HIGH SPECTRAL PURITY MILLIMETRE-WAVE MODULATED OPTICAL SIGNAL GENERATION USING FIBRE GRATING LASERS

F.N. Timofeev, S. Bennett, R. Griffin, P. Bayvel, A.J. Seeds,
Department of Electronic and Electrical Engineering, University College London, Torrington Place, London, WC1E 7JE, U.K.
R. Wyatt, R. Kashyap, and M. Robertson,
BT Research Laboratories, Martlesham Heath, Ipswich, IP5 3RE, U.K.

ABSTRACT

Millimetre-wave optical signal generation by heterodyning two semiconductor fibre grating lasers is demonstrated for the first time. The resulting beat signal, has an extremely narrow linewidth (< 100 kHz), is continuously tuneable (0-40 GHz) and exhibits negligible chirp under direct 2.6 Gbit/s modulation.

INTRODUCTION

Millimetre-wave radio over fibre has recently attracted considerable interest as a means of distributing future broad-band wireless services [1,2]. This technique involves millimetre-wave signals being superimposed on an optical carrier and distributed by an optical fibre network to remote antenna sites. A key requirement for such systems is a practical millimetre-wave modulated optical source.

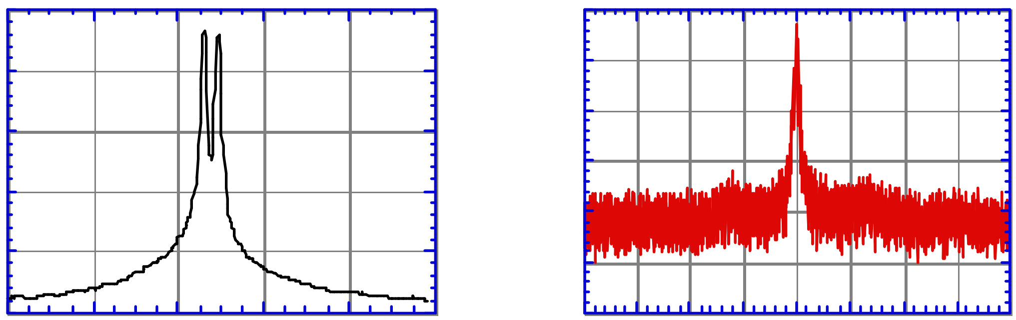
Direct modulation of laser diodes is currently limited to a maximum modulation frequency of around 30 GHz [3]. External modulators can offer lower fibre dispersion penalties through reduced chirp operation and Mach-Zehnder interferometric modulators have been realised with modulation bandwidths of up to 75 GHz [4]. However, in standard single-mode fibre (SSMF), the dispersion-limited transmission distance is only a few km. The use of laser heterodyne techniques with baseband modulation applied to only one of the lasers enables these limitations to be greatly reduced since the dispersion penalty then only applies to the base-bandwidth [5]. Previously the problem of such an approach has been the large phase noise of the beat-signal resulting from the wide linewidth of conventional distributed feedback (DFB) lasers. We report on the generation of high spectral purity millimetre-wave modulated optical signals by heterodyning two fibre grating lasers (FGLs) [6] with very narrow linewidths (< 50 kHz at an optical power of 1 mW).

HETERODYNE EXPERIMENTS

For the heterodyne experiments, two FGLs operating at 1.53 µm were used [6]. Each laser consists of a ~ 450 µm GaInAsP/InP buried heterostructure semiconductor amplifier chip with an angled facet coupled to a lensed fibre grating with a peak reflectivity of 30 % and a FWHM reflection bandwidth of ~ 0.2 nm. The angled facet amplifier chip has a front facet reflectivity of < 0.05 %. The effective length of the external resonator was measured to be 7 mm. Each laser was mounted in a DIL package with a Peltier cooler, providing simultaneous temperature control of the semiconductor amplifier chip and fibre grating.

The outputs of the two lasers were combined via an optical 3 dB coupler and after transmission through SSMF the signal was detected using a high-speed photodetector. The resulting millimetre-wave beat signal was analysed using an RF spectrum analyser with a preselected harmonic mixer. This configuration allowed spectral measurements to be performed within a frequency range of 100 Hz to 40 GHz. Fig. 1

shows the optical spectrum of the combined signal and the corresponding millimetre-wave beat signal at a frequency of 39.2 GHz. The linewidth of each laser was measured using a delayed self-heterodyne technique and found to be < 50 kHz (resolution limited) at an output



(a) (b)

Fig. 1. (a) Optical spectrum of the two combined FGLs spaced by 39.2GHz (resolution bandwidth = 0.1 nm). (b) Corresponding 39.2 GHz beat signal on a high-speed photodetector (resolution bandwidth = 50 kHz).

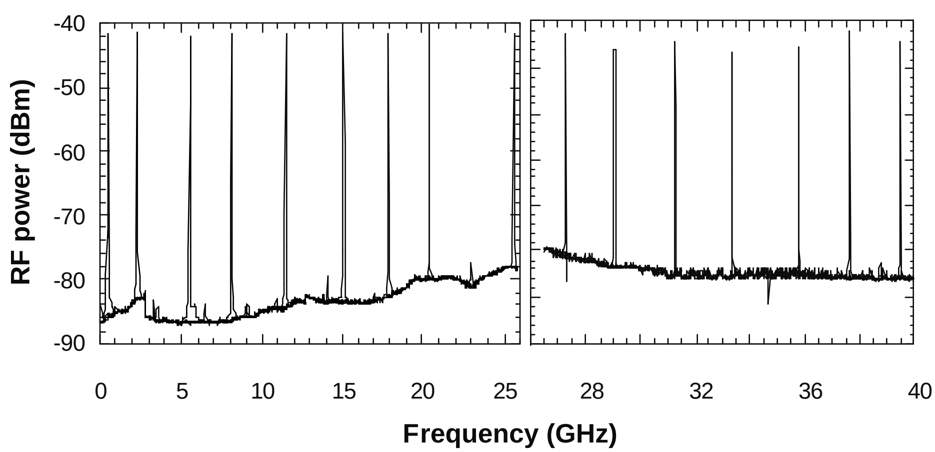


Fig. 2. RF spectrum as the beat signal was tuned across the 0.05 GHz - 40 GHz frequency range (resolution bandwidth = 1 MHz).

power of 1 mW. The lasers were found to have a wavelength tuneability of 40 MHz/mA with injection current and -1.9 GHz/K with temperature tuning. By current or temperature tuning the wavelength of the lasers the beat signal frequency could be continuously tuned across the 100 Hz to 40 GHz frequency range of our measurement system without mode-hopping. The detected spectra of the beat signal as it was tuned across the 0.05 - 40 GHz frequency range are shown in Fig. 2. Fig. 3 shows the dependence of beat signal power on frequency across the same frequency span. Within the calibrated frequency range (0.05 - 26.5 GHz) there was less then 1dB deviation in the detected power of the beat signal. The maximum deviation in the beat frequency was measured to be less than 75 MHz over a time scale of 30 minutes with the amplifier chip and fibre grating temperature stabilised to within 10 mK. This is a significant improvement over the measured beat frequency deviation of > 275 MHz from two DFB lasers temperature stabilised to the same tolerance over the same period.

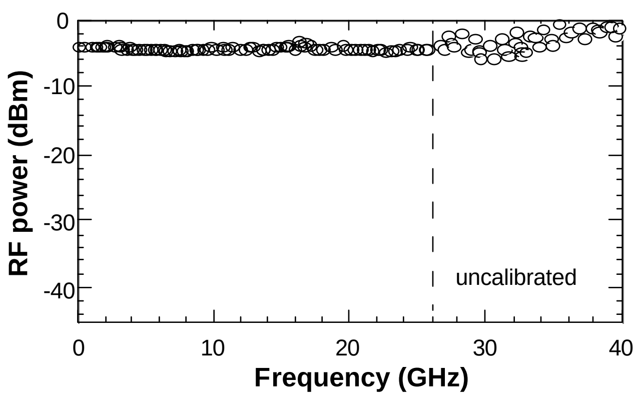


Fig. 3. Dependence of the beat signal power on frequency.

The modulation performance of this heterodyne system was investigated by applying a pseudo-random 2.6 Gb/s NRZ digital signal to the electrical input of one FGL. The frequency spectrum of the beat signal is shown in Fig. 4 with and without modulation current applied. It is clear from Fig. 4 that the modulation envelope is almost transform limited, due to the inherent low chirp of FGLs [6]. Using two DFB lasers under similar conditions we measured a modulation envelope bandwidth of greater than 10 GHz.

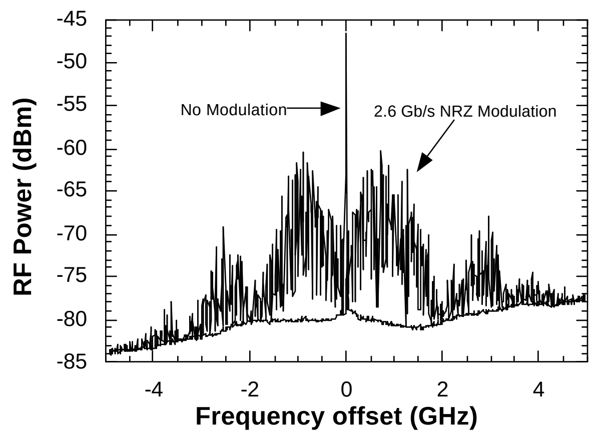


Fig. 4. RF spectrum with and without 2.6 Gb/s NRZ digital modulation applied to one of the FGLs. The laser bias and modulation currents were 62 mA and 40 mA respectively. The central frequency of the beat signal was 21.4 GHz.

The low chirp beat signal produced by the FGLs offers the potential of having an extremely low dispersion penalty when transmitted over SSMF. In this initial experiment, the signal was transmitted over 39 km of unamplified SSMF without measurable degradation. Potentially this distance could be increased to > 300 km (at 2.6 Gb/s data rate) with very low transmission penalty [6,7].

CONCLUSIONS

In conclusion we have reported on the generation and transmission of narrow linewidth millimetre-wave modulated optical signals using FGLs. The frequency of the beat signal was continuously tuneable over a 40 GHz span (measurement system limited) and had very low amplitude and frequency deviation without the need for closed loop control techniques. Both the beat frequency stability and linewidth could be improved dramatically by phase locking the two FGLs in an OPLL [8]. The extremely narrow linewidth of FGLs allows loop realisation with a loop propagation delay (LPD) as high as 20 ns [8], allowing loop implementation with inexpensive electronics. In contrast, the broad beat linewidth of DFB lasers (typically 8 MHz) require a LPD of less than 0.3 ns. The narrow linewidth, good wavelength tuneability, and high bit rate transform limited direct modulation capability of FGLs make them excellent candidates for application in millimetre-wave radio over fibre systems.

ACKNOWLEDGEMENTS

Support for F.N. Timofeev through the EC DAWRON project and UK EPSRC is gratefully acknowledged. S. Bennett is grateful for funding from the UK EPSRC and P. Bayvel acknowledges the support of The Royal Society through a University Research Fellowship.

REFERENCES

[1] A.J. Seeds, "Broadband wireless access using millimetre-wave over fibre systems," IEEE MTT-S International microwave symposium digest, pp.23-25, 1997.

[2] D. Wake, C.R. Lima and P.A. Davies, "Optical generation of millimeter-wave signals for fiber-radio systems using a dual-mode DFB semiconductor laser," IEEE Trans. Microwave Theory Tech., vol. 43, pp 2270-2276, 1995.

[3] Y. Matsui, H. Murai, S. Arahira, S. Kutsuzawa, and Y. Ogawa, "30-GHz Bandwidth 1.55 μm strain-compensated InGaAlAs-InGaAsP MQW Laser," IEEE Phot. Tech. Lett., vol. 9, pp 25-27, 1997.

[4] K. Noguchi, H. Miyazawa, and O. Mitomi, "75 GHz broadband Ti:LiNbO3 optical modulator with ridge structure," Electron. Lett.,vol. 30, pp. 949-951, 1994.

[5] H. Schmuck, "Comparison of optical millimetre-wave system concepts with regard to chromatic dispersion," Electron. Lett. vol. 31, pp. 1848-1849, 1995.

[6] F.N. Timofeev, P. Bayvel, V. Mikhailov, O.A. Lavrova, R. Wyatt, R. Kashyap, M. Robertson, "2.5 Gbit/s directly-modulated fibre grating laser for WDM networks," Electron. Lett.,vol. 33, pp.1406-1407, 1997.

[7] F.N. Timofeev, P. Bayvel, J.E. Midwinter, R. Wyatt, R. Kashyap, M. Robertson, "2.6 Gbit/s dense WDM transmission in standard fibre using directly-modulated fibre grating laser," Electron. Lett., vol. 33, pp.1632-1633, 1997.

[8] R.T. Ramos, and A.J. Seeds, "Delay, linewidth and bandwidth limitations in optical phase-locked loop design," Electron. Lett.,vol. 26, pp. 389-391, 1990.