Radio-on-fiber downlink transmission systems based on optically controlled InP/InGaAs HPT oscillators

Chang-Soon Choi[1], Jun-Hyuk Seo[1], Woo-Young Choi[1], Hideki Kamitsuna[2], Minoru Ida[2], and Kenji Kurishima[2]

[1]Department of Electrical and Electronic Engineering, Yonsei University, Seoul, 120-749, Korea
[2]NTT Photonics Laboratories, NTT Corporation, Atsugi-shi, Kanagawa, 243-0198, Japan

***Abstract* — We present a new antenna base station architecture for millimeter-wave radio-on-fiber downlink transmission systems. The architecture is made up of a single InP HPT oscillator, in which InP HPT device simultaneously performs the optically injection-locked oscillation and harmonic optoelectronic mixing. With this, we successfully demonstrate 16QAM radio-on-fiber downlink transmission in 30GHz band.**

***Index Terms* — Radio-on-fiber system, millimeter-wave wireless link, InP heterojunction phototransistor, optoelectronic mixer, optically injection-locked oscillator.**

I. INTRODUCTION

Radio-on-fiber systems have been regarded as a promising candidate for next generation broadband wireline/wireless convergence networks because they offer not only low loss and huge bandwidth transmission medium but also incorporation with previously deployed fiber-optic networks. As the carrier frequency for wireless link reaches the millimeter-wave band, a large number of antenna base stations are required in order to compensate high transmission loss of millimeter-wave. Therefore, realization of low cost antenna base station architecture is a crucial issue for the practical implementation of radio-on-fiber systems [1].

Three-terminal phototransistors based on InP material systems are useful devices for simplifying antenna base station architecture because they can simultaneously perform several functions such as photodetection to 1.55μm lightwave with intrinsic gain and optoelectronic mixing. Furthermore, they are fully compatible to monolithic microwave integrated circuits, providing the possibility of one-chip integration on a single substrate [2-3]. In particular, InP heterojunction phototransistors (InP HPTs) have been shown to have high optical responsivity and wide photonic bandwidth [3].

When phase-modulation schemes such as PSK and QAM are employed, phase-locked oscillators are required in many base stations and, consequently, the cost and design complexities of antenna base station increase. One solution for this problem is using optically delivered LO signals from the central office to the base stations [4-5]. In such a scheme, data/IF signals are optically delivered to base station using another optical wavelength, and frequency up-converted into desired frequency band with mixing with optical LO signals. Although this scheme has the potential to eliminate phase-locked oscillator in antenna base station, the amount of optical LO power required for efficient frequency mixing and RF radiation is rather high. In this paper, we present a new antenna base station architecture based on an InP/InGaAs HPT oscillator. The InP HPT device can solve above-mentioned problem by simultaneously performing optically injection-locked oscillation and harmonic optoelectronic mixing.

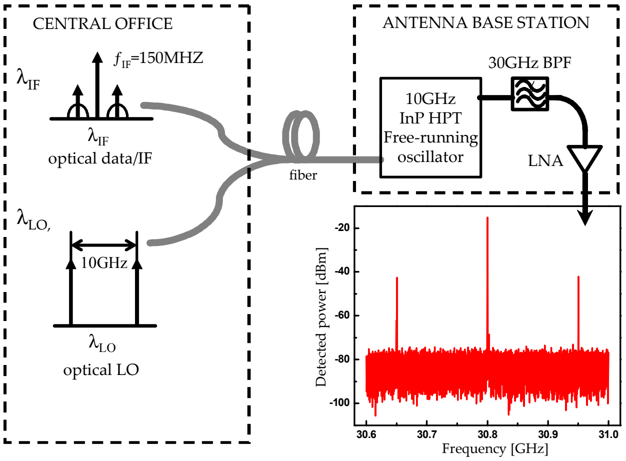

Fig. 1. Proposed antenna base station architecture based on a single optically controlled InP HPT oscillator.

II. PROPOSED SCHEME

Fig. 1 schematically shows the proposed antenna base station architecture for a 30GHz band radio-on-fiber downlink system. A 10GHz free-running oscillator based on InP HPT is first realized by connecting collector signals to base port through discrete narrow bandpass filter. This free-running oscillator is then injection-locked by optically delivered 10GHz LO signal from central office. At the same time, optically transmitted data/IF signals with different wavelength are illuminated to the same InP HPT and harmonic optoelectronic frequency up-conversion to 30GHz band can be achieved. The resulting 30GHz band RF spectrum measured at the output of InP HPT oscillator is shown in the inset of Fig. 1 when optical IF signal frequency is 150MHz. Because the output LO power depends not on incident optical LO power

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but on the free-running oscillator itself [3], it allows efficient frequency up-conversion independent of incident optical LO power. Although discrete components are used for our present investigation, an integrated approach should be equally applicable, which can greatly simplify the antenna base station.

III. EXPERIMENTAL DEMONSTRATION

The detailed InP/InGaAs HPT structure can be found in [6]. It has a 70nm undoped InP emitter, a 50nm carbon-doped InGaAs base and 300nm InGaAs collector. The optical window with 5μm diameter is located on the top of emitter. Fig. 2 shows the optical modulation response of the InP HPT. Under PD-mode where base-emitter junction is shorted, HPT operates as a photodiode without internal gain. In this condition, the InP HPT shows the DC responsivity of 0.2A/W. In Tr-mode, the HPT is actively biased and provides internal gain. The phototransistor internal gain is defined as the output power ratio of Tr-mode to PD-mode. The fabricated InP HPT exhibits the internal gain of 16dB at 10GHz modulation frequency.

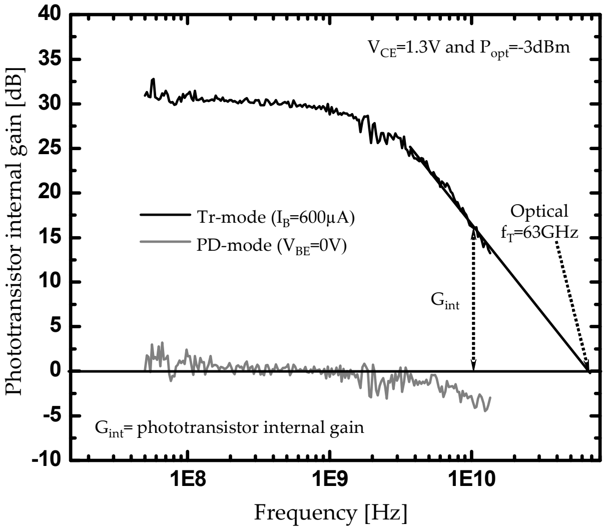


Fig. 2. Measured optical modulation response of InP/InGaAs HPT. G_{int} is phototransistor internal gain.

Direct optical injection-locking characteristics of an InP HPT oscillator are investigated with the focus on the third harmonic of 10GHz LO for 30GHz applications. For experiments, DFB laser diode at 1552nm was directly modulated with a frequency synthesizer, and its output optical signals were illuminated onto the InP HPT with lensed fiber. The third harmonic at 30GHz band was observed after a bandpass filter. Fig. 3 shows the 30GHz band output RF spectra for (A) free-running (B) optically injection-locked and (C) unlocked conditions. While the free-running oscillator was unstable and very sensitive to environmental conditions, the optically injection-locked oscillator exhibited stabilized oscillation and suppressed phase-noise characteristics as shown in Fig. 4. When incident optical power is lower than -6dBm, it shows the unlocked condition where many sidebands are observed due to the frequency mixing of optically injected signals and free-running oscillation signals.

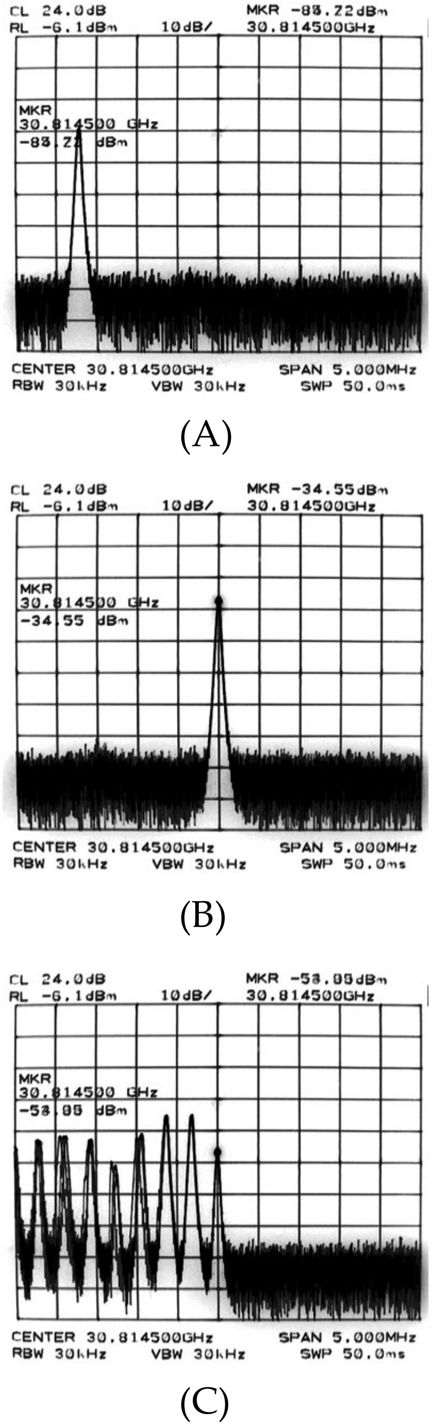


Fig. 3. RF spectra for 3rd harmonic of 10GHz InP HPT oscillator under (A) free-running (B) injection-locked (P_{opt}=-3dBm) and (C) unlocked (P_{opt}=-6dBm) conditions

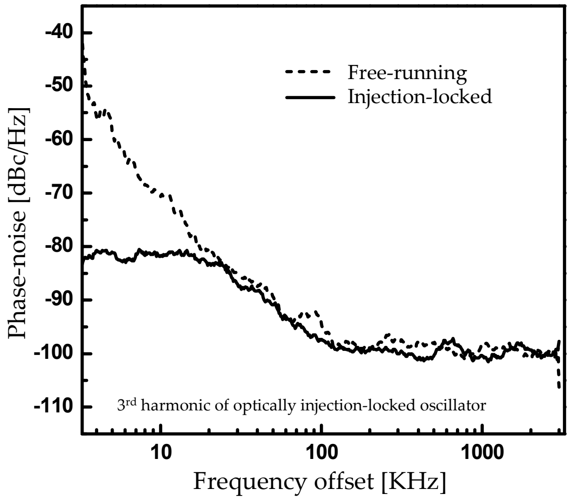
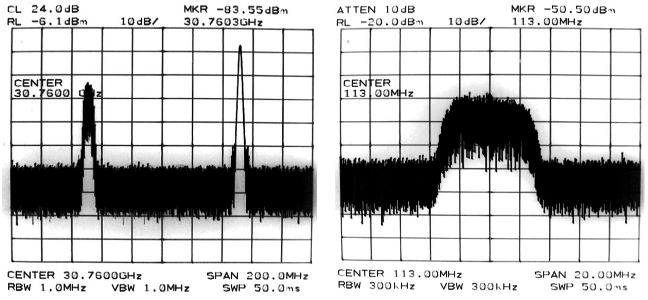


Fig. 4. Phase-noise characteristics of free-running and optically injection-locked oscillator.

With the help of low phase-noise characteristics provided by optically injection-locked oscillator, 16QAM data transmission in 30GHz band was successfully demonstrated. Fig. 5 shows the constructed 30GHz radio-on-fiber systems adopting proposed antenna base station architecture. The optical generation of 10GHz LO signals was achieved by Mach-Zehnder modulator biased at minimum transmission point, resulting in double sideband with suppressed carrier (DSB-SC). The 20Mbps 16QAM data with 100MHz IF were directly modulated to DFB laser diode at 1552nm for optical data/IF signals. These two optical LO and data/IF signals were combined and illuminated onto the InP HPT. Optical LO signals locked the free-running oscillator, and optical data/IF signals were simultaneously frequency up-converted to 30GHz band. The resulting RF spectrum after filtering and amplification is shown in Fig. 6-(A) that includes lower sideband 16QAM signals and 3rd harmonic of LO signal. In practical radio-on-fiber transmission system, these signals would be radiated to free-space through an antenna.



(A) (B)

Fig. 6. (A) 30GHz band RF spectrum including the 3rd harmonic of optical injection-locked LO and frequency up-converted 16QAM data signals. (B) RF spectrum for frequency down-converted 16QAM signal at IF band.

In order to evaluate the link performance of the constructed radio-on-fiber system, these 30GHz band signals were frequency down-converted into IF band whose spectrum is given in Fig. 6-(B). After additional low-pass filtering, the received 16QAM data were analyzed with HP89441 vector signal analyzer by measuring error vector magnitudes (EVM). Under incident optical IF signal power of -6dBm, EVM is about 5.18% which corresponds to 25.7dB signal-to-noise ratio (SNR), which should be more than sufficient for most applications. In this condition, the constellation and eye-

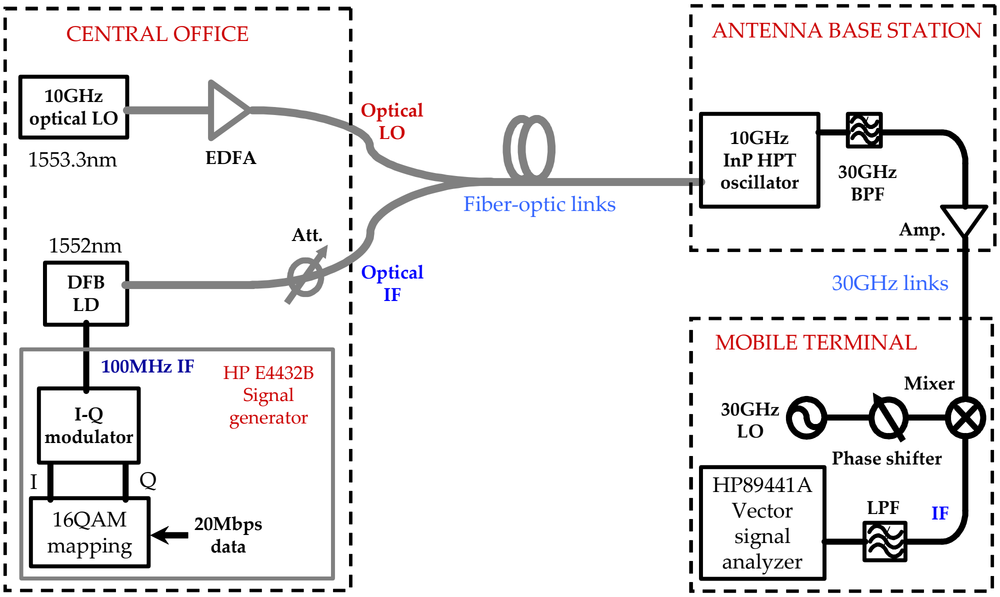


Fig. 5. 30GHz-band radio-on-fiber systems based on optically controlled InP HPT oscillator

diagram for recovered 16QAM data are shown in Fig. 7. With decreasing optical IF power, the EVM is increased as shown in Fig. 8. Without optical injection-locking, the performance of the InP HPT oscillator was seriously deteriorated so that QAM data transmission could not be done. For example, the frequency up-converted 30GHz spectrum and vector signal analyzer outputs including constellation and eye diagram are shown in Fig. 9 for unlocked condition.

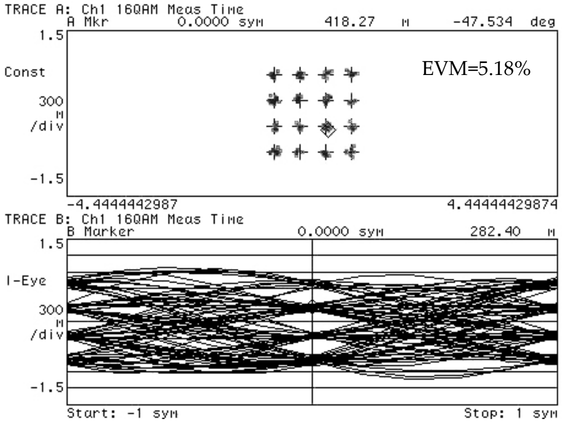


Fig. 7. Constellation (upper) and eye-diagram (lower) for recovered 16QAM data signals.

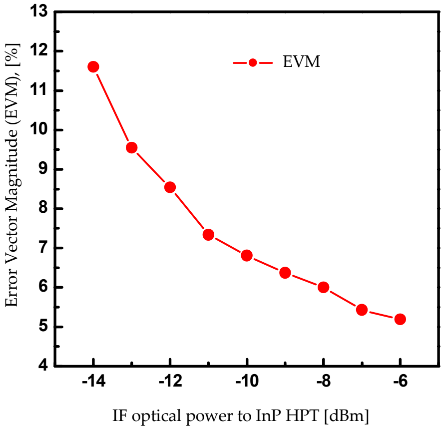
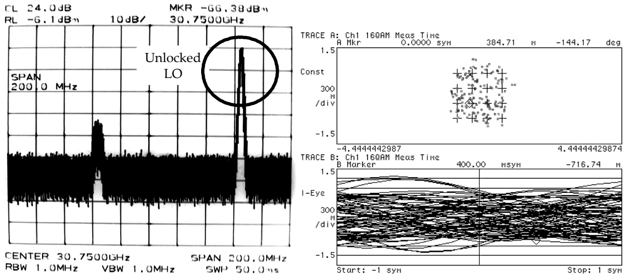


Fig. 8. Error vector magnitude (EVM) as a function of optical IF power to InP HPT



(A) (B)

Fig. 9. (A) 30GHz band output spectrum of InP HPT oscillator under unlocked condition (B) constellation and eye-diagram when unlocked oscillator is used for 16QAM data transmission.

IV. CONCLUSION

We presented a new antenna base station architecture based on an optically controlled InP HPT oscillator for millimeter-wave radio-on-fiber systems. It is possible to simultaneously achieve the optically injection-locked oscillation and harmonic optoelectronic mixing in the InP HPT oscillator. Utilizing this scheme, a simple antenna base station was realized and downlink 16QAM data transmission was successfully demonstrated.

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