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Millimeter-wave InP/InGaAs HPT optoelectronic mixers and their application to 60GHz bi-directional radio-on-fiber systems

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***Abstract* — We demonstrate the use of InP/InGaAs heterojunction phototransistors as optoelectronic mixers for bi-directional millimeter-wave band radio-on-fiber systems. For downlink transmission, optically transmitted IF signals are frequency up-converted to millimeter-wave band signals in InP HPT optoelectronic mixer with remotely-fed optical local oscillator (LO) signals. Uplink signals at millimeter-wave band are applied to the base port of InP HPT and frequency down-converted to IF band. Utilizing this proposed scheme, bi-directional radio-on-fiber transmission in 60GHz band is demonstrated.**

***Index Terms* — Phototransistor, optoelectronic mixer, optoelectronic MMIC, radio-on-fiber system, millimeter-wave wireless communication system.**

I. INTRODUCTION

There have been many efforts to utilize fiber-optic technologies in millimeter-wave wireless communication systems in order to overcome difficulties in millimeter-wave generation and transmission. Fiber with its low-loss, large bandwidth transmission characteristics can make a great contribution for realizing micro/pico cellular networks in millimeter wave communication systems [1].

One of important technical issues in these radio-on-fiber systems is simplification of antenna base station architecture since a large number of antenna base stations are needed in millimeter-wave systems. Phototransistors based on InP are useful for this purpose because they can be used as optoelectronic mixers that simultaneously perform photodetection to 1.55μm lightwave with high internal gain and frequency conversion in a single device. Furthermore, they are fully compatible to monolithic microwave integrated circuits (MMIC) process, allowing the possibility of one-chip antenna base station [2-3].

In this paper, we present the use of a single InP heterojunction phototransistor (HPT) that can be used both up- and down-conversion optoelectronic mixer in bi-directional radio-on-fiber systems. Utilizing the InP HPT optoelectronic mixers, bi-directional transmission of 16 quadrature amplitude modulation (QAM) data in 60GHz band is successfully demonstrated.

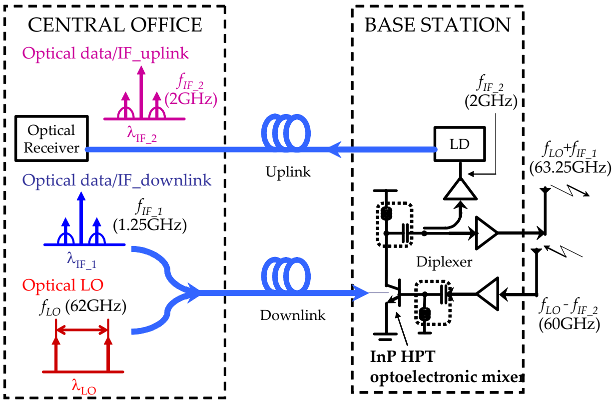

Fig. 1. InP/InGaAs HPT optoelectronic mixer for bi-directional radio-on-fiber systems.

II. PROPOSED ANTENNA BASE STATION ARCHITECTURE BASED ON HPT OPTOELECTRONIC MIXER

Fig. 1 schematically illustrates the use of InP HPT optoelectronic mixer for remote up/down conversion 60GHz bi-directional radio-on-fiber systems. Optical heterodyne LO signals (f_{LO}) are generated at the central office and distributed to many antenna base stations through optical fiber. For downlink transmission, IF signals (f_{IF_1}) are optically transmitted to base stations and frequency up-converted in InP HPT into f_{LO}+f_{IF_1}. Uplink millimeter-wave signals at f_{LO}-f_{IF_2} are applied to the base port of InP HPT and frequency down-converted to IF band (f_{IF_2}) with the help of optical LO signals. With the IF transmission in fiber, the dispersion induced carrier to noise (CNR) suppression problem is avoided [4]. Furthermore, expensive millimeter-wave phase-locked local oscillators and frequency mixers are not required for antenna base stations. In addition, high conversion efficiencies are possible because InP HPT can provide high phototransistor internal gain for detecting high frequency modulated optical signals [2-3].

III. HETEROJUNCTION PHOTOTRANSISTOR

The detailed description of InP/InGaAs heterojunction phototransistor (HPT) used in our investigation can be found in [5]. It consists of 70nm undoped InP emitter,

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50nm carbon-doped $In_{0.53}Ga_{0.47}As$ base and 300nm $In_{0.53}Ga_{0.47}As$ collector from top to bottom. Optical window with 3μm diameter is located on the top of emitter layer.

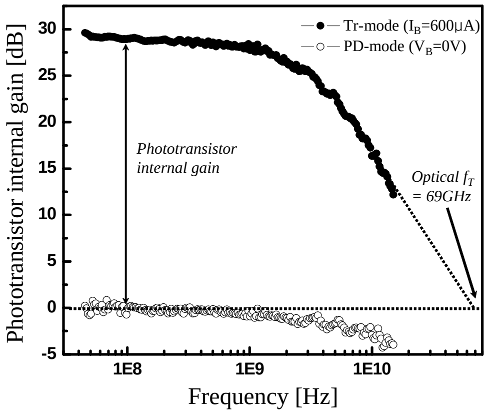


Fig. 2. Measured optical modulation responses of InP/InGaAs HPT under Tr-mode (I_B=600μA) and PD-mode (V_{BE}=0V).

Fig. 2 shows the optical modulation responses of InP HPT under actively biased (Tr-mode, I_B=600μA) and cut-off (PD-mode, V_{BE}=0V) conditions. Measurements were performed by directly modulating a DFB laser having 1553nm wavelength with a network analyzer after careful calibration of characterization setup. In PD-mode, the HPT operates as a photodiode that gives DC responsivity of 0.18A/W. In Tr-mode, the HPT provides phototransistor internal gain, which can be quantized with the detected power ratio between Tr-mode and PD-mode. For detecting low-frequency signals such as optical IF signals in our radio-on-fiber links, the phototransistor internal gain is larger than 27dB. With the optical gain cutoff frequency defined as the optical modulation frequency where phototransistor gain is 0dB, the InP HPT has 69GHz optical gain cutoff frequency. Consequently, it is possible to detect optically delivered 62GHz LO signals with internal gain.

IV. Frequency Up-converter for Downlink Transmission

First, the frequency up-conversion using InP HPT was experimentally demonstrated using the setup shown in Fig. 3. 62GHz optical heterodyne LO signals were generated by the Mach-Zehnder modulator biased at minimum transmission point, which produces double sideband with suppressed carrier (DSB-SC) signals. An EDFA was used for the amplification of optical LO signals. DFB laser at 1552.3nm was directly modulated by 20Mbps 16QAM data with 1.25GHz IF for producing optical downlink IF signals. Optical LO and IF signals were combined by optical 3dB coupler and injected to HPT through single mode lensed fiber. During these experiments, no fiber transmission was performed for their simplicity. The optical spectrum of these signals is shown in Fig. 4. In HPT, optical IF signals are mixed with optical LO signals and frequency up-converted to 63.25GHz band. The resulting electrical spectrum after bandpass filtering and amplification is shown in Fig. 5-(A). In order to evaluate the link performance, these signals were frequency down-converted to the IF band whose spectrum is shown in Fig. 5-(B). After additional low-pass filtering, these down-converted 16QAM data were analyzed with a vector signal analyzer by measuring error-vector magnitude (EVM). The resulting constellation and eye diagrams with 2dBm optical LO injected into HPT are shown in Fig. 6. In this condition, EVM is about 4.53% which corresponds to 24.5dB signal-to-noise ratio (SNR), which should be sufficient for many wireless applications.

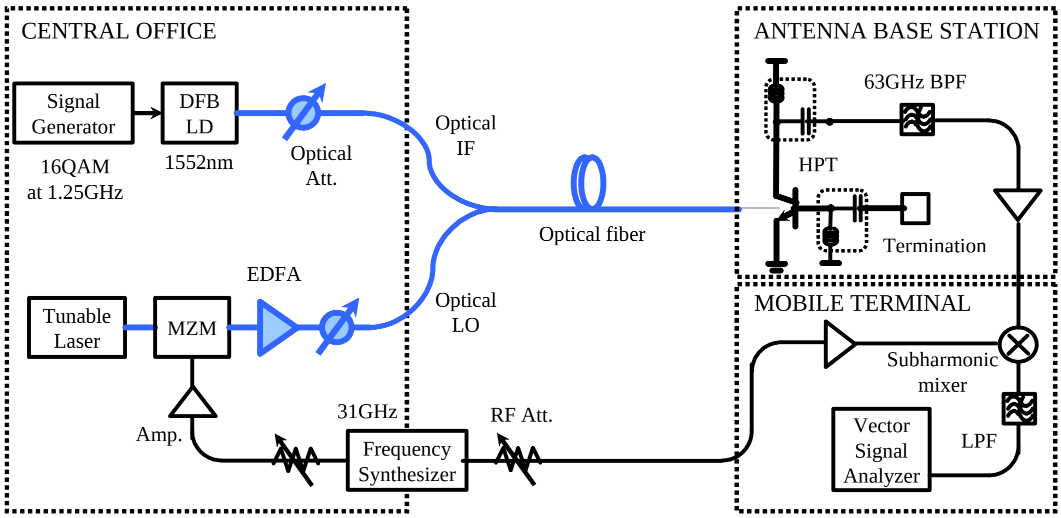


Fig. 3. Experimental setup for 60GHz-band downlink data transmission using InP HPT optoelectronic frequency up-converter

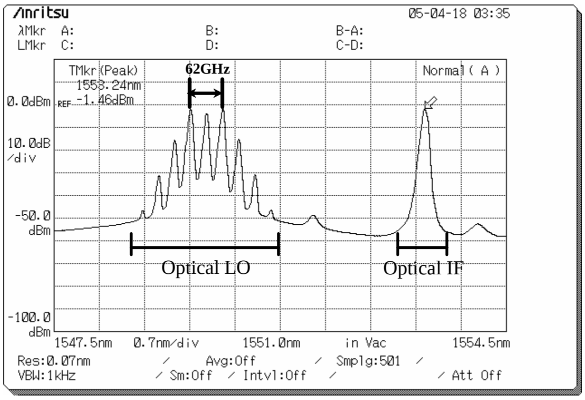
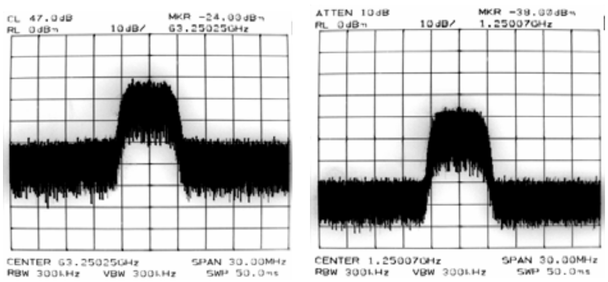


Fig. 4. Optical spectrum after combining optical LO and optical IF signals.



(A) (B)

Fig. 5. (A) 20Mbps 16QAM data spectrum at 63GHz band measured at collector port of InP HPT. (B) Frequency down-converted data spectrum 1.25GHz IF band.

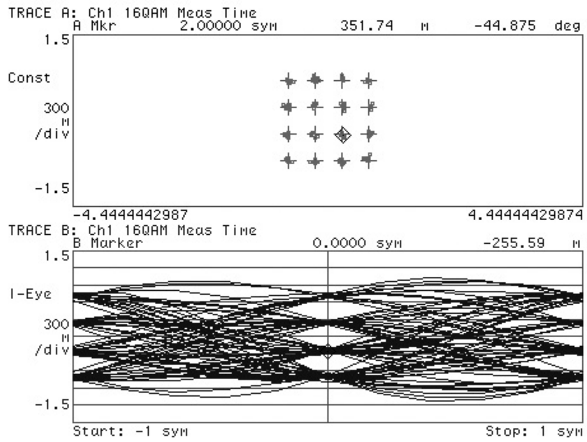


Fig. 6. Constellation (upper) and eye-diagram (lower) for recovered 16QAM data signal in radio-on-fiber downlink transmission

IV. Frequency Down-converter for Uplink Transmission

Next, we demonstrated the frequency down-conversion using InP HPT down-converter. Fig. 7 shows the experimental setup for uplink data transmission. For 60GHz-band data generation, the 16QAM data with 2GHz IF signals were frequency up-converted to 60GHz band with a subharmonic mixer. Fig. 8-(A) shows the 16QAM data spectrum at 60GHz band after 60GHz band-pass filtering. These signals were amplified and applied to the base port of InP HPT for optoelectronic mixing. The 62GHz optical heterodyne LO signals were simultaneously illuminated to the same InP HPT. 60GHz RF signals and optical LO signals were mixed in the InP HPT optoelectronic mixer, resulting in frequency down-converted signals at 2GHz IF band. Fig. 8-(B) shows spectrum of the resulting IF signals at the collector output of InP HPT. In practical radio-on-fiber uplink transmission, these signals can be easily delivered

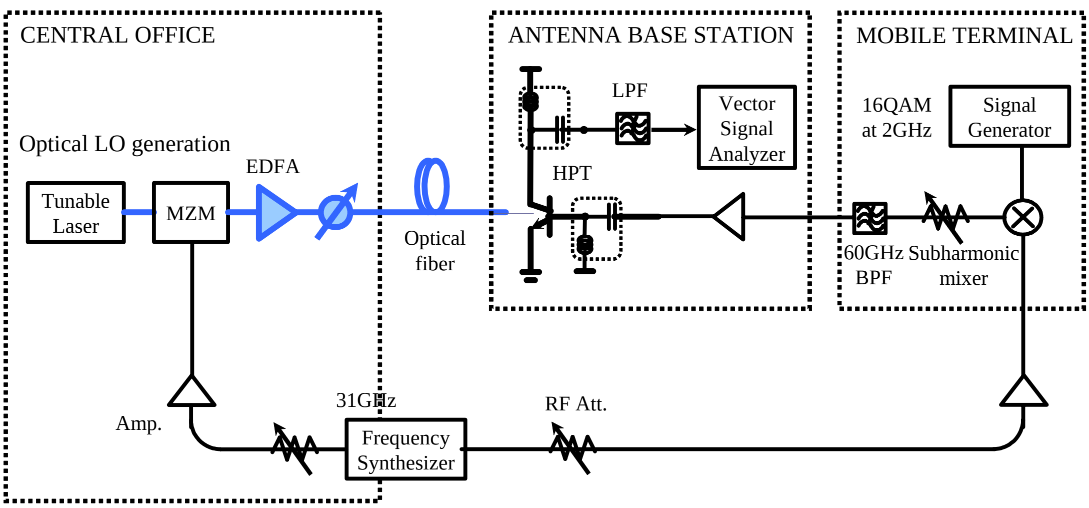
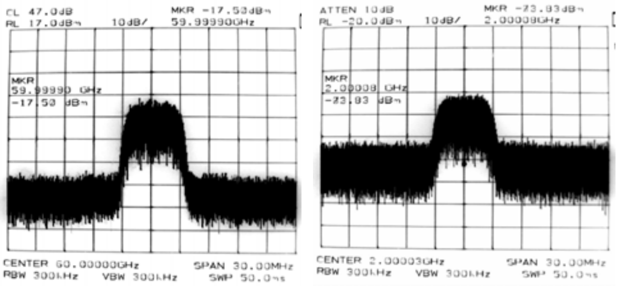


Fig. 7. Experimental setup for 60GHz-band uplink data transmission using InP HPT optoelectronic frequency down-converter

to central office by directly modulating a laser diode. The down-converted 16QAM signals were analyzed by a vector signal analyzer. Fig. 9 shows the constellation and eye diagram for received 16QAM data. The EVM was 4.67%, which corresponds to 24dB SNR.



(A) (B)

Fig. 8. (A) 20Mbps 16QAM data spectrum at 60GHz band applied to base port of InP HPT. (B) Frequency down-converted data spectrum at 2GHz IF band measured at collector port of InP HPT.

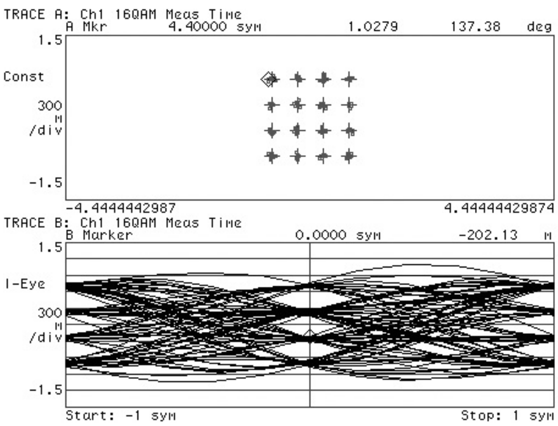


Fig. 9. Constellation (upper) and eye-diagram (lower) for recovered 16QAM data signal in radio-on-fiber uplink transmission

VII. Conclusion

We presented the use of InP HPT optoelectronic mixer for millimeter-wave band bi-directional radio-on-fiber systems. With remotely-fed optical LO signals, both frequency up and down conversion are possible in a single InP HPT device. Utilizing this, we demonstrated bi-directional 16QAM data transmission in radio-on-fiber systems. Although it was experimentally verified individually in both directions, we believe that mutual interference between downlink and uplink data signals may be negligible because frequency division is utilized. InP HPT provides not only optoelectronic mixing function but also the possibility of one chip integration with other circuitries, which can greatly simplify antenna base station architecture.

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