Fiber-supported millimeter-wave data transmission systems based on InP HEMTs

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***Abstract* — Phototransistors based on InP HEMTs can be utilized as subharmonic optoelectronic mixers or optically injection-locked self-oscillating optoelectronic mixers. Using these mixers, two configurations for fiber-supported millimeter-wave data transmission systems are experimentally demonstrated, which are expected to provide simple antenna base station architecture.**

I. INTRODUCTION

Recent years have seen the growing interest in fiber-supported millimeter-wave data transmission systems that utilize optical fiber as low-loss and wide bandwidth transmission medium for deliveries of broadband data or high frequency signals in millimeter-wave wireless links. For their practical implementation, low-cost and miniaturized antenna base station architectures are indispensable because a large numbers of antenna base station are required in order to compensate high transmission loss of millimeter-wave [1].

Phototransistors based on InP HEMTs are attractive for simplifying antenna base station architecture since they can provide several useful functions such as optoelectronic mixing and optical injection-locked oscillation [2]. Furthermore, they are fully compatible to monolithic micro/millimeter-wave integrated circuits, providing one chip solution for antenna base stations.

In this paper, we present fiber-supported millimeter-wave data transmission systems based on InP HEMT. Our main interests are demonstrating new applications, namely, subharmonic optoelectronic mixers and optically injection-locked self-oscillating optoelectronic mixers. After investigating their operation characteristics, fiber-supported millimeter-wave data transmission systems are experimentally demonstrated.

II. SUBHARMONIC OPTOELECTRONIC MIXER AND ITS SYSTEM APPLICATIONS

Phototransistors based on InP HEMTs can be used as optoelectronic mixers which simultaneously perform the photodetection to 1.55µm lightwave with amplification and frequency mixing in a single device. Therefore, it is possible to eliminate a high frequency electrical mixer in antenna base stations.

Unfortunately, they essentially require high frequency local oscillator (LO) for frequency up-conversion to RF band. As carrier frequency for wireless link reach millimeter-wave frequency band, it imposes serious problem on antenna base station architecture in terms of cost and design complexities. In this section, we present the use of InP HEMT as subharmonic optoelectronic mixer having the potential of using low LO frequency which is some integer fraction (1/n) of fundamental LO frequency. Fig. 1 shows the schematic diagram for utilizing InP HEMT as a subharmonic optoelectronic mixer and its frequency up-converted spectrum at 60GHz band. When 30GHz LO is applied to the gate port and 100MHz optical IF signal is illuminated to the device, harmonic optoelectronic mixing products, $2f_{LO}+f_{IF}$ (60.1GHz) and $2f_{LO}-f_{IF}$(59.9GHz) and 2nd harmonic of LO at $2f_{LO}$ (60GHz) are clearly observed. Detailed device characteristics and optoelectronic mixing mechanism can be found in [2].

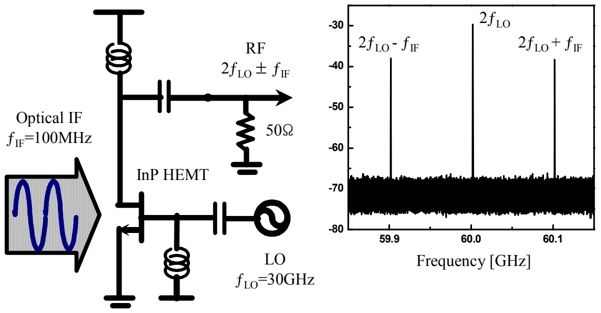


Fig. 1. InP HEMT as a subharmonic optoelectronic mixer and its output spectrum at 60GHz band.

In order to obtain the maximum optoelectronic mixing performance, gate-to-source bias conditions (V_{GS}) of InP HEMT were optimized considering internal conversion gain, defined as the power ratio of optoelectronic mixing signal to primary photodetected signal [2]. Fig. 2 shows the internal conversion gain as a function of V_{GS} bias conditions. It should be noted that the harmonic mixing products at $2f_{LO}+f_{IF}$ can be selectively enhanced at V_{GS} of -0.9V while suppressing other mixing products at $f_{LO}+f_{IF}$. At this condition, 17dB internal conversion gain was obtained.

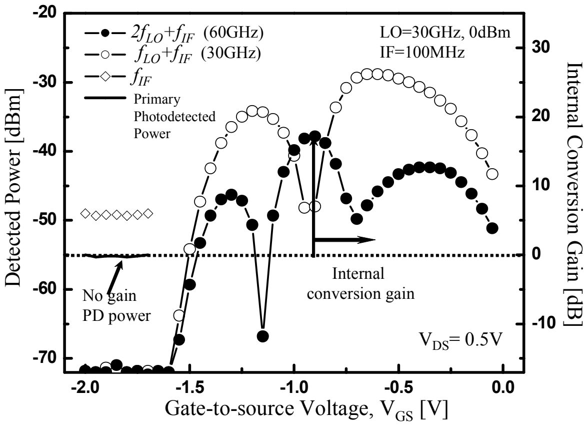
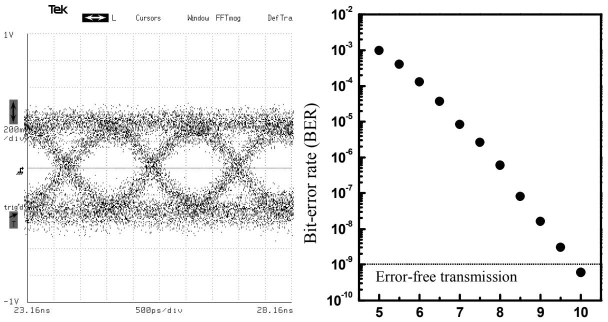


Fig. 2. Mixing products at $f_{LO}+f_{IF}$ and $2f_{LO}+f_{IF}$ as a function of V_{GS}. The solid line indicates the primary photodetected power (f_{IF}) extracted from measured data at turn-off state. The internal conversion gain is defined as the power ratio of frequency up-converted signals to primary photodetected signal

LO pumping power determines the conversion efficiency in a frequency mixer. Fig. 3-(A) shows the internal conversion gain at $2f_{LO}+f_{IF}$ as a function of LO pumping power. The LO power required for positive internal conversion gain is about -7dBm. When LO power is higher than 6dBm, internal conversion gain begins to saturate. LO frequency range of subharmonic optoelectronic mixer is also investigated for its uses at V-band. As observed in Fig. 3-(B), the InP HEMT subharmonic optoelectronic mixer exhibits wide LO frequency ranges while maintaining high internal conversion gain, which are expected to be sufficient for millimeter-wave operation.

In order to investigate the feasibility of using InP HEMT subharmonic mixer in fiber-supported 60GHz downlink systems, 622Mbps data transmission is demonstrated in the constructed 60GHz wireless link shown in Fig. 4. The resulting eye-diagram and bit-error rate (BER) characteristics are shown in Fig. 5-(A) and Fig. 5-(B), respectively.



Eye diagram for recovered 622Mbps data
Incident optical power to HEMT [dBm]

(A)
(B)

Fig. 5. (A) Eye diagram for recovered 622Mbps data signal (B) Bit-error rate (BER) characteristics as a function of incident optical power to the InP HEMT

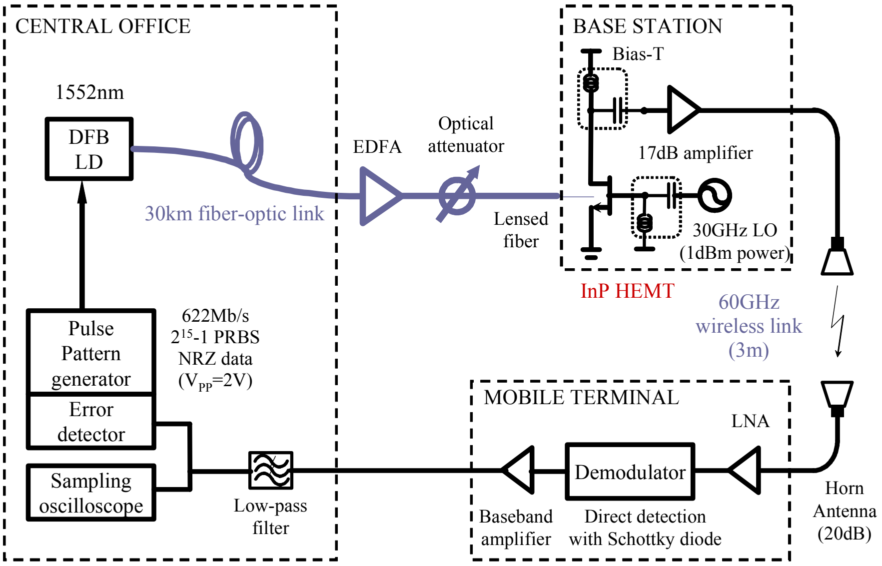


Fig. 4. Fiber-supported 60GHz broadband data transmission system utilizing InP HEMT as a subharmonic optoelectronic mixer

III. OPTICALLY INJECTION-LOCKED SELF-OSCILLATING OPTOELECTRONIC MIXER AND ITS SYSTEM APPLICATIONS

As described previously, the applications of InP HEMT to subharmonic optoelectronic mixers are useful for simplifying antenna base station architecture. However, they inevitably require high frequency phase-locked oscillator for wireless data transmission adopting phase-modulation schemes such as PSK and QAM, which severely increase the complexities of antenna base station architecture. These requirements can be relaxed by introducing optically delivered LO signals from central office to many antenna base stations [3]. In such a scheme, data/IF signals are optically transmitted to base station using another optical wavelength, and frequency up-converted into desired frequency band with mixing with optical LO signals. Although high output power of LO is typically required for efficient frequency mixing and RF radiation, the optical LO schemes cannot afford to support them, to make matters worse, their output power strongly depends on optical transmission distance. In this section, new antenna base station architecture consisting of InP HEMT self-oscillating optoelectronic mixer is presented. It performs optical injection-locked oscillation and harmonic optoelectronic mixing, simultaneously. Utilizing it, 16QAM data transmission in fiber-supported 30GHz data transmission system is demonstrated.

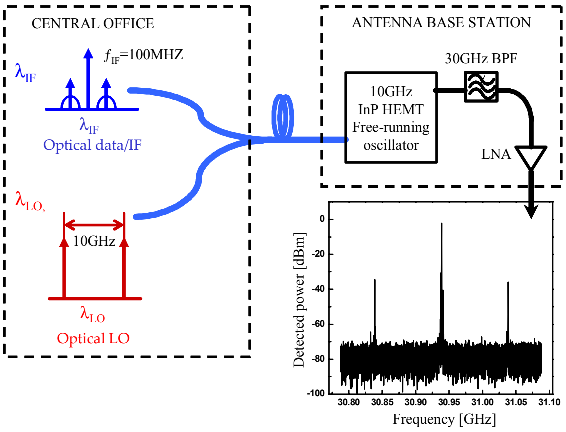
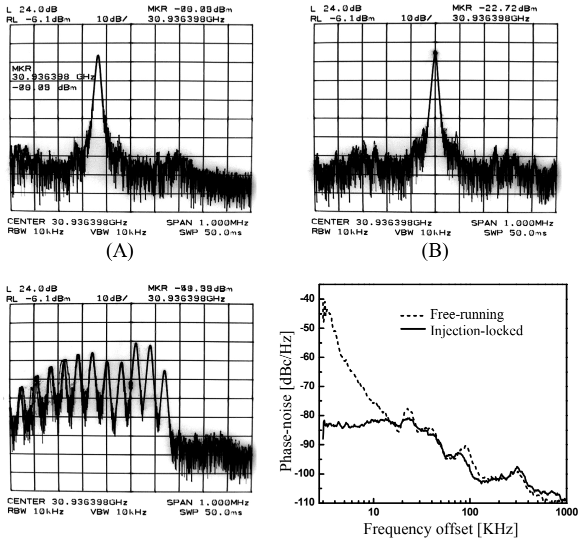


Fig. 6. Proposed antenna base station architecture based on optically injection-locked self-oscillating optoelectronic mixer

Fig. 6 schematically illustrates the proposed simple antenna base station architecture. Using InP HEMT, a 10GHz free-running oscillator is first realized by simple feedback method using discrete bandpass filter, and injection-locked by the optically delivered 10GHz LO signal from a central office. At the same time, optically transmitted data/IF signals with different wavelength are illuminated to the same InP HEMT. Since InP HEMT provides optoelectronic mixing function as demonstrated previously, harmonic frequency up-conversion to 30GHz band can be achieved with optically injection-locked LO, referred to optically injection-locked self-oscillating optoelectronic mixer in this work.

First, direct optical injection-locking characteristics are investigated. 10GHz optical LO signals having the 1552nm wavelength are illuminated to InP HEMT acting as a 10GHz free-running oscillator. We focus on the 3rd harmonic of 10GHz LO for 30GHz applications. Fig. 7-(A), (B) and (C) show the RF output spectra for free-running, optically injection-locked and unlocked conditions (out of locking range), respectively. While the free-running oscillation is unstable and sensitive to environmental conditions, the optically injection-locked oscillator exhibits stabilized oscillation and suppressed phase-noise characteristics as shown in Fig. 7-(D). Under unlocked condition, many sidebands can be observed due to the frequency mixing of free-running LO signals and optically injection signals.



(A) (B)

(C) (D)

Fig. 7. Output RF spectra of InP HEMT oscillator under (A) free-running, (B) optical injection-locked (C) unlocked condition. Phase-noise characteristics of free-running and optically injection-locked are compared in (D)

With the help of these low phase-noise characteristics, 20Mbps 16QAM data transmission is successfully demonstrated. Fig. 8 shows the constructed fiber-supported 30GHz data transmission system employing our proposed scheme. Under the optically injection-locked condition, the optical 16QAM data at 100MHz IF having 1553.5nm wavelength are simultaneously illuminated to the InP HEMT. It performs the harmonic optoelectronic mixing of these incoming data signals with the 3rd

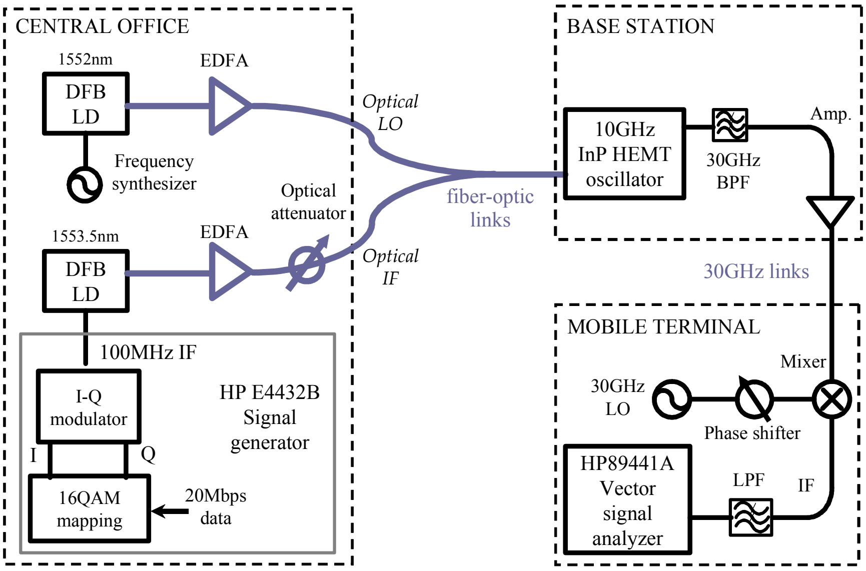


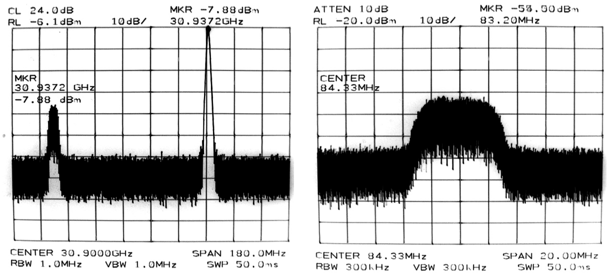
Fig. 8. Fiber-supported 30GHz data transmission system utilizing optically injection-locked self-oscillating optoelectronic mixer

harmonics of optically injection-locked LO. Fig. 9-(A) shows the output spectrum of the optically injection-locked self-oscillating optoelectronic mixer at 30GHz band, which includes lower sideband 16QAM signal and 3rd harmonic of 10GHz injection-locked LO. In actual wireless systems, these signals would be radiated to free-space through the antenna.

In order to evaluate signal quality, the resulting signals are frequency down-converted to IF band whose spectrum is shown in fig. 9-(B). After low-pass filtering, error vector magnitude (EVM) which is defined as the ratio of average error magnitude to normalized peak signal magnitude is measured with a vector signal analyzer. Under incident optical data/IF signal power of 9dBm, EVM is about 4.7% which corresponds to 24dB SNR.

IV. CONCLUSION

It was experimentally shown that phototransistors based on InP HEMTs can be utilized as subharmonic optoelectronic mixers or optically injection-locked self-oscillating optoelectronic mixers. Utilizing these attractive features of InP HEMTs, fiber-supported millimeter-wave data transmission systems were constructed and experimentally demonstrated.



(A) (B)

Fig. 9. (A) 30GHz band output spectrum including 3rd harmonic of LO and frequency up-converted 16QAM data signal (B) down-converted 16QAM signal at IF band.

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