Optical Delivery of Modulated Millimetre-Wave signals Using Free-Running Laser Heterodyne with Frequency Drift Cancellation

Leif A. Johansson and Alwyn J. Seeds

Department of Electronic and Electrical Engineering, University College London, Torrington Place, London WC1E 7JE, United Kingdom. e-mail: a.seeds@ee.ucl.ac.uk

Abstract **— A new millimetre-wave over fibre architecture is proposed and demonstrated using remote cancellation of phase and frequency fluctuations of two-laser heterodyne. A 36 GHz millimetre-wave carrier is optically delivered with –85 dBc/Hz noise level at 10 kHz offset. The system is used to demonstrate transmission of a 68 Mbit/s BPSK modulated 36 GHz signal through 25 km standard singlemode fibre.**

I. INTRODUCTION

Hybrid fibre/wireless systems have been proposed for transferring system functionality and complexity from the base stations/antenna units to the central station in a wireless network. This is especially advantageous in a wireless network requiring a high density of base stations, such as millimetre-wave systems, where the free-space transmission range is limited. The key challenge in millimetre-wave over fibre systems is the generation of a dispersion resistant millimetre-wave modulated optical carrier with sufficient purity and stability to support transmission of broadband wireless data. Heterodyning of two optical sources produces single sideband modulation and very high modulation depth, up to 100% [1]. However, when heterodyning two free-running lasers, the phase and frequency stability of the generated signal is limited to that of the lasers used. The relative phase and frequency between the lasers can be locked by using special arrangements, such as optical injection locking [2], optical phase-lock loops [3] or combined systems, such as the optical injection phase-lock loop [4]. An alternative approach that has been demonstrated is feed-forward modulation [5]. This avoids the need for phase-locking two lasers at millimetre-wave frequencies, allowing free-running lasers to be used to produce a coherent beat between one laser line and an intensity modulation sideband derived from the second laser line. A disadvantage of this method is poor utilisation of generated optical power, partly because of the insertion loss of the external optical modulator used to produce the intensity modulation sideband and partly because only one of the modulation sidebands contributes to the millimetre-wave carrier.

In this paper, we show how a feed-forward architecture can be realised where functions have been moved from the optical domain to the electrical domain, where more mature and less expensive technology can be used. A less complex optical arrangement is now achieved with more efficient utilisation of the optical power for the generation of millimetre-wave carriers at the base station. The system is then used to demonstrate optical delivery of a 68 Mbit/s BPSK modulated 36 GHz carrier over 25 km of standard singlemode fibre.

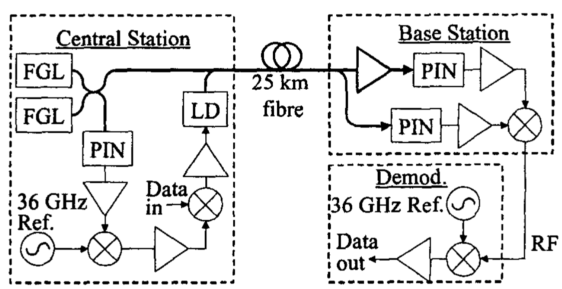

Fig. 1. Layout of the experimental system. Thick line indicates optical path.

II. EXPERIMENTAL ARRANGEMENT

Fig. 1. shows the experimental arrangement used. Two 1540 nm external cavity fibre-grating lasers (FGL) were tuned by regulating the temperature to give a relative frequency difference of about 38 GHz. The heterodyne beat is photodetected and compared with a 36 GHz reference. The error signal, with or without data imposed, is then used to modulate a low-cost Tekmar 1310 nm fibre-optic transmitter. The two optical signals are multiplexed transmitted through 25 km of standard singlemode fibre, demultiplexed and individually photodetected in the base station. The optical amplification of the 1540 nm FGL heterodyne in the base station was needed to boost the detected power of the

millimetre-wave beat signal sufficiently to drive the double-balanced mixer used to mix the two signals.

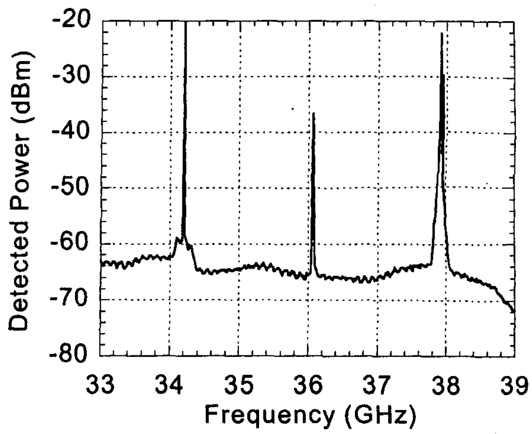

Fig. 2. Detected spectrum after mixing of optically transmitted FGL heterodyne signal and error signal. Res. B/w: 3 MHz.

Fig. 2 shows the output signal from the mixer. The reference frequency has here been reduced to 34.2 GHz so that the image frequency after mixing can be seen within the frequency range of the spectrum analyser (26.5-40 GHz). The centre frequency component in the figure is the leakage of the LO signal, derived from the heterodyne signal from the two free-running FGL's. The left frequency component is the phase and frequency cancelled mixing product between the LO and the unmodulated error signal transmitted from the central station. The phase and frequency of this signal is now determined by the reference source in the central station. The right frequency component is the image mixing product, with double the phase and frequency fluctuations of the LO.

In order to achieve a high degree of phase noise cancellation, the transmission length of the two paths of the FGL heterodyne and the error signal must be carefully matched. The spectrum close to the carrier with path mismatch present can be calculated in the same manner as for feed-forward modulation in the optical domain [5]:

$$S(\omega) = 2\pi e^{|\tau|/t_b}\delta(\omega) + |\tau|/t_b \qquad (1)$$

Where ω is the frequency, $1/\pi t_b$ is the FWHM of the Lorentzian linewidth of the FGL heterodyne beat and τ is the path mismatch. The corresponding S/N ratio in one Hertz bandwidth is then given by $2\pi t_b/|\tau|^2$ In this experiment, low linewidth lasers are chosen to relax the path-matching requirements. The FWHM of the heterodyne beat of the FGL's is less than 1 MHz. The maximum path mismatch is estimated to be < 0.1m, corresponding to < 0.5ns or <–129 dBc/Hz noise spectral density close to the carrier due to path mismatch.

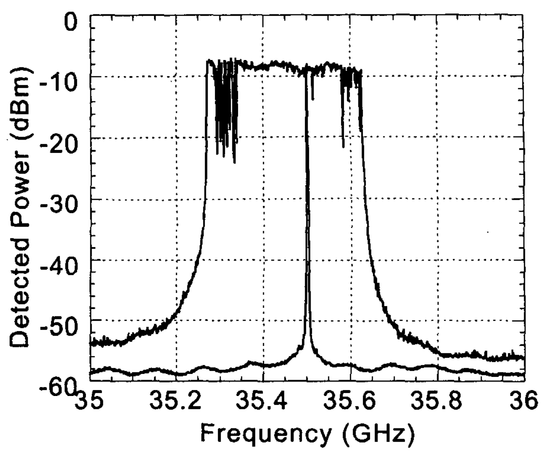

Fig. 3. Detected free-running FGL heterodyne signal and drift-cancelled signal using maximum hold function of the spectrum analyser over a period of 5 min. Res. B/w: 1 MHz.

III. RESULTS

Fig. 3 shows the improvement of the frequency stability of the generated carrier compared to the free-running beat signal. The two spectra were taken separately using the maximum hold function of the spectrum analyser over a period of five minutes. The frequency of the free-running heterodyne is drifting within a 400 MHz frequency window while in contrast the frequency of cancelled signal remains constant during the period. Fig. 4 shows the detected relative noise spectral power density of the phase and drift cancelled millimetre-wave carrier for transmission through 0 km and 25 km fibre and of the reference. The detected noise level of the carrier after 0 km fibre transmission is limited by the reference down to just below 1 MHz offset, after which the noise performance is limited by the millimetre-wave receiver in the central station. After transmission through 25 km the noise level remains less than –85 dBc/Hz for offsets from 10 kHz to 1 MHz, falling to – 108 dBc/Hz at offsets greater than 100 MHz.

The system can be used for optical delivery of a data modulated millimetre-wave carrier by applying data to the error correction signal. Here this was achieved by switching the phase with a double-balanced mixer, generating BPSK modulation. Fig. 5 shows the detected eye diagram after transmission through 25 km fibre. The best BER obtained was 10^{-8}, limited by slow variations of the relative phase between the FGL heterodyne and the error correction signal, relative to the phase-locked reference sources. This is due to variations in the optical length of the fibre transmission. Using carrier recovery at the base station, or a non-synchronous modulation scheme would improve the BER performance. In a system where the BER performance is limited by the noise of the optically delivered signal, error-free (BER<10^{-9}) detection should be easily available.

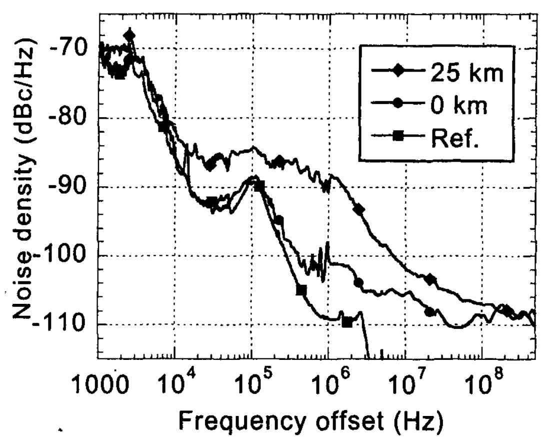

Fig. 4. Detected relative noise spectral power density for phase and drift-cancelled carrier transmitted through 25 km and 0 km, compared to the noise of the reference.

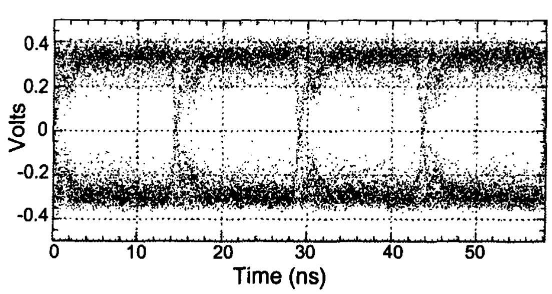

Fig. 5. Detected eye for optically delivered 68 Mbit/s BPSK modulated 36 GHz carrier after 25 km fibre transmission.

V. Conclusion

In this paper, a new architecture for optical delivery of modulated millimetre-wave carriers has been demonstrated. The system is based on electrical phase and frequency drift cancellation of a free-running laser heterodyne at the remote base station. Delivery of a 68 Mbit/s BPSK modulated 36 GHz carrier has been demonstrated for 25 km transmission through standard singlemode fibre. This method shares the advantage of a very simple and flexible generation of millimetre-wave modulated signals, free running optical heterodyne, with previous work [1]. Phase-locking of the two lasers is not needed and by performing the phase and frequency drift cancellation in the electrical domain, more mature and less expensive technology can be used for functions such as amplification and frequency conversion, than if performed in the optical domain [5]. Furthermore, by separating the transmission of the millimetre-wave modulated optical signal from the data-modulated error signal, one millimetre-wave modulated signal can be used as a reference for many remote antenna units.

Acknowledgement

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