Fiber Optic Microwave Transmission Using Harmonic Modulation and Optoelectronic Mixing/Optically Pumped Mixing

Hiroyo Ogawa and Yoshiaki Kamiya

ATR Optical and Radio Communications Research Laboratories
Sanpeidani, Inuidani, Seika-cho, Soraku-gun, Kyoto 619-02, Japan

Abstract

This paper proposes two configurations of fiber optic links for use in microwave and millimeter-wave transmissions. Harmonic generation and the optoelectronic mixing/optically pumped mixing are successfully utilized in the fiber optic links. The performance of laser diodes as a harmonic modulator is experimentally investigated in the 10-GHz band. The *pin* photodiode is used as an optoelectronic microwave mixer and an optically pumped microwave mixer, and the microwave characteristics of the mixers are demonstrated. The two fiber optic links are promising to transmit microwave and millimeter-wave frequencies.

INTRODUCTION

ATR(*Advanced Telecommunications Research Institute International*) has been investigating wrist-watch size portable TV telephone systems. This system requires a wideband transmission capability, and a very small and handy personal terminal. Because of the small equipment configuration, the portable terminal cannot generate high output power. This decreases the distance between the central terminals and the portable terminals. Therefore, the number of sub-central terminals which connect the central terminal and the portable terminal must be increased to provide the signals to numerous personal telephones. In order to achieve the wideband transmission capability and signal supply network for a number of sub-central terminals, fiber optic links[1][2] must be adopted for the wrist-watch telephone systems. The sub-central terminal has the function of the frequency conversion from optics to microwaves/millimeter-waves or vise versa.

Microwave or millimeter-wave transmissions by fiber optic link have been attempted using an external modulator[3], a direct modulator[4], the indirect subharmonic injection-locking techniques[5][6] or laser diode nonlinearities[7]. In this paper, two fiber optic links utilizing the harmonic generation method[8] and the optoelectronic mixing[9][10] or the optically pumped mixing[11][12] are proposed. A simple way to obtain higher frequencies at the sub-central terminal is to detect the laser diode harmonics[13]. The detected signal can be used as the local input power for the optoelectronic mixer. The optically pumped mixer investigated in this paper utilizes harmonics from laser diodes. Both mixers have the advantages of frequency upconversion and allowing simplification of the receiver. The mixers make it possible to increase the output frequency of the sub-central terminal.

CONFIGURATION OF FIBER OPTIC LINKS

The basic configurations of the fiber optic link proposed in this paper are shown in Figs.1 and 2. The functions of the central terminal are modulation/ demodulation, and E/O - O/E conversion. The baseband signal is supplied to the electrical modulator to obtain the microwave subcarrier. The modulated

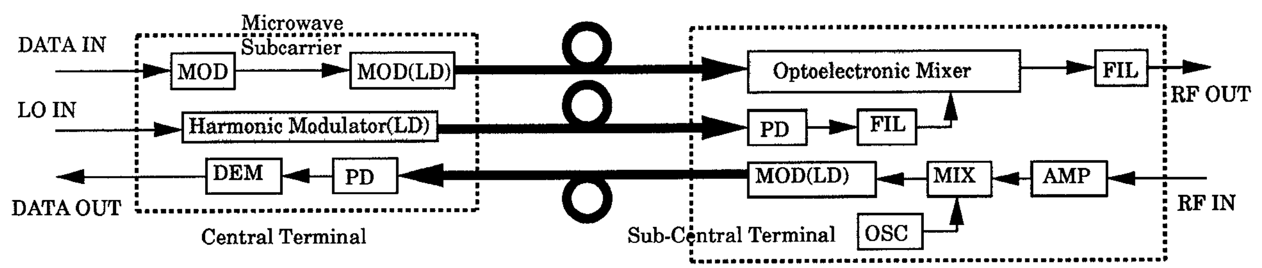


Fig.1. Fiber optic configuration for microwave and millimeter-wave transmission using harmonic modulation and optoelectronic mixing.

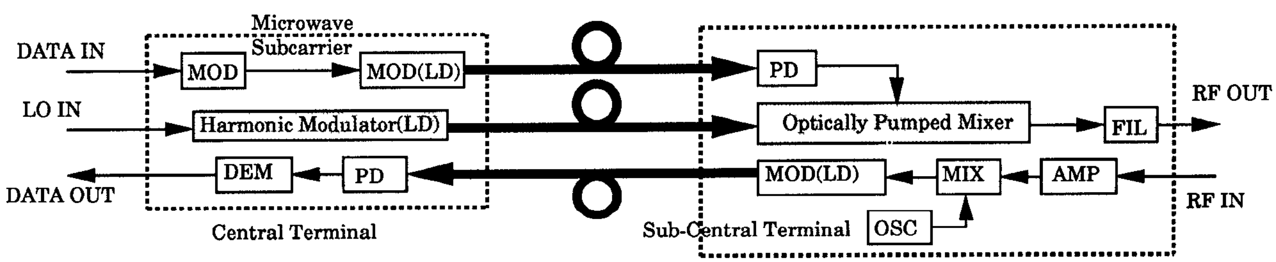


Fig.2. Fiber optic configuration for microwave and millimeter-wave transmiossion using harmonic modulationand optically pumped mixing.

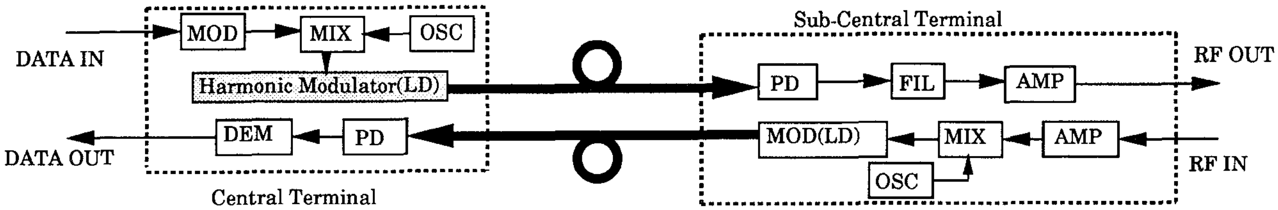


Fig.3. Fiber optic link configuration of microwave and millimeter-wave transmissions using harmonic modulation.

microwave signal is supplied to the optical modulator. The intensity modulated optical signal obtained by the laser diode is transmitted to the sub-central terminal through the fiber optic link and detected by the optoelectronic mixer or the optically pumped mixer. The local power for the optoelectronic mixer is obtained from the harmonic modulator in the central terminal. The amplitude of the harmonics is optimized using the bias condition of the laser diode, the input signal power level and modulating frequencies[8]. The received harmonics are detected by the photodiode and the desired frequency is selected by the microwave filter. The upconverted or down-converted signals are obtained from the optoelectronic mixer. The output frequency is determined from the local frequency and the subcarrier microwave frequency. The local frequency can be increased by the large-signal modulation of laser diode[13], and the subcarrier microwave frequency up to 10GHz is achieved by the commercially available laser diodes, therefore, the optoelectronic components which convert optical signals to microwave/millimeter-wave signals play an important role in the fiber optic links. The received signals at the sub-central terminal are converted to the intermediate frequency which can drive the optical modulators. The optical modulated signal is transmitted to the central terminal and detected by the photodiode.

In Fig.2, the optically pumped mixer is used for generation of microwave signals instead of the optoelectronic mixer. Harmonics generated from the laser diode are detected by the mixer and are used as local frequencies. The signal frequency is detected by the photodetector and supplied to the mixer diode. The upconverted or down-converted signals in the vicinity of harmonic frequencies are obtained.

In the link configuration shown in Figs.1 and 2, three fiber cables are required to connect the central terminal with the sub-central terminal. However, the other fiber optic link

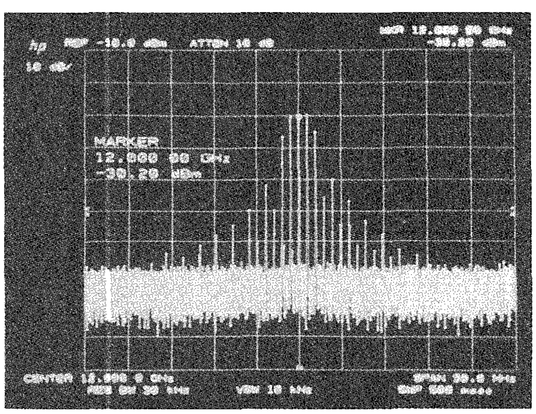
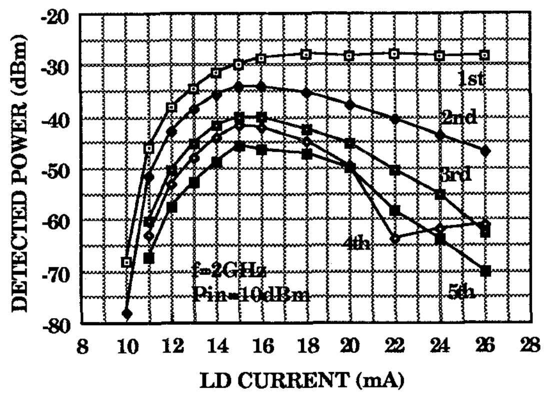
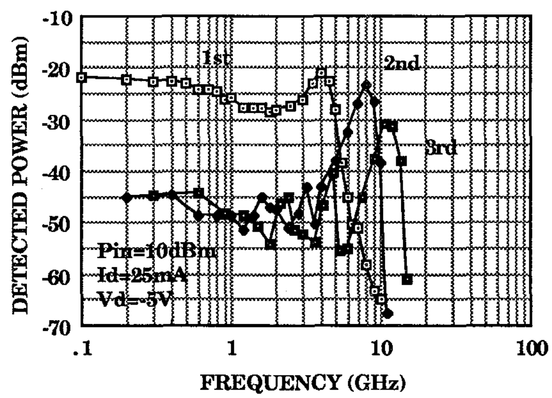


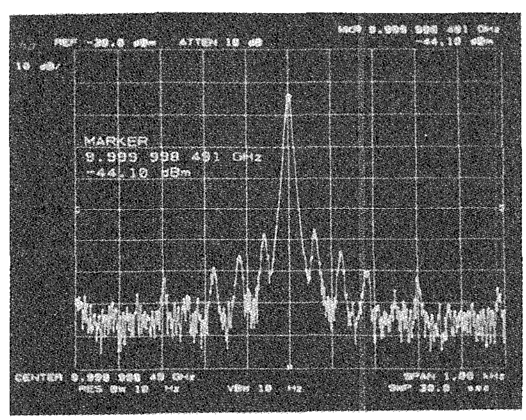
Fig.4. FSK modulated spectrum at 12GHz (fundamental frequency=4GHz). Modulation frequency is 1MHz and frequency deviation is 1MHz.



(a) Output power of harmonics



(b) Frequency response of harmonics



(c) Spectrum of 5th order harmonic (1st=2GHz)

Fig.5. Nonlinearity characteristics of laser diode.

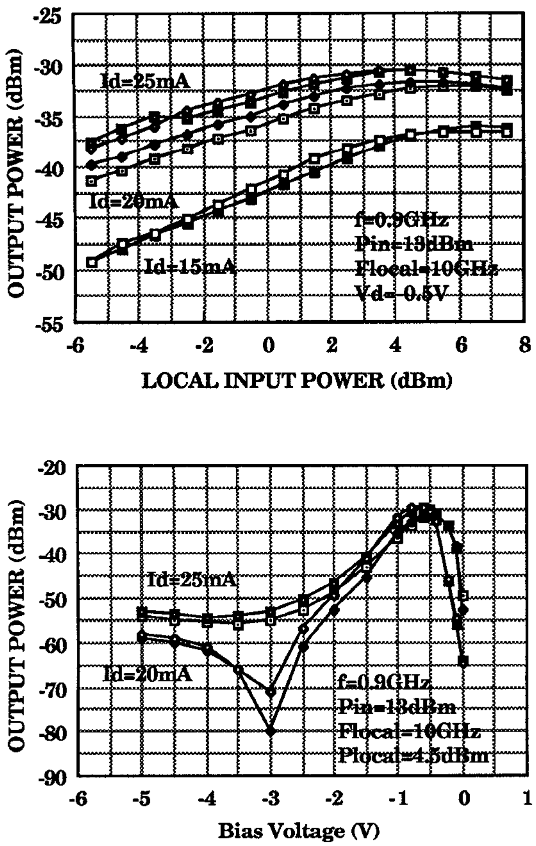


Fig.6. Performance of optoelectronic mixer.

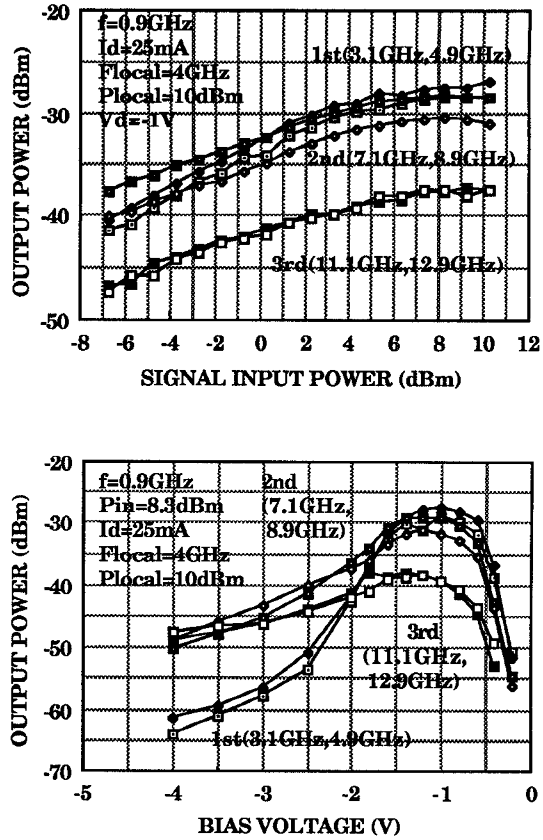


Fig.7. Performance of optically pumped mixer.

configuration, shown in Fig.3, needs two fiber cables. The reduction of the number of fiber cables are required for phased array antenna systems[14]. The modulated signal is converted to the microwave subcarrier and supplied to the harmonic modulator. The harmonics are transmitted to the sub-central terminal and detected by the photodiode. The desired frequency is selected by the microwave filter. Although the optical link is similar to the *Central Data Mixing*[15] link configuration, the modulation techniques are limited due to the frequency multiplication. However, FSK modulation techniques can be used in the links. Fig.4 shows the spectrum of the detected FSK signal at 12GHz, which corresponds to the third order harmonics. The modulation index number of the frequency modulator is adjusted according to the order of harmonics. This link will be evaluated using the bit error rate as well as the intermodulation distortion[16][17].

EXPERIMENT RESULTS

Two fiber optic links are experimentally investigated. The harmonic modulator is based on the InGaAsP laser diode(Mitsubishi FU11SLD-N). The laser diode has a threshold current of 10mA and an output power of 1.1mW at the forward bias current of 25mA. The InGaAs *pin* photodiode(Lasertron QDEUHS-035) used as the mixers has a 3-dB bandwidth of 10GHz with responsivity of 0.58A/W. The microwave 3-dB hybrid was used for separation of the 10-GHz local input power/0.9-GHz signal input power and the upconverted/down-converted output signals.

The nonlinearity characteristics of the laser diode are shown in Fig.5. The harmonics level is optimized by adjusting the modulation frequencies and the bias current. The bias current must be increased to obtain high harmonics level as the modulating frequency increases. The link loss of 4th harmonic (fundamental frequency=2GHz) is 52dB, while that of 2nd harmonic (fundamental frequency=4GHz) 34dB. The significant loss reduction was achieved under the large-signal modulation close to relaxation oscillation frequency[8]. The frequency spectrum of 5th harmonic is shown in Fig.5(c). The phase noise of 65dBc/Hz at 500Hz offset was obtained.

The performance of the optoelectronic mixer is shown in Fig.6. The conversion loss is saturated at the local input power of 4dBm, and the link loss of 43dB was attained in the 10-GHz band. The mixer characteristics are strongly dependent on the bias conditions. The minimum conversion loss was obtained at the reverse bias voltage of 0.5V. The intrinsic conversion loss of the mixer is estimated to be 8dB because the link loss of the signal frequency of 0.9GHz is 35dB. This results show photodiodes can have the function of microwave mixing as well as photodetection.

The input signal power and the bias voltage dependences of the optically pumped mixer are shown Fig.7. The 2nd harmonic at 8GHz and the 3rd harmonic at 12GHz was used as local frequency. The signal conversion loss of 36dB and 45dB was achieved at the local frequency of 8GHz and 12GHz, respectively. Since the local input power is dependent on the harmonics level generated in the laser diode, the signal conversion loss of the optically pumped mixer is larger than that of the optoelectronic mixer. In order to decrease the conversion loss, higher output power of the laser diode is required. The optimum bias condition for the optically pumped mixer is slightly different from that for the optoelectronic mixer. The experiment shows the reverse bias voltage of 1V gives the minimum conversion loss.

CONCLUSION

Two fiber optic radio links for microwave and millimeter-wave transmissions are proposed and experimentally investigated. The fundamental behavior of the optoelectronic mixer and the optically pumped mixer is described and these electro-optic devices are successfully applied to fiber optic microwave transmissions. Since the optic links are based on harmonic generation from laser diodes and optoelectronic or optically pumped mixers, the sub-central terminal can be simplified. Although the experiment was done in the 10-GHz band, the links can be expected to transmit millimeter-wave frequencies by choosing an ultra high-speed laser diode and photoodiode.

Fiber optic distribution networks are also constructed using the fiber optic link proposed in this paper. Each sub-central terminal forms microcell zones for communications between the central terminal and a number of wrist-watch size portable TV telephones. The inexpensive and simple sub-central terminals will have the potential for use in personal communication systems or phased array antenna systems.

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REFERENCES

[1] Special Issue on Applications of Lightwave Technology to Microwave Devices, Circuits, and Systems, *IEEE Trans. Microwave Theory Tech.*, vol.MTT-38, pp.465-688, May 1990.

[2] Special Issue on Applications of RF and Microwave Subcarriers to Optical Fiber Transmission in Present and Future Broadband Networks, *IEEE J. Select. Areas Commun.*, vol.SAC-8, pp.1221-1396, Sept. 1990.

[3] J.J. Pan, "21 GHz wideband fiber optic link," *IEEE MTT-S International Microwave Symp. Dig.*, pp.977-978, May 1988.

[4] R.D. Esman, L. Goldberg and J.F. Weller, "0.83- and 1.3-micron microwave (2-18GHz) fiber-optic links using directly modulated laser sources," *IEEE MTT-S International Microwave Symp. Dig.*, pp.973-976, May 1988.

[5] R.F. Herczfeld, A.S. Daryoush, A. Rosen, A.K. Sharma and V.M. Contarino, "Indirect subharmonic optical injection locking of a millimeter-wave IMPATT oscillator, "*IEEE Trans. Microwave Theory Tech.*, vol.MTT-34, pp.1371-1375, Dec.1986.

[6] A.S. Daryoush, A.P.S. Khanna, K. Bhasin and R. Kunath, "Fiber optic links for millimeter wave communication satellite," *IEEE MTT-S International Microwave Symp. Dig.*, pp.933-936, May 1988.

[7] A.S. Daryoush, P.R. Herczfeld, Z. Turski and P.K. Wahi, "Comparison of indirect optical injection-locking techniques of multiple X-band oscillators," *IEEE Trans. Microwave Theory Tech.*, vol.MTT-34, pp.1363-1369, Dec.1986.

[8] A.S. Daryoush, "Optical Synchronization of millimeter-wave oscillators for distributed architectures," *IEEE Trans. Microwave Theory Tech.*, vol.MTT-38, pp.467-476, May 1990.

[9] R.N. Simons, "Microwave performance of an optically controlled AlGaAs/GaAs high electron mobility transistor and GaAs MESFET," *IEEE Trans. Microwave Theory Tech.*, vol.MTT-35, pp.1444-1455, Dec.1987.

[10] C. Rauscher, L. Goldberg and A.M. Yurek, "Self-oscillating GaAs FET demodulator and downconverter for microwave modulated optical signals," *IEEE MTT-S International Microwave Symp. Dig.*, pp.721-724, June 1986.

[11] N.J. Gomes and A.J. Seeds, "Tunneling metal-semiconductor contact optically pumped mixer," *IEE Proc.*, vol.136, Pt. J, pp.88-96, Feb.1989.

[12] A.J. Seeds, I.D. Blanchflower, G. King, S.J. Flynn and N.J. Gomes, "New developments in optical control techniques for phased array radar," *IEEE MTT-S International Microwave Sym. Dig.*, pp.905-908, May 1988.

[13] A.S. Daryoush, R. Glatz and P.R. Herczfeld, "Analysis of large-signal modulation of laser diodes with application to optical injection locking of millimeter wave oscillators," Proc. Conference in Lasers and Electro-optics, April 1987.

[14] K.B. Bhasin and R.R. Kunath, "Optically interconnected phased arrays," *Proc. SPIE*, vol.947(Interconnection of High Speed and High Frequency Devices and System), 1988

[15] I. Koffman, P.R. Herczfeld and A.S. Daryoush, "High speed fiber optic links for short-haul microwave applications," *IEEE MTT-S International Microwave Symp. Dig.*, pp.983-986, June 1989.

[16] K.Y. Lau and A. Yariv, "Intermodulation distortion in a directly modulated semiconductor injection laser," Appl. Phys. Lett., vol.45, pp.1034-1036, Nov.1984.

[17] W.I. Way, "Large signal nonlinear distortion prediction for a single-mode laser diode under microwave intensity," *J. Lightwave Technol.*, vol.LT-5, pp.305-315, Mar.1987.