Fiber Optic Microwave Links Using Balanced Laser Harmonic Generation, and Balanced/Image Cancellation Laser Mixing

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Abstract
This paper proposes three configurations of fiber optic links for use in microwave transmission. Two laser diodes are used for balanced harmonic generation and the optical power from each diode is combined and detected by photodiodes. The fundamental and odd harmonics are suppressed and even harmonics added. The balanced and image cancellation laser mixing which utilizes the combination of microwave components and optical devices can suppress the local and image frequencies, respectively. These configurations are experimentally investigated at microwave frequencies and the fequency suppression is successfully demonstrated.

INTRODUCTION

A number of fiber optic links has been investigated for microwave and millimeter-wave signal transmissions[1]-[5]. The performance of optical devices is being improved and the maximum operating bandwidth has exceeded the Ka-band[6][7]. Another technique which can extend the bandwidth of fiber optic links is utilization of inherent nonlinearities of the optical devices, i.e. laser diodes[8] and photodiodes[9][10]. A laser diode modulated by a large *rf* signal power whose frequency is close to a relaxation oscillation frequency can generate high level harmonics[8]. The generated harmonics can then be used as the carrier reference signal[3]. The photodiode nonlinearity can also produce harmonics and these harmonics are exploited to convert the frequency of the detected modulation signal[9]. These harmonics not only extend the fiber optic link bandwidth, but also often generate undesired spurious frequencies. To suppress the undesired spurious frequencies, microwave filters must be connected to optical devices.

In this paper, three fiber optic link configurations that utilize the combination of microwave functional components and optical devices are proposed. These links can suppress undesired spurious frequencies generated by laser diode nonlinearities. One configuration is a balanced laser harmonic generation link which consists of two laser diodes, an out-of-phase divider, one or two photodiodes, an in-phase combiner and one or two fibers. The other configurations are the balanced/image cancellation laser mixing links which are composed of two laser diodes, two photodiodes, out-of-phase dividers, in-phase combiners, 90° hybrid circuits and two fibers. The fundamental behavior of these configurations is discussed and the basic performance is demonstrated at microwave frequency bands.

LINK CONFIGURATIONS

A. Balanced Laser Harmonic Generation Link
The configurations of the balanced laser harmonic generation link are shown in Fig.1. The single-fiber link consists of an out-of-phase divider, two laser diodes, an optical combiner and a photodiode, while the twin-fiber link utilizes two photodiodes and an in-phase combiner instead of an optical combiner. Since the basic behavior of the single-fiber link is the same as that of the twin- fiber link, the mechanism to cancel undesired signals is discussed below for only the single-fiber link. The input microwave signal is divided out-of-phase and then modulates the laser diodes. Two intensity modulated optical signals which contains harmonics of the input frequency are combined by an optical combiner and detected by a photodiode. The fundamental and odd harmonics are suppressed because these frequencies whose

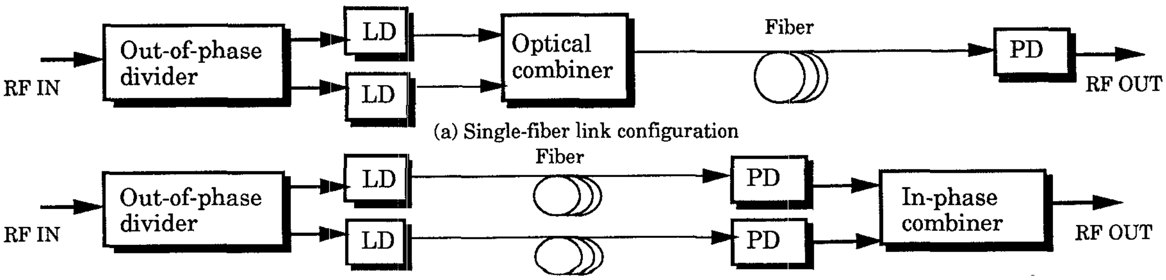

Fig.1. Link configurations of balanced laser harmonic generation

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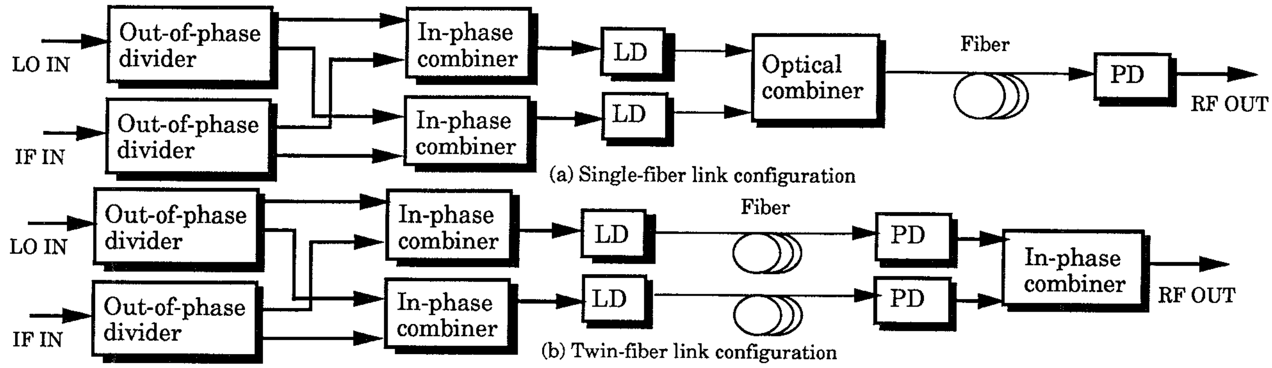


(a) Single-fiber link configuration

(b) Twin-fiber link configuration

Fig.2. Link configurations of balanced laser mixing

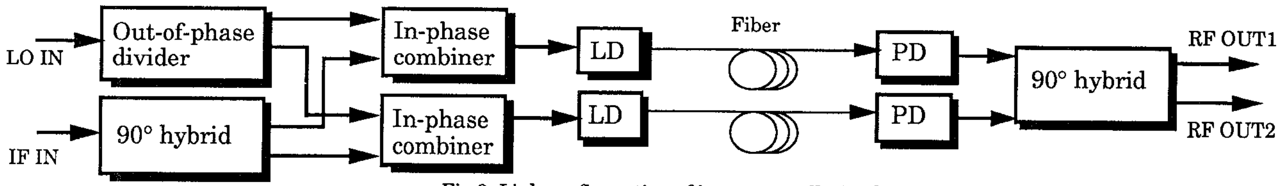


Fig.3. Link configuration of image cancellation laser mixing

phase relation is given by the microwave out-of-phase divider are detected out-of-phase. The even harmonics are added because of the in-phase relationship. Thus, in principle the detected microwave frequencies include only the even harmonics of the input frequency. Although the same idea was demonstrated using an optical interferometer[8], the link configuration proposed here utilizes the microwave functional circuits such as out-of-phase dividers and combiners.

B. Balanced Laser Mixing Link

Since the laser diode can operate as an optical source and a microwave frequency mixer simultaneously[11], the laser diode (mixer) generates down-/up-converted signals as well as a local frequency if two frequencies (local and IF signal) are supplied. The output power level at the local frequency is larger than that of the down-/up-converted signals if the modulation signal level is low[12]. To suppress the local frequency, a microwave filter must be connected to the photodiode output. The balanced laser mixing link shown in Fig.2 can eliminate the local frequency without filters. Two out-of-phase dividers and two in-phase combiners are required to supply the out-of-phase local frequencies and out-of-phase IF signals to the laser diodes. The down-/up- converted signals are generated by the laser diode nonlinearity. Since two detected local frequencies have a phase difference of 180°, they are canceled at the detector output. The detected output does not include the local frequency but the down-/up- converted signals.

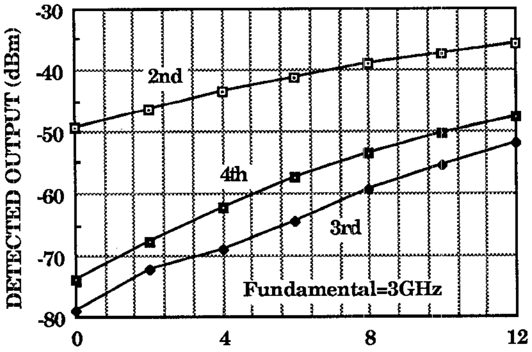
C. Image Cancellation Laser Mixing Link

If the out-of-phase divider for the IF signal is replaced by a 90° hybrid circuit, the link can transmit the down- and up-converted signals separately. Fig.3 shows the configuration of the image cancellation laser mixing link. The image cancellation configuration is based on the image cancel microwave mixer[13]. The local frequency is divided out-of-phase, while the IF signal is divided 90° phase difference. These divided frequencies are supplied to laser diodes and the frequency mixing is accomplished by the laser diode nonlinearity. Two photodiodes detect the modulated optical power and the detected microwave frequencies are combined by the 90° hybrid circuit. The down- and up-converted signals are obtained from each output port.

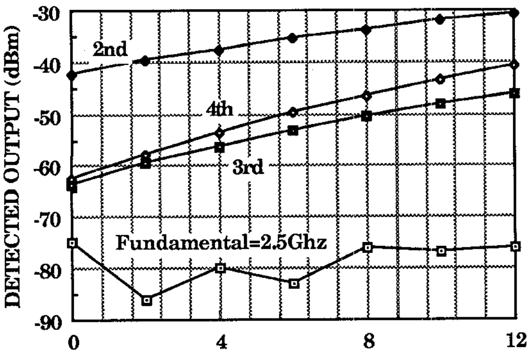
EXPERIMENTAL RESULTS

To verify the fundamental behavior of fiber optic links, the balanced laser harmonic generation link and the image cancellation mixing link are experimentally investigated. Two InGaAsP laser diodes (Ortel 1515A) are used as harmonic generators and laser mixers. The first and second laser diodes have a threshold current of 19mA and 15mA and *cw* output power of 1mW at a forward bias current of 36mA and 38mA, respectively. The InGaAs *pin* photodiode (Ortel 2515A) has a 3dB bandwidth of 10GHz and a responsivity of 0.6mA/mW. A conventional microwave 180° hybrid circuit is used as an out-of-phase divider. The optical coupler is used for an optical power combiner with a 3dB optical power loss.

The detected harmonic level is shown in Fig.4. The fundamental frequencies of the single- and twin-fiber links are 3GHz and 2.5GHz, respectively. The detected second, third and fourth harmonic levels of the single-fiber link are -35.8dBm, -52dBm and -47.8dBm, respectively, at a local input power of

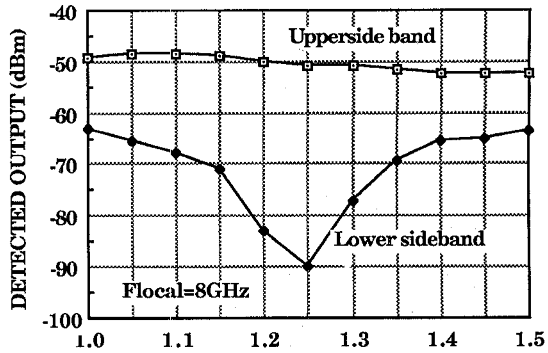


(a) Single-fiber link performance

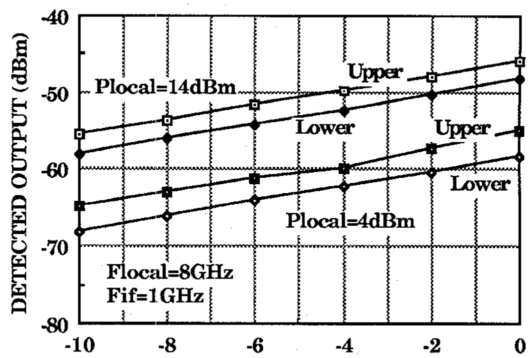


(b) Twin-fiber link performance

Fig.4.Performance of balanced laser harmonic generation links.



(a) Frequency response



(b) Detected output power vs. IF input power

Fig.6. Performance of image cancel laser mixing link.

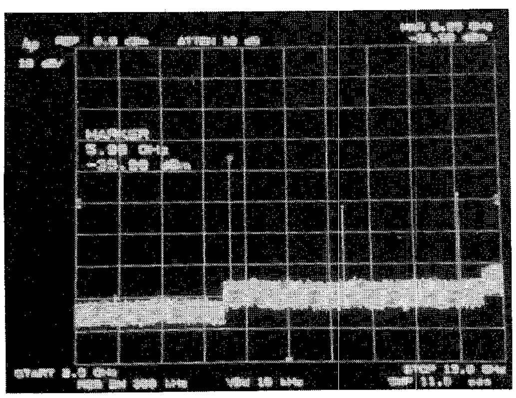


Fig.5.Frequency spectrum of balanced laser harmonic generation link. The input RF frequency is 3GHz and the input power is 12dBm.

12dBm. Since the detected fundamental frequency level is less than -80dBm, the suppression ratio of the fundamental and second harmonic is larger than 44dB. Fig.4(b) shows the detected harmonic output. The second harmonic level is improved due to the absence of an optical combiner. Its value is -30.6dBm. Fig.5 shows the detected harmonics spectrum of the single-fiber link at an input power of 12dBm. The fundamental frequency can be suppressed and even harmonics are added.

The frequency response of the image cancellation laser mixing link is shown in Fig.6(a). The local frequency is 8GHz and the local power is 14dBm. The image rejection of 39dB is obtained at an IF frequency of 1.25GHz. Fig.6(b) shows the upper sideband output (9GHz) and lower sideband output (8GHz) performance at an IF frequency of 1GHz.

CONCLUSION

Three fiber optic links are proposed and experimentally demonstrated. The fundamental behavior of each link is described. Microwave functional components and optical devices are successfully combined and the frequency suppression effect has been achieved at microwave frequency bands. Although the experiment was done in the microwave frequency, the links can be expected to operate at millimeter-frequency bands by choosing ultra high-speed laser diodes and photodiodes, and millimeter-wave circuit components.

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