Optical/Microwave Circuit Technologies for Microwave and Millimeter-Wave Fiber Optic Links

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Abstract *This paper proposes a simple and cost-effective fiber optic link configuration for microwave and millimeter-wave subcarrier transmission, an optical/microwave monolithic integrated circuit configuration, and a monolithic integrated antenna structure. The 25-GHz FM modulated signal is successfully transmitted using an external optical modulator. Monolithic integrated HEMT photodetectors are experimentally investigated and utilized to achieve an optical/microwave mixer which combines the functions of optical detection and microwave frequency conversion.*

INTRODUCTION

Fiber optic subcarrier transmission links are being investigated for use in radio distribution networks[1]-[4]. In mobile communications, a large number of radio base stations with optical/RF transducers are required for radio signal transmission to the numerous mobile terminals. Therefore, it is very important to construct compact and cost-effective radio base station hardware. The primary function of a radio base station is to convert optical to RF signals, amplify RF signals, and send RF signals to the mobile terminals; and vice versa. RF signals are amplified using conventional monolithic integrated circuits[5]. As light intensity modulation is commonly used for RF signal transmission for simplicity, the typical receiver components of a radio base station are a photodetector, frequency converter, amplifier and an antenna[6]. The number of components must be reduced to avoid complex and expensive receiver configuration. Optical/microwave mixing architectures can simplify the optical receiver through a reduction in components[7][8]. The advantages of the optical/microwave mixing link, and its use of optical/microwave monolithic integrated circuits are discussed in this paper. Monolithic integrated active antennas also play an important role in simplifying the optical receiver i.e. the radio transmitter, as well as the optical transmitter i.e. the radio receiver. This antenna structure is also proposed. Experimental results in component performance are also discussed.

LINK CONFIGURATION

Fiber optic link configuration using optical/microwave mixing is shown in Fig.1. The link consists of an optical transmitter located at the central base station, optical fiber, and an optical receiver at the radio base station. The optical carrier is intensity modulated by an external optical modulator. Millimeter-wave local oscillator is installed at the optical receiver to up-/down-convert the millimeter-wave frequencies detected by the optical/microwave mixer. Two functions, i.e. optical signal detection and RF frequency conversion are integrated into the mixer. If the radiation antenna can be monolithically integrated with other circuits, receiver configuration is significantly simplified. Although only the down-link configuration from the central base station to the radio base station is shown in Fig.1, the up-link is configured using the same concept.

OPTICAL/MICROWAVE MONOLITHIC INTEGRATED CIRCUIT

A concept of optical/microwave monolithic integrated circuits which detect optical signals, amplify and radiate RF signals is illustrated in Fig.2. The optical signal is coupled to the photodetector using an optical lens. A few microwave devices can detect optical signals using photoconductive or photovoltaic effect[9][10]. The schematic configuration of a HEMT photodetector is shown in Fig.3. HEMT devices have the advantages of high frequency response speed and high responsivity despite a low coupling efficiency due to electrode

structure. Another advantage of HEMT devices is 3-terminal configuration[11]. Two terminal devices, such as metal-semiconductor-metal photodetectors require additional circuits to accomplish optical/microwave mixing. A photograph of the active slot antenna pattern fabricated on a GaAs substrate is shown in Fig.4. The RF signal is transmitted to slotlines through the HEMT. As a result, integration of photodetection devices and radiation elements is feasible using the HEMT fabrication process.

EXPERIMENTAL RESULTS

The fiber optic link is first investigated using 1.3-μm optical devices. The frequency response of a commercially available laser diode and LiNbO3 based optical guided waveguide modulator is shown in Fig.5. In the experiment, the external modulator has a wider range of frequency response than the laser diodes. A 25-GHz FM modulated signal with baseband width of 4.2MHz and required RF bandwidth of 36MHz is supplied to the external modulator to evaluate link performance. The weighted SNR versus the modulation input power of the LiNbO3 modulator is shown in Fig.5(b). Since the weighted SNR without the optical link is about 64.5dB, the deterioration through laser intensity noise and photodiode shot noise is less than 1dB. Photographs of HEMT photodetectors are shown in Fig.6. Common source and common drain HEMT detectors are evaluated and the characteristics of these devices are compared with PIN and MESFET photodetectors. The frequency responses of HEMT, MESFET and PIN detectors are shown in Fig.7. The detected power decreases as frequency increases due to the band limitations of the laser diode. HEMT and MESFET optical/microwave mixing performance is also measured and link loss improved. The same FM modulator with a RF frequency of 300MHz is used to measure the weighted SNR of HEMT and MESFET devices. The weighted SNR versus the drain-source current is shown in Fig.7(b). Although SNR fluctuated within 4dB due to the instability of the laser diode output power and optical beam vibration, a weighted SNR of 60dB is attained by MMIC process based photodetectors.

CONCLUSION

The feasibility of optical/microwave mixing links using optical/microwave monolithic integrated circuit technologies, as well as a monolithic active antenna is proposed and experimentally investigated. FM modulated signals are used to evaluate the performance of the fiber optic links and good transmission characteristics obtained. MMIC process based HEMT photodetectors, i.e. MMIC compatible optical devices could be utilized to microwave and millimeter-wave fiber optic links.

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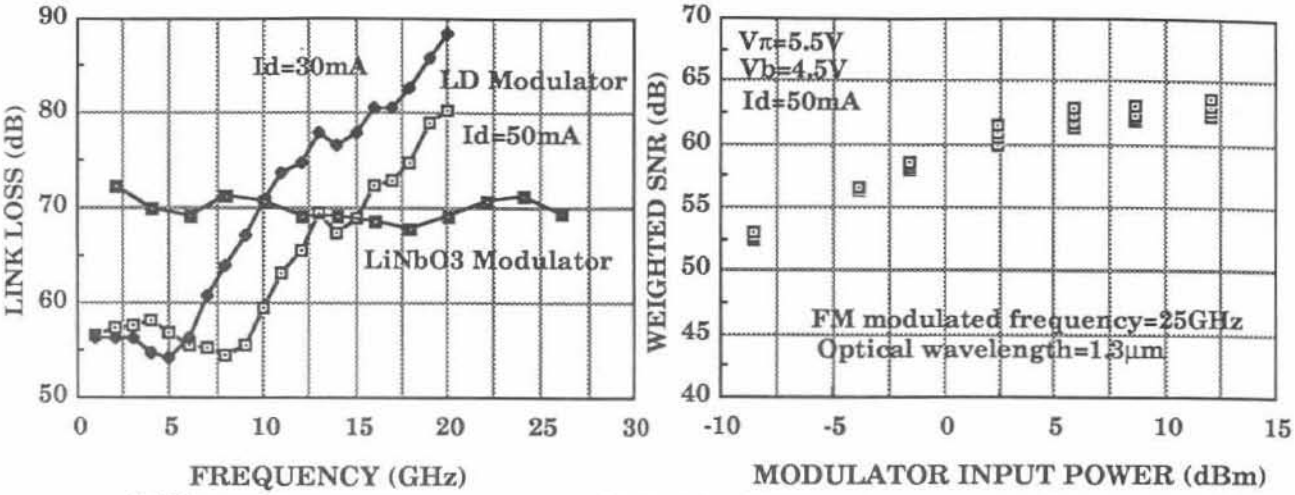
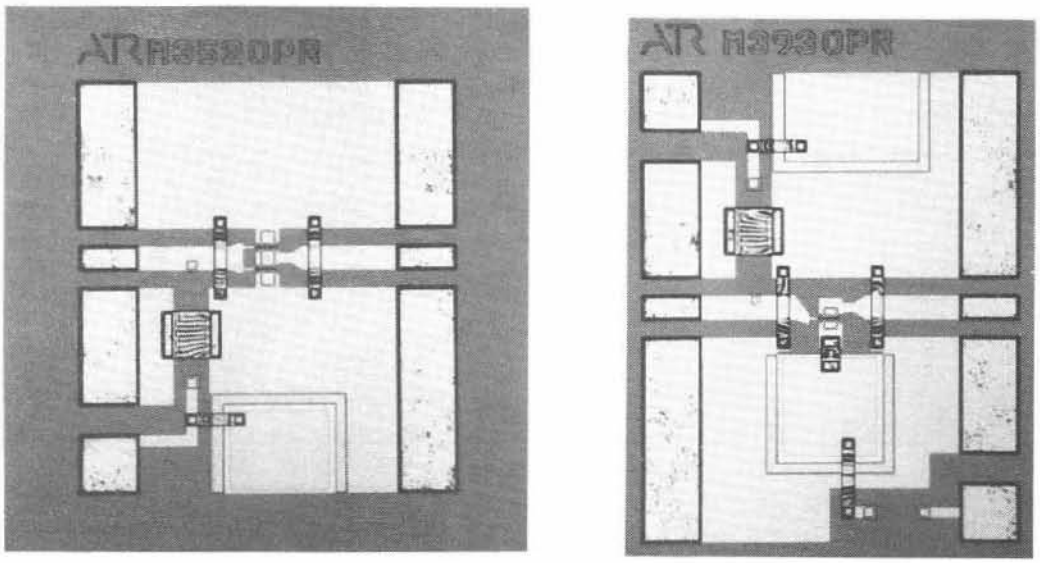


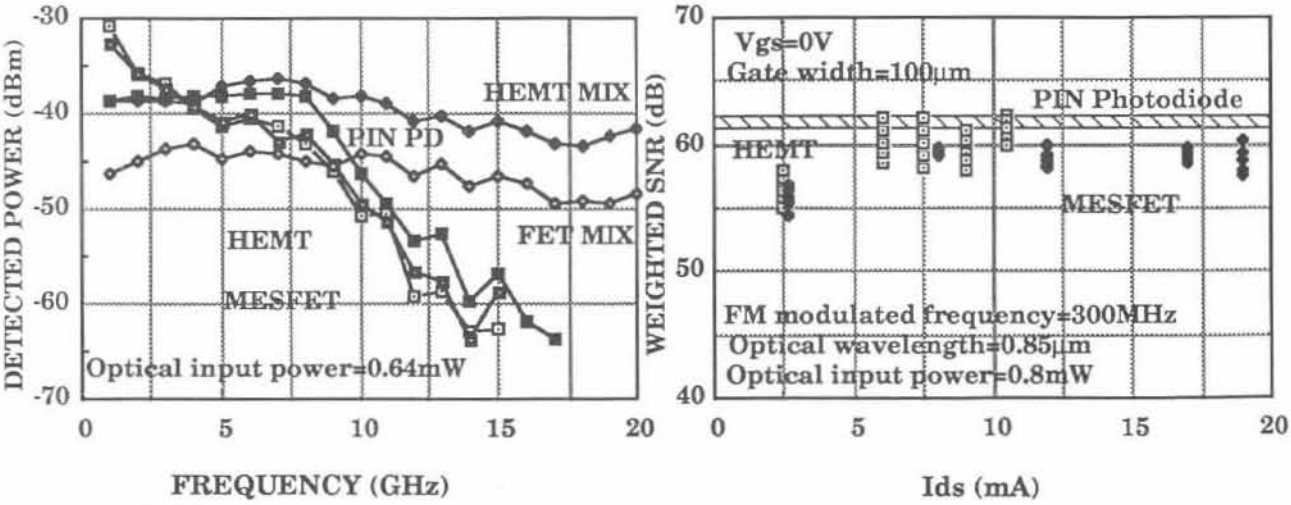
(a) Frequency response (b) Weighted SNR vs. input power of external modulator

Fig.5. Fiber optic link performance using 1.3μm optical devices.



(a) Common source HEMT detector (b) Common drain HEMT detector

Fig.6. Photographs of MMIC HEMT photodetectors.



(a) Frequency response (b) Weighted SNR vs. HEMT drain current

Fig.7. Performance of MMIC HEMT photodetector.

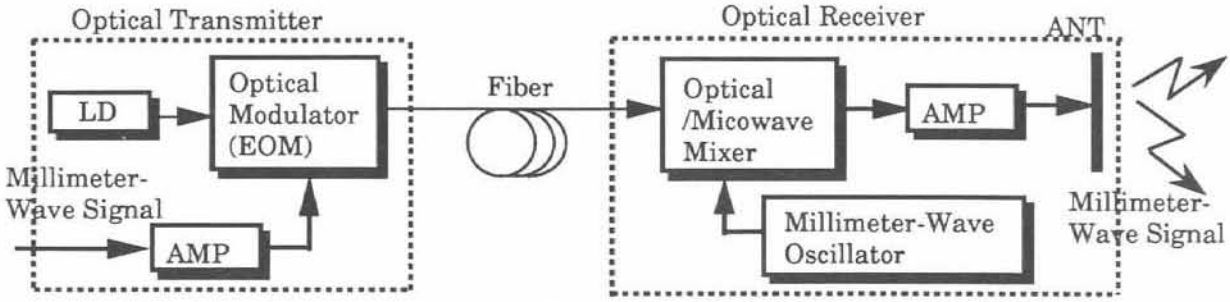


Fig.1. Fiber optic link configuration of microwave/millimeter-wave transmission.

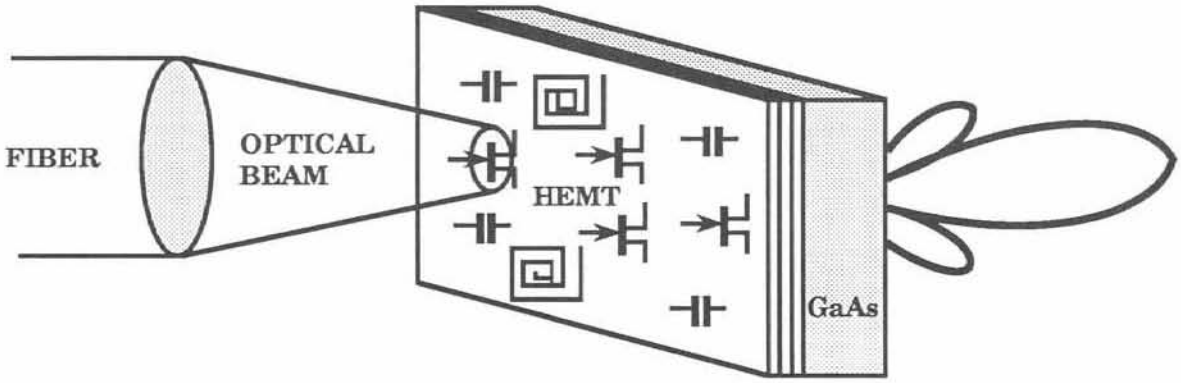


Fig.2. Schematic illustration of optical/microwave monolithic integratred circuit for optical receiver.

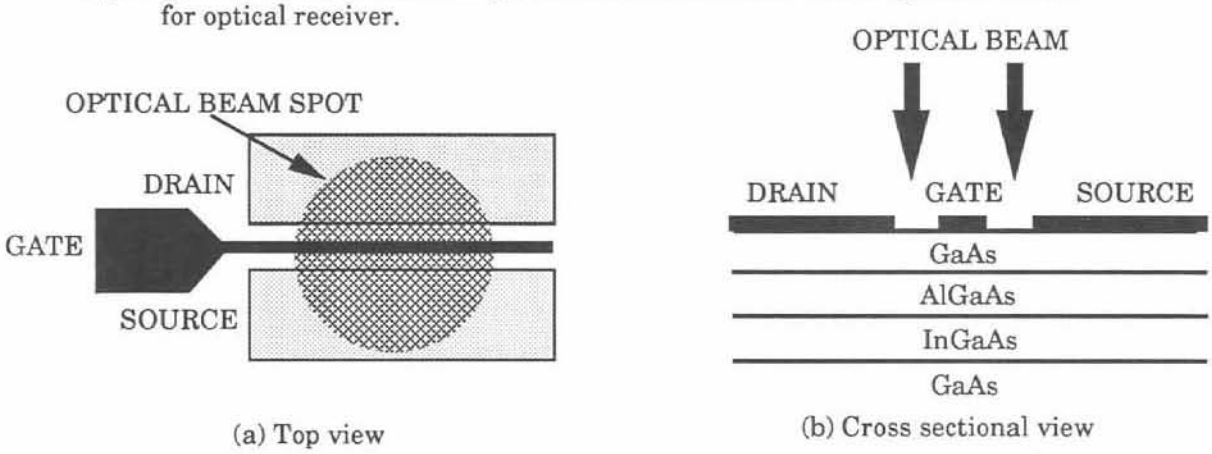


Fig.3. Schematic configuration of HEMT optical detector.

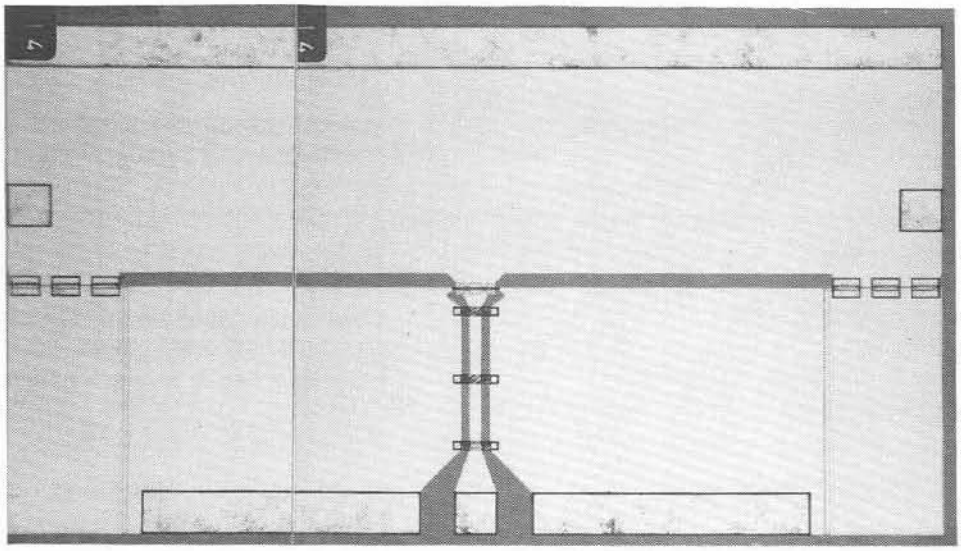


Fig.4. Photograph of active slot antenna pattern fabricated on GaAs substrate and designed at 16GHz. Chip size is 4mmX2mm.