MONOLITHIC IMAGE REJECTION OPTOELECTRONIC UP-CONVERTERS THAT EMPLOY THE MMIC PROCESS

Hideki Kamitsuna and Hiroyo Ogawa

ATR Optical and Radio Communications Research Laboratories
2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-02, Japan

Abstract

This paper presents very small 30-GHz-band monolithic image rejection optoelectronic up-converters that employ the HEMT-MMIC process for the first time. An in-phase divider and a branch-line hybrid with two HEMT optoelectronic mixers are successfully integrated in an MMIC chip area of 1.5 mm x 1.1 mm. Fundamental performance is demonstrated and excellent wideband performance, which comes from the well balanced operation of monolithic integrated circuits, is confirmed.

INTRODUCTION

Fiber optic distributed networks are very attractive for mobile radio communication systems[1]. Since a large number of radio base stations are required, hardware size and cost reduction for numerous radio base stations is the key to realizing such systems[1]. Furthermore, the RF frequency must be increased to transmit a large number of subcarriers because transmission capability is limited by RF frequency bands. To meet these requirements simultaneously, the radio base stations (optical transceivers) must not only operate at high frequency bands, e.g. millimeter-wave bands, but also be configured using monolithic integrated circuit technologies. In the down link for such systems, it is enough to obtain millimeter-wave carrier signals at the radio base station regardless of the frequency of the subcarrier signals transmitted over an optical fiber. In the millimeter-wave mixing configuration[1], relatively low frequencies are utilized as subcarrier signals. After detection, they are up-converted to millimeter-waves by electrical mixers housed in the radio base station. Unlike the millimeter-wave subcarrier transmission link configuration, this enables us to utilize commercially available optical devices. Although, additional components are required for such configurations, optoelectronic mixing[2],[3] allows us to eliminate the electric mixer. Furthermore, functional fiber optic link configurations utilizing the combination of microwave functional components and optical devices (optoelectronic mixers), proposed by the authors, allow us to suppress undesired spurious frequencies without using microwave filters[4],[5]. However, a large number of components are still required and their demonstrated bandwidths are narrow owing to the hybrid constitution of discrete devices. Therefore, monolithic integration is indispensable. As regards integration, electrical integrated circuit technologies represented by MMICs have been significantly improved and are superior to OEICs from the cost and electrical operation frequency points of view. Since the components required for optical receivers (except optical detectors) are micro-/millimeter-wave components, the optical detection[6],[7] and optoelectronic mixing[8]-[12] characteristics of MMIC compatible devices, e.g. MESFETs and HEMTs have been investigated to achieve monolithic integrated optical receivers.

This paper presents very small 30-GHz-band monolithic image rejection optoelectronic up-converters that employ the HEMT-MMIC process, by adapting the idea of functional optical receivers[4],[5], for the first time. An in-phase divider and a branch-line hybrid with two HEMT optoelectronic mixers are successfully integrated in an MMIC chip area of 1.5 mm x 1.1 mm. Fundamental performance is demonstrated and excellent wideband performance, which comes from the well balanced operation of monolithic integrated circuits, is confirmed.

CONFIGURATION AND PRINCIPLE

The configuration of the monolithic image rejection optoelectronic up-converter as well as the local oscillator and the optical transmitter[4],[5] are shown in Figure 1. This configuration can eliminate the image frequencies at RF output ports without using filters. The optical transmitter, i.e. a 90° power divider, two laser diodes and two optical fibers, are utilized to obtain two intensity-modulated optical signals with a phase difference of 90°. Two HEMT optoelectronic mixers are illuminated separately by these two optical signals and simultaneously electrical local frequencies are supplied to each gate terminal of the HEMT in-phase through the input port. The up-/down-converted frequencies are generated by mixing the detected optical signals and local signals with the HEMT nonlinearity[8]-[12]. Since two generated RF frequencies have a phase difference of 90°, they are divided by the 90-degree-phase combination.

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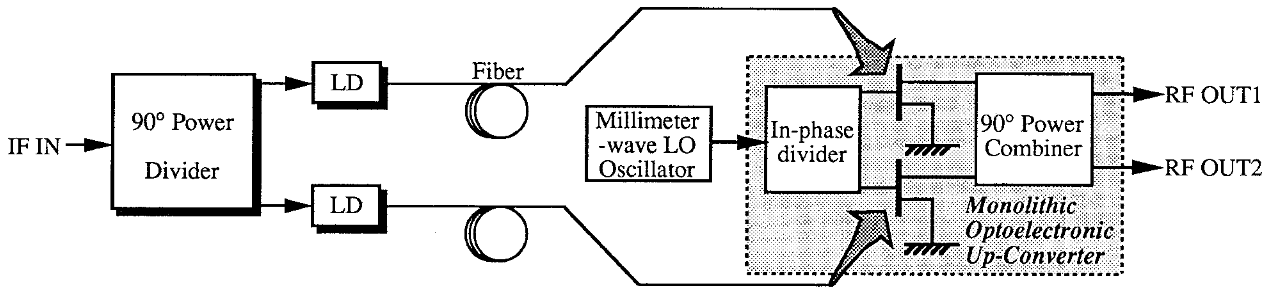

Fig.1. The configuration of monolithic image rejection optoelectronic up-converters as well as the local oscillator and the optical transmitter.

The key to achieving good fiber optic link performance is to assure the uniformity of both the optical path and optical receivers, i.e. each optoelectronic mixer as well as the passive components. The optical path can be made uniform by using such means as wavelength multiplex techniques. In this configuration, the uniformity of optoelectronic mixers is critical since they are utilized for both optical detection and mixing. Therefore, monolithic integration of the optical receiver is expected to achieve excellent performance in comparison with the hybrids that use photodiodes as optoelectronic mixers[4],[5]. Monolithic optoelectonic mixers using the MMIC process have the following advantages: (1) Simplification of optical receiver configurations which utilize electric mixers as up-/down converters. (2) Since IF or RF frequencies are supplied by optical illumination, microwave input circuits for such frequencies are not required and perfect LO to IF or RF isolation is assured. (3) Since MMIC compatible devices are, unlike photodiodes, three-port devices, no additional microwave components, which separate incident local signals and reflected signals, are required[4],[5]. (4) If optoelectronic mixers are utilized as up-converters, the bandwidth of fiber optic links can be extended and full monolithic optical receivers can easily be achieved owing to the absence of IF-band circuits in the receiver (see Fig. 1). (5) It is easy to integrate not only microwave passive components but also active components such as amplifiers and oscillators, thus producing compact and cost-effective 1-chip optical receivers. (6) Well balanced operation is easily obtained by closely allocating transistors on the semiconductor substrate.

EXPERIMENTAL RESULTS

30-GHz-band monolithic image rejection optoelectronic up-converters were designed and fabricated using the HEMT-MMIC process. Fig. 2 shows a photomicrograph of the fabricated circuit. The chip size is 1.5 mm x 1.1 mm. The gate length and the width of the HEMTs are 0.25 µm and 100 µm respectively. The gap between two HEMTs is approximately 100 µm. Coplanar waveguides (CPWs) parallel-T junctions and 30-GHz-band branch-line hybrids which consist of 35-Ω and 50-Ω CPWs are

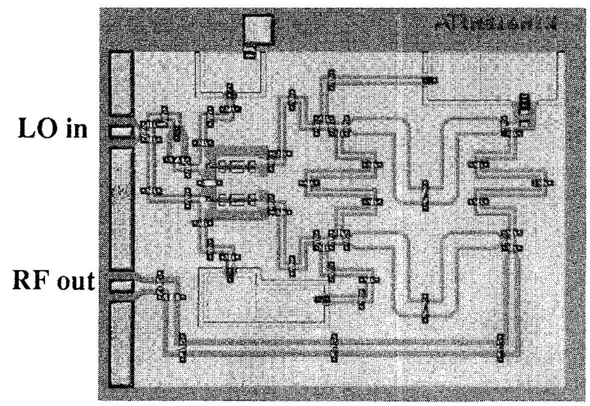

Fig.2. Photomicrograph of the monolithic image rejection optoelectronic up-converter. Chip size: 1.5 mm x 1.1 mm.

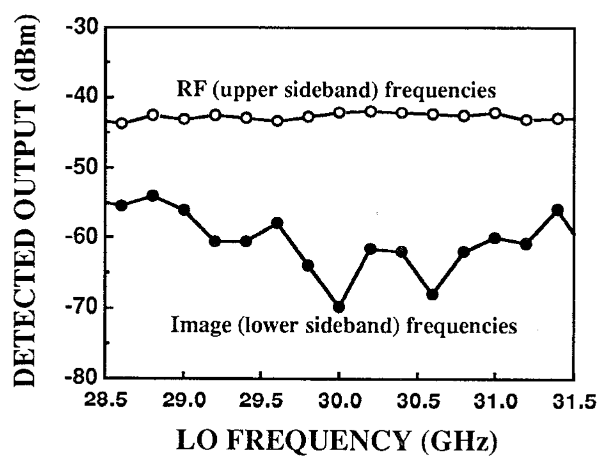

Fig.3. Measured RF (upper sideband) and Image (lower sideband) frequency output power versus the LO frequencies at an LO input power of 4 dBm, an IF input power of 16 dBm and an IF frequency of 110 MHz.

respectively utilized as LO in-phase dividers and RF 90° combiners. One of the output ports of this branch-line hybrid is terminated by a 50-Ω absorbent resistor. The chip size can be reduced by using thin film microstrip (TFMS) lines[13] as transmission lines instead of CPWs.

The monolithic image rejection optoelectronic up-converters were measured in the experimental set-up shown in Fig. 1, by using Cascade Microtech microwave and lightwave on-wafer probes. Two laser diodes (Mitsubishi FU-01SLD, λ = 0.85 μm), a 100-MHz-band 90° power divider and two multi-mode fibers were utilized as the optical transmitter. Each active region of two HEMT optoelectronic mixers was illuminated through two lightwave on-wafer probes. The optical output power of each laser diode was set to approximately 3 mW, and the position of each lightwave on-wafer probe was adjusted to obtain equal IM/DD performance at the identical bias condition. The effective illuminated optical power is assumed to be about 0.2 mW on a 20-μm optical spot[7] taking into account IM/DD performance. In the measurement, the drain bias is set to 2 V and gate biases are set to near pinch-off voltages.

Fig. 3 shows the measured RF (upper sideband) and Image (lower sideband) frequency output power versus the LO frequencies at an LO input power of 4 dBm, an IF input power of 16 dBm and an IF frequency of 110 MHz. In the LO frequency range of 29.2~31.2 GHz, an image rejection of better than 15 dB is achieved. Fig. 4 shows LO input power dependence of both RF and Image frequencies at an LO frequency of 30 GHz. Fig. 5 shows the measured return loss at the RF output port. A return loss of better than 15 dB is obtained in the RF frequency range of 27.0~33.7 GHz. Fig. 6 shows the IF frequency response at an LO frequency of 30 GHz and an IF input power of 16 dBm. Image rejection of better than 20 dB is obtained in the IF frequency range of 70~170 MHz. Since the IF-band 90° power divider utilized in this study operates in the frequency range 80~150 MHz, the measured results show that suppression of the image frequency is based on the phase relationship of the microwave signals. Both the LO and IF frequency responses are significantly improved in comparison with the hybrid link configuration utilizing discrete devices[4],[5].

CONCLUSION

This paper presents very small 30-GHz-band monolithic image rejection optoelectronic up-converters that employ the HEMT-MMIC process for the first time. An in-phase divider and a branch-line hybrid with two HEMT optoelectronic mixers are successfully integrated in an MMIC chip area of 1.5 mm x 1.1 mm. Fundamental performance is demonstrated and excellent wideband performance, which comes from the well balanced operation of monolithic integrated circuits, is confirmed. This optical receiver configuration allows us to easily integrate amplifiers and oscillators. Therefore, the demonstrated monolithic optoelectronic mixers

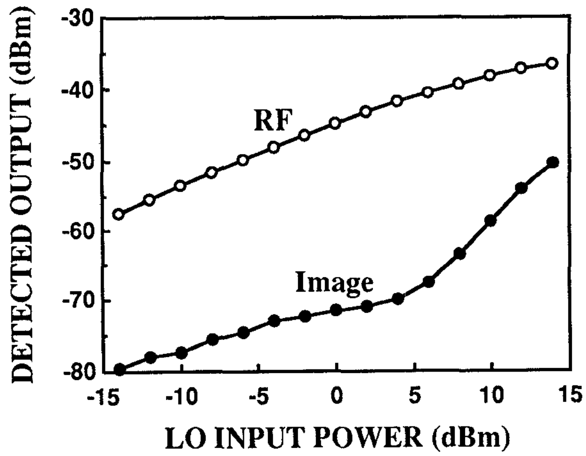

Fig.4. LO input power dependence of both RF and Image frequencies at an LO frequency of 30 GHz, an IF frequency of 110 MHz and an IF input power of 16 dBm.

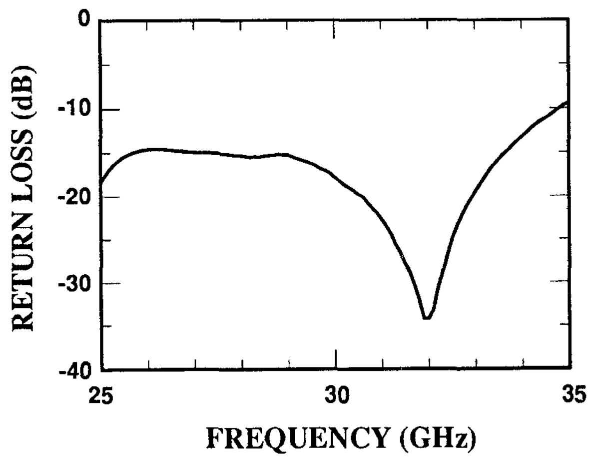

Fig.5. Measured return loss at the RF output port.

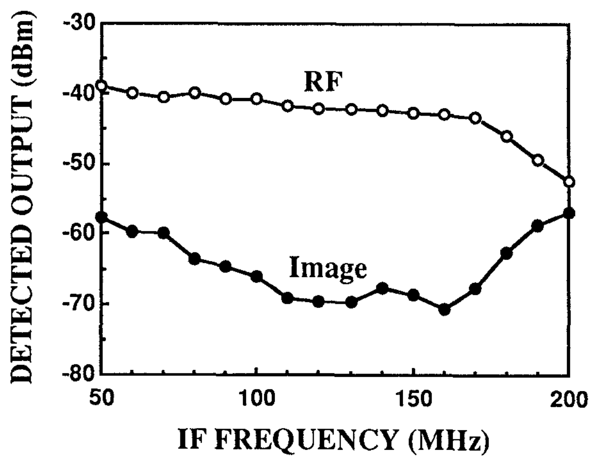

Fig.6. IF frequency response at an LO frequency of 30 GHz, an LO input power of 4 dBm and an IF input power of 16 dBm.

promise to realize compact and cost-effective 1-chip optical receivers for fiber optic millimeter-wave subcarrier transmission links. Furthermore, by utilizing MMIC miniaturized techniques such as line-unified FET[14] and multilayer MMIC structures[13], multi-function monolithic optoelectronic mixers such as balanced type can be realized with a significant size reduction.

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