Millimetre-wave over fibre transmission using a BPSK reference-modulated optical injection phase-lock loop

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Abstract: We report generation of single sideband millimetre-wave modulated optical signals by a reference-modulated optical injection phase-lock loop. A 36GHz 68Mbit/s BPSK signal is transmitted over 25km unamplified SMF with 8dB optical power margin and BER<10^-9.

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1. Introduction

Broadband millimetre-wave over fibre transmission is an attractive technology for local multipoint distribution system (LMDS) and new generation wireless access systems since it allows much of the system complexity to be removed from the necessarily numerous antenna sites [1]. A key challenge is the generation of the required millimetre-wave modulated optical signals. Some form of single sideband or suppressed carrier transmission is normally used to avoid dispersion problems in long lengths of standard single mode fibre (SMF). Although several schemes have been proposed [2-5], most of these are not power efficient and need optical amplification for successful error-free transmission. Optical amplifiers are expensive components and are not viable for these applications unless used to overcome optical splitting losses in situations where one optical source is used for many remote antenna sites. Optical heterodyning of two laser diodes can generate enough optical power to overcome the need for optical amplification. Successful transmission experiments using optical injection locking (OIL) techniques [6] and, at 9 GHz, optical phase-lock loop (OPLL) techniques [7] have been reported, but need milli-Kelvin precision laser temperature control.

We have shown previously how an efficient optical millimetre-wave generator, the optical injection phase-lock loop (OPLL), can be constructed using standard DFB laser diodes without the need for precision temperature control [8]. In this paper we demonstrate how the wide locking range of the OPLL permits high rate BPSK data to be applied directly to the microwave reference, generating a single sideband modulated optical signal and removing the need for signal filtering at the antenna site. Transmission performance is verified in a 36 GHz 68 Mbit/s BPSK experiment using no optical amplification.

2. Optical millimetre-wave generation scheme

The millimetre-wave modulated optical signal generation technique used in this work is similar to the optical phase-lock loop [7,9] but adds an optical injection locking path to allow low cost, wide linewidth semiconductor lasers to be used. This new technique overcomes the disadvantages of the OPLL, stringent loop delay or laser linewidth requirements, together with the necessity for special lasers with uniform FM response. It also overcomes the main disadvantage of OIL, narrow locking range, in a scheme that combines power efficiency, dispersion immunity and wide locking range. Furthermore it is simple to construct from commercially available fibre optic components.

Figure 1 (top left) shows the layout of the OPLL. The master laser is modulated at a subharmonic of the desired millimetre-wave carrier frequency generating a series of modulation sidebands. The wavelength of the slave laser is such that the beat with the central master laser line generates the desired millimetre-wave frequency at the antenna site by optical heterodyne. The slave mode is injection locked by one of the master laser harmonic sidebands to give broadband phase noise suppression. Shown inset in Figure 1 (a) is a schematic of the resulting optical spectrum, where the main master and slave lines and the master laser modulation sidebands can be observed. The phase-lock loop provides close-in phase noise suppression and temperature tracking resulting in single sideband phase noise of <-90dBc/Hz at 10kHz offset and a phase error variance of less than 0.005 rad^2 in a 100MHz bandwidth. The locking bandwidth was greater than 30GHz, which relaxes the differential temperature control requirements between master and slave lasers to ±3K, thus ensuring good long-term stability. This compares to a locking bandwidth of around 3GHz for the OIL system alone.
3. Transmission Experiment

Previously we have demonstrated 36GHz 140 Mbit/s ASK transmission using an external optical modulator at the output of the OPLL [10]. For optical heterodyne systems, direct modulation of the laser diodes is more attractive since fewer optical components are then needed and higher optical output is achieved by removing the modulator insertion loss. One option is to modulate one of the lasers with data on an intermediate frequency (IF) subcarrier, generating modulation sidebands around the millimetre-wave carrier [6]. Single sideband modulation is then only generated for the millimetre-wave carrier. After heterodyne upconversion of the modulated IF subcarrier at the antenna unit, the unwanted IF sideband must be removed for RF spectral efficiency. A simpler method is to apply the modulation directly to the microwave reference, generating a true single sideband modulated optical signal. Previously this has only been demonstrated for an OPLL system using a PAL video signal of 6MHz bandwidth [7], limited by the restricted loop bandwidth and locking range of such systems.

In this experiment we utilise the wide locking bandwidth of the OIPLL to demonstrate millimetre-wave transmission, using 68Mbit/s BPSK modulation of the microwave reference. The layout of the data transmission experiment is shown in Figure 1. The master laser is directly modulated with the BPSK data superimposed on the subharmonic reference signal. The signal was detected after transmission through 25km of standard SMF (loss 7.6 dB, including connectors) and then downconverted and demodulated to retrieve the data. Also shown inset in Figure 1 (b) is the received eye diagram. The electrical spectrum of the downconverted BPSK signal is shown in Figure 1 (c). Error-free (<10^-9 BER) performance is obtained for a received optical power level of –15dBm or greater. With 1.1dBm launched power, this corresponds to 8dB optical power margin. Figure 2 shows how the bit error rate (BER) varies with received optical power at the detector for back to back, 12.6km and 25km fibre spans. The very small (0.6 dB) degradation of BER due to the fibre transmission indicates the low sensitivity to dispersion. This is confirmed by the correspondingly small degradation of the detected carrier-to-noise level due to the fibre transmission, shown in Figure 3.

Due to the multiplication of the reference, the phase shifts due to modulation are also multiplied so that in the case here, π-BPSK is transformed to 3π-BPSK. The capability of the OIPLL to track this phase change shows the robustness of the locking. With phase compression, multilevel PSK modulation at higher symbol rates will be possible. Frequency modulation of the reference is an alternative possibility.
4. Conclusions

The optical injection phase locked loop technique has been shown to be capable of 68Mbit/s BPSK millimetre-wave over fibre transmission over 25 km of standard SMF by direct data modulation of the microwave reference, generating a single sideband modulated optical signal. OIPLL signal generation power efficiency was demonstrated in our transmission experiment by the 8dB optical power margin for error free transmission with no optical amplification required at either the transmitter or receiver. The result shows the OIPLL technique is not only optical power efficient, eliminating the need for optical amplifiers used in most previous millimetre-wave over fibre transmission experiments, but also RF spectrum efficient, eliminating the need for RF filtering at the antenna unit. Furthermore, the system is constructed around two standard DFB laser diodes without any need for precision temperature control. The OIPLL is therefore a serious candidate technology to enable millimetre-wave over fibre systems to realise their potential.

5. References