

60-GHz Bidirectional Radio-on-Fiber Links Based on InP–InGaAs HPT Optoelectronic Mixers

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Abstract—We demonstrate 60-GHz band bidirectional radio-on-fiber (RoF) links based on InP–InGaAs heterojunction phototransistor (HPT) optoelectronic mixers. They employ remote up/down conversion scheme with optical local oscillator signals distributed from the central office and intermediate frequency (IF) fiber transmission for both up- and down-links. Since frequency up/down conversions and photodetection are carried out by a single HPT optoelectronic mixer, base station architecture is greatly simplified. In order to validate its feasibility, both up- and down-link RoF transmissions of 16 quadrature amplitude modulator data are successfully demonstrated at 60-GHz band using 1.25-GHz IF for down-link and 2.0-GHz IF for up-link.

Index Terms—60-GHz band, bidirectional links, heterojunction phototransistor (HPT), millimeter-wave, optoelectronic mixer, photodetector, radio-on-fiber (RoF) system.

I. INTRODUCTION

OVER THE last few years, there have been significant research interests in millimeter-wave radio-on-fiber (RoF) systems. RoF systems utilize optical fiber as low-loss and wide-bandwidth transmission medium, which makes distribution of broad-band data and/or high frequency signals into many base stations easy.

There are several approaches to construct millimeter-wave RoF systems. In one configuration, millimeter-wave signals are optically generated at central office and transmitted to base stations for down-link transmission [1], [2]. For up-link transmission, however, base stations should have expensive optical transmitters operating at millimeter-wave band, which can enormously increase base station cost and complexity. Moreover, it is well known that this approach is sensitive to fiber chromatic dispersion that can induce carrier-to-noise (CNR) penalty and phase-noise degradation [3].

In another approach, intermediate frequency (IF) signals are optically transmitted in both up- and down-link fiber transmissions [4]. This can alleviate above-mentioned problems and employ low-cost optical transmitters such as directly modulated laser diodes in base stations. However, complex base station architecture cannot be avoided because both millimeter-wave frequency mixers and phase-locked oscillators

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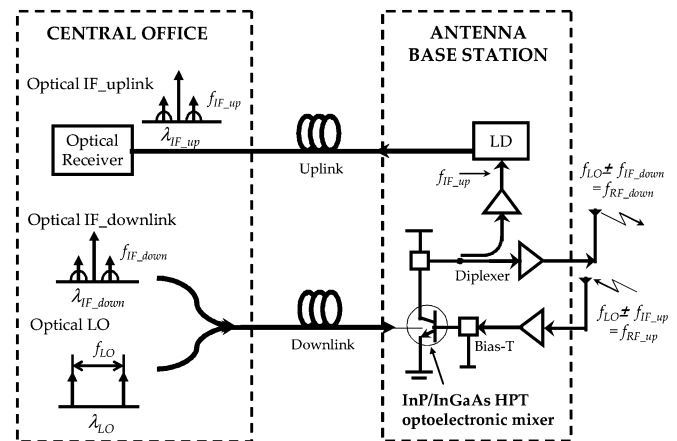


Fig. 1. Bidirectional RoF link based on an InP–InGaAs HPT optoelectronic mixer.

are required. One possible solution is to introduce optically delivered local oscillator (LO) signals from central office to base stations [5]. Although this optical LO distribution can eliminate phase-locked oscillators in base stations, efficient frequency up/down converters are still required because photodetected optical LO power can be considerably low.

Phototransistors based on InP material systems are regarded as one attractive solution for this remote up/down conversion scheme because they can be utilized as optoelectronic mixers which simultaneously perform photodetection and frequency mixing [6]. In addition, they are fully compatible to monolithic microwave integrated circuit process, which makes one-chip integration of all base station components except the antenna a possibility.

In this letter, we demonstrate a 60-GHz band remote up/down conversion bidirectional RoF link based on an InP–InGaAs heterojunction phototransistor (HPT) optoelectronic mixer. The configuration of proposed bidirectional RoF link is schematically shown in Fig. 1. Optical heterodyne LO signals at λ_{LO} are generated at central office and distributed to many base stations through optical fiber along with optical IF signals at λ_{IF_down} . Wavelength-division-multiplexing technologies can be used for accessing different base stations using a dedicated λ_{IF_down} for each base station.

At each base station, an HPT optoelectronic mixer performs frequency up-conversion of optically transmitted IF signals (f_{IF_down}) to RF band and produces down-link wireless signals at $f_{LO} \pm f_{IF_down}$ at the collector port. These down-link signals are then filtered, amplified, and delivered to mobile users through an antenna. At the same time, up-link RF signals ($f_{RF_up} = f_{LO} + f_{IF_up}$ or $f_{LO} - f_{IF_up}$) received by the

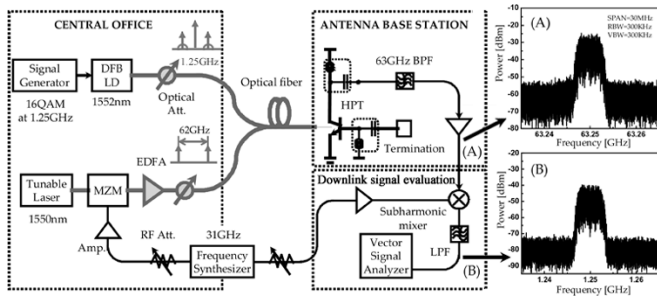


Fig. 2. Experimental setup for 60-GHz band downlink data transmission using HPT optoelectronic mixer. (a) 20-Mb/s 16 QAM data spectrum at 63.25-GHz band measured at the collector port of HPT after 63-GHz bandpass filtering. (b) Frequency down-converted spectrum at 1.25-GHz IF band. MZM: Mach-Zehnder modulator. EDFA: Erbium-doped fiber amplifier. BPF: Bandpass filter. LPF: Low-pass filter.

antenna are connected to the base port of HPT and frequency down-converted to IF band with the same optical LO signals transmitted from central office. The resulting down-converted data/IF signals at f_{IF_up} flow through the collector port can be easily separated from f_{RF_down} using a diplexer. f_{IF_up} signals are converted into optical signals at λ_{IF_up} by a laser diode and then delivered to central office through optical fiber. Up-link signals from different base stations can be also distinguished using a dedicated λ_{IF_up} for each base station.

In this scheme, dispersion-induced CNR fading problems can be avoided with the IF transmission in fiber. Furthermore, expensive millimeter-wave band frequency mixers and phase-locked oscillators are not required and optical LO signals can be shared by many base stations, which promise a simple remote up/down conversion bidirectional RoF system. Although our scheme utilizes frequency-division multiplexing for up- and down-link signals, an approach based on time-division multiplexing can be easily implemented using a switch for up- and down-link transmission.

II. 60-GHz BIDIRECTIONAL RoF SYSTEM DEMONSTRATION

First, down-link transmission at 60-GHz band was demonstrated using experimental setup shown in Fig. 2. The 62-GHz optical heterodyne LO signals at 1550 nm were generated by a Mach-Zehnder modulator biased at the minimum transmission point, which produces double sideband with suppressed carrier signals. An erbium-doped fiber amplifier was used for amplification of optical LO signals. For optical IF channel, 20-Mb/s 16 quadrature amplitude modulator (QAM) data signals at 1.25-GHz IF were directly applied to a distributed feedback (DFB) laser diode at 1552 nm. It should be noted that the data bandwidth used for our demonstration was limited by equipments available to us, not by our scheme. Both optical IF signals and 62-GHz optical LO signals were combined and illuminated to a single discrete InP-InGaAs HPT through a lensed fiber. In our feasibility demonstration, only one base station was considered and the length of fiber linking central office to base station was only a few meters.

The detailed device characteristics of the HPT used in our investigation can be found in [7]. It is made up of, from top to the bottom, 70-nm undoped InP emitter layer, 50-nm carbon-doped In_{0.53}Ga_{0.47}As base and 300-nm In_{0.53}Ga_{0.47}As collector layers. The electrical current gain cutoff frequency (f_T) and maximum frequency of oscillation (f_{max}) are 157 and 110 GHz,

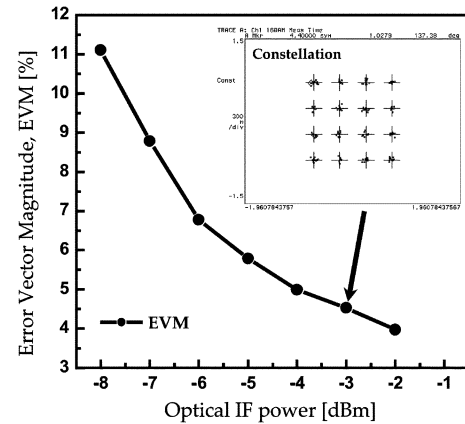


Fig. 3. EVM for downlink transmission as a function of input optical IF power. Optical LO power is 2 dBm. The inset shows the constellation of received 16 QAM data when optical IF power is -3 dBm.

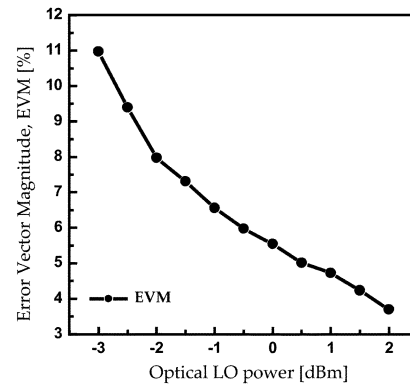


Fig. 4. EVM for downlink transmission as a function of input optical LO power. Optical IF power is -2 dBm.

respectively. Top illumination was applied through the optical window having 3- μ m diameter located on top of the emitter layer.

By intrinsic nonlinearities of HPT device, optical IF signals can be mixed with optical LO signals producing at the collector port frequency up-converted signals at 63.25 and 60.75 GHz. The RF spectrum for 63.25-GHz signals after bandpass filtering and amplification is shown in the inset (a) of Fig. 2. The HPT bias conditions optimized for highest frequency up-conversion efficiency were base current (I_B) of 500 μ A and collector-to-emitter voltage (V_{CE}) of 1 V when optical LO power was 2 dBm. The frequency up-converted signals could be radiated to free-space through an antenna in practical RoF systems, but in our feasibility demonstration, wireless link transmission was not tried.

In order to evaluate the link performance, transmitted 16 QAM data signals at 63.25-GHz band were frequency down-converted to IF band using an electrical subharmonic mixer. The RF spectrum for down-converted 16 QAM data at 1.25-GHz band after additional low-pass filtering is shown in the inset (b) of Fig. 2. These signals were analyzed with a vector signal analyzer by measuring error-vector magnitudes (EVMs). The EVM is defined as the ratio of average error magnitude to the normalized peak signal amplitude. Fig. 3 shows the measured EVMs as a function of optical IF power with 2-dBm optical LO power. These optical powers were measured at the output of lensed fiber. The constellation for received 16 QAM data at -3-dBm optical IF power is shown in

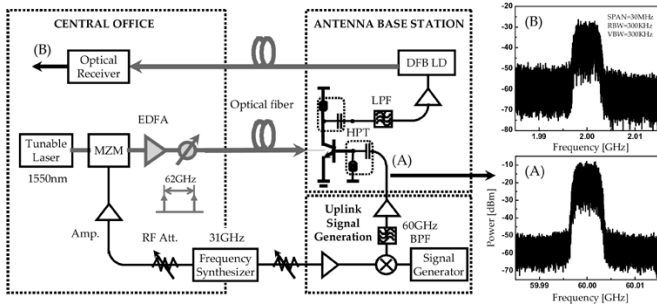


Fig. 5. Experimental setup for 60-GHz band uplink data transmission using HPT optoelectronic mixer (A) 20-Mb/s 16 QAM data spectrum at 60-GHz band applied to the base port of HPT. (B) 2-GHz IF band spectrum measured at the output of photodetector after uplink fiber transmission.

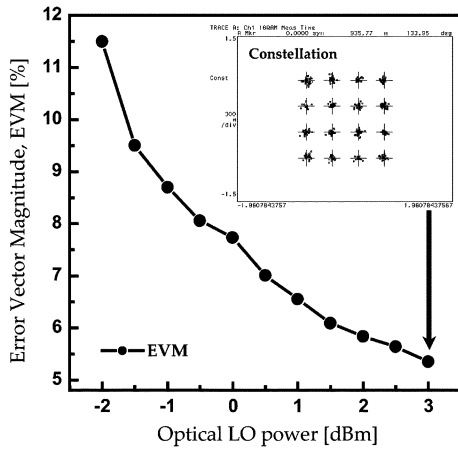


Fig. 6. EVM for uplink transmission as a function of input optical LO power. The inset shows the constellation of received 16 QAM data when optical LO power is 3 dBm.

the inset of Fig. 3. In this condition, EVM is about 4.53% which corresponds to 24.5-dB signal-to-noise ratio (SNR). We believe this should be sufficient for most wireless applications. With decreasing optical LO power, the EVM increases as shown in Fig. 4. It indicates that higher optical LO power provides higher frequency up-conversion efficiency of the HPT optoelectronic mixer and lower RoF link loss. For the applications requiring many base stations, this can be a problem since the amount of optical LO power that can be delivered from central office can be limited. One possible solution for this is using optically injection-locked self-oscillating optoelectronic mixers in base stations as we have demonstrated [8] because it can provide high electrical output LO power independent of input optical LO power.

Fig. 5 shows the experimental setup for 60-GHz band RoF up-link transmission. For 60-GHz band data generation, 16 QAM data at 2-GHz IF were frequency up-converted to 60-GHz band using an electrical subharmonic mixer. The resulting spectrum after 60-GHz bandpass filtering and low noise amplification is shown in the inset (a) of Fig. 5. These signals were applied to the base port of HPT, in which the RF signals were mixed with 62-GHz optical heterodyne LO signals resulting in frequency down-converted 2-GHz up-link IF signals at the collector port of HPT. After amplification, these down-converted IF signals were delivered to central office by a low-cost 2.5-Gb/s DFB laser. The inset (b) of Fig. 5 shows the resulting RF spectrum measured at the output of photodetector located at central office. Optimum HPT bias conditions

for highest down-conversion efficiency were I_B of 500 μ A and V_{CE} of 1 V, same as those for frequency up-conversion process. For evaluating uplink fiber transmission performance, the photodetected IF signals at the output of photoreceiver were also analyzed by vector signal analyzer. Fig. 6 shows EVM dependence on optical LO powers with 0-dBm uplink optical IF power. The constellation for received 16 QAM data with 3-dBm optical LO power is shown in the inset of Fig. 6. At this condition, EVM was 5.35%, which corresponds to 23-dB SNR. Simultaneous operation of frequency up/down conversions for the HPT optoelectronic mixer was not possible mainly due to lack of instrument available to us. There is a concern that interference between up- and down-link signals can cause degradation in transmission performance but careful filtering of up- and down-converted signals or time-domain switching between up- and down-link transmissions can be a possible solution.

III. CONCLUSION

A new 60-GHz band bidirectional RoF link using an InP–InGaAs HPT optoelectronic mixer is presented and its feasibility is experimentally demonstrated. With the help of remotely delivered optical LO signals, a single HPT optoelectronic mixer can perform both frequency up- and down-conversion. Since this approach provides the possibility to eliminate frequency mixers and phase-locked oscillators in base stations, it is expected to greatly reduce the complexity and cost of bidirectional RoF base stations.

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