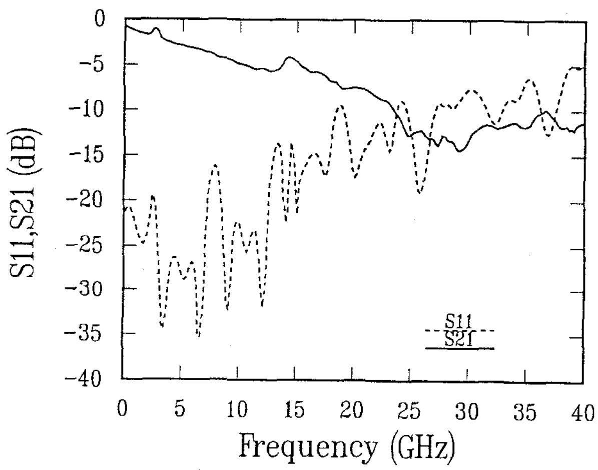
Millimeter-wave signal transmissions by fiber optic links have been attempted using external modulators[11], indirect subharmonic injection-locking techniques[12], laser diode nonlinearity[13], photodiode nonlinearity[14] and heterodyne techniques[15]. The frequency response of laser diodes is limited below a relaxation oscillation frequency[16]. On the other hand, external optical modulators such as $LiNbO_3$ integrated devices[17] are capable of millimeter-wave modulation despite their high driving voltage and optical insertion loss. In this paper, fiber optic links that combine the advantages of laser-diode direct modulation and $LiNbO_3$ external modulation are proposed for millimeter-wave subcarrier transmissions.

The basic link configurations for the down link which is defined as the link from the central base station to the radio base station are shown in Fig.2. The up-link from the radio base station to the central base station is not shown in Fig.2, because it is the same as the link described in Ref.[18]. Although multiplexed millimeter-wave frequencies are converted to optical signals at the central base station in Fig.1(a), modulated data signals whose frequency is below a relaxation oscillation frequency are multiplexed and modulate a laser diode at the central base station. Millimeter-wave output frequencies at the radio base station are obtained from the frequency mixer whose local frequency is optically transmitted by $LiNbO_3$ external modulator. Thus the frequency multiplexed millimeter-wave signals are radiated into the microcell zones through radio base stations.

The advantages of the link shown in Fig.2(a) are a reduction of the number of laser diodes, photodiodes and fibers, and simplification of base-station hardware. The disadvantage is an increase of link loss at local frequencies due to the limited output power of a laser diode. To decrease the link loss, frequency multiplexed data signals and local frequency are separately transmitted using different fibers, as shown in Fig.2(b). The output power of an optical source for a $LiNbO_3$ modulator can be increased because no wide-band frequency response or high linear performance are required. The data link and the local link can be independently designed and optimized despite an increase in the number of optical devices.



(a) Link loss of laser diode direct modulation link and LiNb3 external modulation link



(b) Frequency response of coplanar waveguide electrodes

Fig.3. Frequency response of direct modulation and external modulation links.

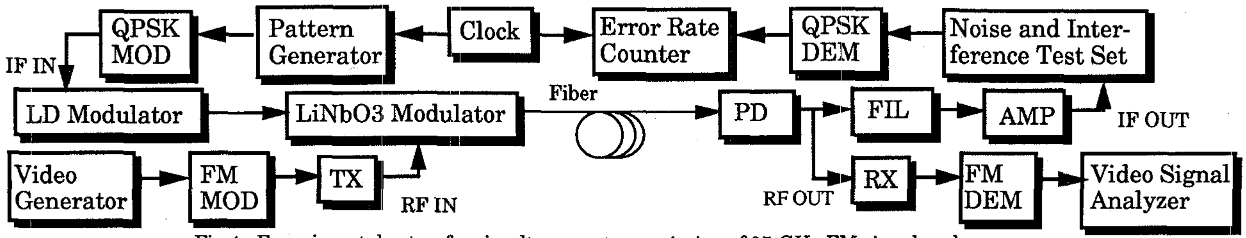


Fig.4. Experimental setup for simultaneous transmission of 25-GHz FM signal and 70-MHz QPSK signal using LD direct modulator and LiNbO3 external modulator.

EXPERIMENTAL RESULTS

To verify the fundamental operation of fiber optic links shown in Fig.2, the single-fiber link configuration is experimentally investigated. An InGaAsP laser diode (Ortel 1530A) is used as a direct modulator. The laser diode has a threshold current of 16mA and *cw* output power of 3.3mW at a forward bias current of 50mA, and the laser diode's 3dB electrical bandwidth is approximately 10GHz at a bias current of 50mA. A 40-GHz bandwidth photodetector (New Focus 1011) is used, whose responsivity is 0.48mA/mW.

The frequency response of direct modulation and external modulation is shown in Fig.3. A Sumitomo Cement optical guided waveguide modulator is used as an external modulator. The device is constructed from a Z-cut $LiNbO_3$ crystal with coplanar waveguide electrodes. The optical insertion loss is approximately 7dB and the voltage $V\pi$ for 100% modulation is 5.5V. The frequency response of coplanar waveguide electrodes is also shown in Fig.3. The input impedance characteristics deteriorate above 25GHz because of stray components between *rf* connectors and coplanar waveguides. Although the link loss of the external modulator is larger than that of the direct modulator at lower frequency bands below 10GHz, the loss is flat (70+2dB) in the frequency range of 2-26GHz.

The experimental setup for the single fiber link is shown in Fig.4. A bit error rate (BER) measurement is used to characterize the direct modulation link and an FM analog modulation scheme is used to evaluate the external modulation link. The laser diode is modulated by 70-MHz QPSK signal. The clock frequency of QPSK modulator is 6.312MHz. The detected IF signal is amplified and then supplied to the demodulator through a CNR measurement test set. The external modulator is modulated by a 25-GHz FM signal whose baseband width is 4.2MHz and required *rf* bandwidth is 36MHz. The BER performance is shown in Fig.5. A CNR degradation from the theoretical value is within 1.5dB at an error rate of 10^{-4}. Since its value is the same as that obtained without fiber optic links, no CNR degradation by fiber optic link connected between MODEM is observed. The external modulation link is characterized by the SNR measurement. Fig.6 shows the SNR versus the input power of RX and the modulation index m[19]. The SNR is first measured by a direct connection of TX and RX, and then measured using the $LiNbO_3$ external modulator. A small amount of SNR fluctuation is observed because of the instability of the TX transmitting frequency and RX local frequency. The average weighted SNR of the TX-RX link is about 60dB, while that of the single fiber link is about 59dB at a modulation index of 0.66. The weighted SNR is also a function of the modulation index m. Fig.5(b) shows the modulation index dependence of the SNR. The 60-dB SNR is obtained by an increase in the modulation index.

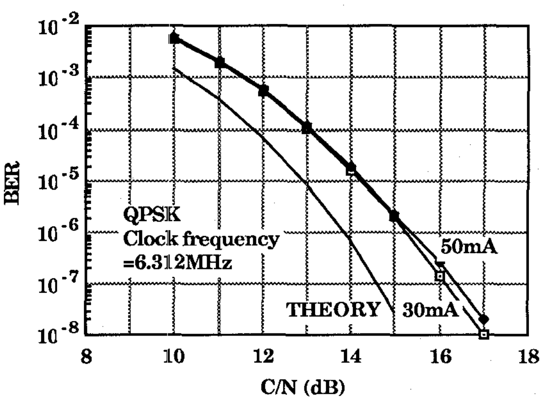
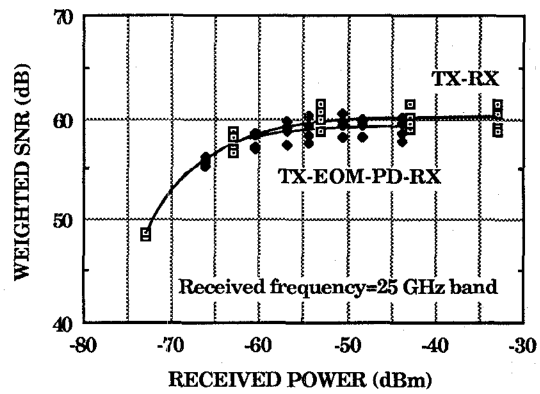
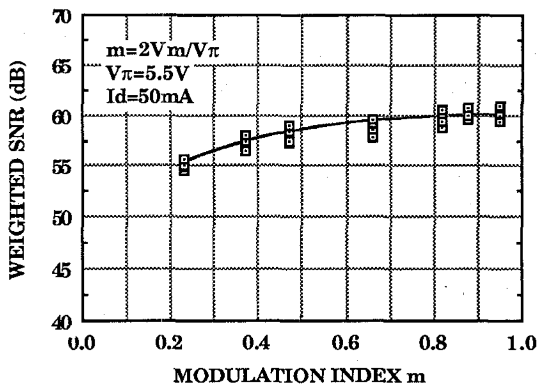


Fig.5. QPSK BER results of 70-MHz single fiber link.



(a) Weighted SNR versus received RX input power



(b) Weighted SNR versus modulation index of external modulator

Fig.6. Weighted SNR performance of 25-GHz single fiber link.

CONCLUSION

Two fiber optic configurations for millimeter-wave subcarrier transmissions are discussed and experimentally investigated. The system concept which utilizes the above optical links as well as its advantages are described. The combination of direct and external modulation is successfully configured to transmit both 25-GHz FM and 70-MHz QPSK signals. The degradation caused by the insertion of the fiber optic link is not observed in our experiment. Although the experiment was done in the 25-GHz band, the links discussed in this paper can be expected to transmit higher millimeter-wave frequencies by choosing an appropriate external modulator such as a resonant electrode modulator[17].

ACKNOWLEDGMENT

The authors would like to thank Dr. K.Habara, Dr. Y. Furuhama and Dr. M.Akaike for their continuous support and encouragement.

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