Khawaja, B. A. M., & Cryan, M. J. (2009). A hybrid mode locked laser as millimetre wave modulated data source for radio-over-fiber systems. In IEEE/LEOS Summer Topical Meeting, 2009 (LEOSST '09), Newport Beach, CA. (pp. 67 - 68). Institute of Electrical and Electronics Engineers (IEEE). 10.1109/LEOSST.2009.5226227

TuB3.2
4:00 PM – 4:15 PM

A Hybrid Mode Locked Laser As Millimetre Wave Modulated Data Source for Radio-Over-Fiber Systems

B.A. Khawaja and M.J. Cryan
Photonics Research Group, Department of Electrical and Electronic Engineering, University of Bristol, Bristol, BS8 1UB, UK.
email: m.cryan@bristol.ac.uk

Abstract: The paper presents a characterisation of a hybrid mode locked laser under external injection locking. It shows how such a system can be used to transmit baseband data without the requirement of an external modulator.

1. Introduction

The demand for high speed data transmission has increased dramatically and recently there has been much interest in the use of the millimeter-wave (mm-wave) frequency bands. They offer large transmission bandwidths at 60GHz and also overcome the problem of spectral congestion at lower frequency ranges [1, 2]. To completely exploit this band there are, for example, recently released standards for consumer based systems for distribution of High Definition TV signals around the home operating at 4Gbps with a 60GHz carrier [3]. It has long been recognized that Radio-over-Fibre (RoF) could play an important role in systems such as this when signals need to be distributed over many 100's or 1000's of meters [4]. Cost will be a very important factor in the success of these systems and the main issue for RoF solutions is the cost of modulating a laser at 60GHz. Traditionally, this would be done with an expensive Electro-Optic modulator [2] although more recently Electro-Absorption modulators have been explored [5]. One interesting, potentially low cost, solution is the use of Mode Locked Lasers (MLLs) that can be designed to operate at millimetre pulse repetition frequencies [6]. Not only can these devices be used to transmit data on a mm-wave carrier, they can also implement mm-wave phase shifting [6, 7] which can be used for smart antenna beamforming. This paper presents MLL behaviour under injection locking and compares it to the classical injection locked oscillator (ILO). The paper also present 26MB/s BPSK data transmission using an injection locked MLL and shows that maximum data rate is dependent on the injection locking range. These results show the potential for MLLs to be used as mm-wave modulated data sources and remove the need for expensive modulators in 60GHz RoF links.

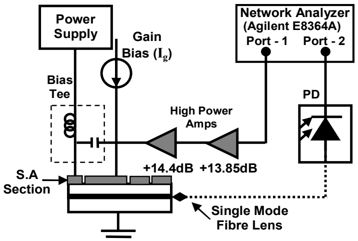

Figure 1 : MLL injection locking measurement setup using mm-wave amplifiers and VNA

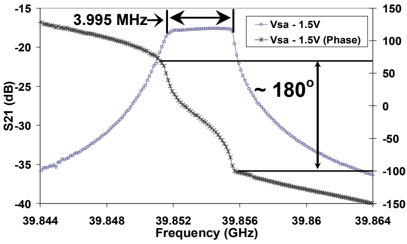

Figure 2 : Zoom-in on S_{21} amplitude response showing plateau across locking range and its relativephase shift of ~180^0

2. Results

A multi-section MLL chip integrated with a saturable absorber (SA), gain, phase and distributed Bragg reflector sections has been used for the measurements. The MLL is supplied by HHI, Berlin [8] having a total device length of 1080μm which produces an output pulse repetition frequency of around 40GHz. The MLL has an excellent optical output power characteristic of ~ 7.5mW into a single mode fiber lens (SMF lens) at 110mA gain section current and at 15^{o}C. The MLL passive mode locking frequency range has been characterised and is found to be 446.7MHz as shown in [6]. A novel approach of hybrid injection locking the MLL has recently been presented using the vector network analyzer (VNA) [6] by exploiting the phase locking nature of a VNA. Figure 1 shows the measurement setup. This technique allows a straight forward characterization of mm-wave injection locking and phase shift induced due to RF injection locking of two systems, this is possible by using the VNA phase measuring capability. According to the theory for ILOs [9, 10], an ILO steady state phase will have a shift of 180^o ($-\pi/2$ to $+\pi/2$) as the injected signal is tuned across the oscillator's locking range. It is also well known that the injection locking range is dependent on the amount of injected power with greater input power producing increased locking ranges given by the formulae in Eq. 1 and Eq.2 respectively,

$$\theta(\omega_1) = Sin^{-1}\left(\frac{\omega_0 - \omega_1}{\Delta\omega_L}\right) \qquad (1) \qquad\qquad \Delta\omega_L \propto \sqrt{P_{inj}} \qquad (2)$$

Where ω_0, ω_1 and $\Delta\omega_L$ are the output, injected signals and locking range of the ILO respectively and where P_{inj} is the injected RF power to MLL. Figure 2 shows MLL injection locked measured S_{21} amplitude and its phase and an overall phase shift of ~180^o is observed. It is important to note that the injection locked MLL presented in [6] and here is behaving like an electronic ILO by showing a phase shift of ~180^o for +0.6dBm injection power (P_{inj}) to the SA section shown in

978-1-4244-3914-0/09/$25.00 ©2009 IEEE

figure 2. But in reality it is an optoelectronic system which is fundamentally different and more complex then an electronic ILO system. To observe the effect of P_{inj} on the locking range as shown in Eq. 2, the MLL is injection locked with two high power amplifiers (HPAs) shown in figure 1. Port 1 of VNA is used to input a mm-wave signal into the SA section to obtain injection locking. Light is coupled out of the laser using 1m SMF lens and into a high speed photodiode and back into port 2 of the VNA. The gain section was biased at 110mA and the S.A section was biased at range of voltages V_{sa} = -0.5V to -1.5V. Figure 3 shows the locking range is quite linear with respect to the $\sqrt{P_{inj}}$ up to 4.2mW then it starts to saturate for the injected power of 5.9mW which shows that an injection locked MLL is deviating from what would be expected in an electronic ILO system.

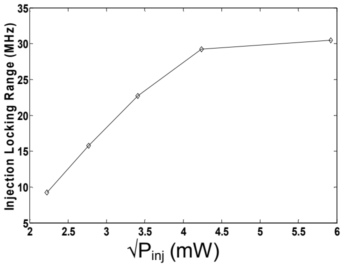

Figure 3 : Dependence of injection locking range on square root of locking signal power

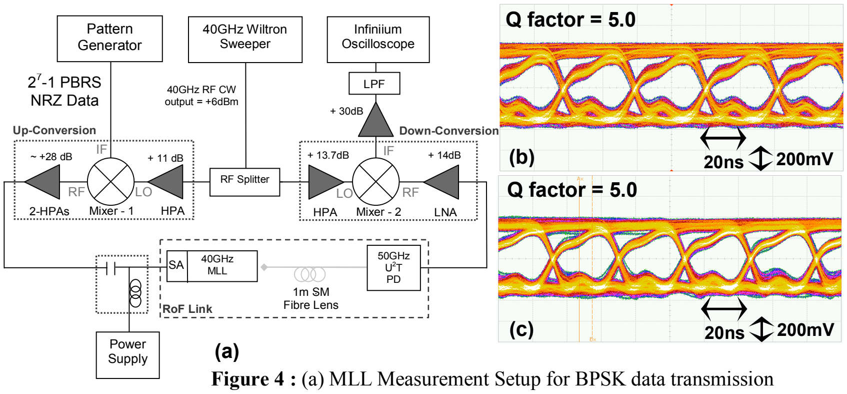

Figure 4 : (a) MLL Measurement Setup for BPSK data transmission (b) Downconverted NRZ BPSK data eye diagrams for the data rates of 24MB/s and (c) 26MB/s over MLL-RoF Link

MLL modulation using BPSK data was then implemented. The setup diagram in figure 4(a) shows that a pseudorandom (2^7-1) non-return-to-zero (NRZ) bit sequence is generated from Anritsu ME522A pattern generator. The BPSK data is upconverted to 40GHz using a Hittite (HMC-560) GaAs mixer. A Wiltron sweeper is used as a local oscillator (LO) source to drive the mixers. The sweeper output power is +6dBm which after the splitter becomes 0dBm which is very low to drive the mixers. So, to overcome the low power problem, a HPA is used at each side. The upconverted data is then amplified by ~ 28dB by two HPAs in series and injected to the MLL SA section for injection locking. This amplification overcomes the losses of the bias-tee, V-K cable, transmission line and bondwire which were separately measured as -6.8dB. The mm-wave modulated signal from the MLL collected using SMF lens and after the PD was amplified using a +14dB low noise amplifier (LNA) and fed to the RF port of mixer-2 for down conversion. The downconverted data at the IF port was then amplified using a +30dB gain low frequency amplifier. After the low pass filter, the data was fed into an Agilent Infiniium 13GHz oscilloscope to observe the detected pattern eye-diagrams in the time domain as shown in figure 4 (b-c). The good eye opening and quality factor ‘Q’ of 5 shows the successful data transmission up to 26MB/s. It is important to note that maximum data rate is dependent on injection locking range which is +30.46MHz in this case as shown in figure 3.

3. Conclusion

We have shown the behaviour of a MLL under hybrid injection locking and compared it with an electrical ILO. We have also presented 26MB/s BPSK data transmission over MLL-RoF link. As shown in [11] these devices can be integrated along side small planar antennas to produce very low cost mm-wave modules. At 60GHz it may also be possible to produce fully monolithic devices where an antenna is integrated directly along side the MLL.

4. References

[1] P.F.M. Smulders *et al*, “60 GHz radio: prospects and future directions”, *Proceedings Symposium IEEE Benelux Chapter on Communications and Vehicular Technology*, 2003, Eindhoven
[2] R. W. Ridgway *et al.*, “Generation and Modulation of a 94-GHz Signal Using Electro-optic Modulators”, *IEEE Photonics Tech. Lett*, Vol. 20, No. 8, pp. 653-655, Apr 2008
[3] WiHD (http://www.wirelesshd.org/)
[4] Z. Ahmed *et al.*, “37-GHz Fiber-Wireless System for Distribution of Broad-Band Signals” *IEEE Trans. Microw. Theory Tech.*, vol. 45, no. 8, pp. 1431–1435, Aug. 1997
[5] K.-S. Choi *et al.*, “System-on-Packaging with Electroabsorption Modulator for a 60-GHz Band Radio-Over-Fiber Link*”, IEEE Trans. on Adv. Pack*, Vol. 31, No. 1, pp. 163-169, Feb 2008
[6] B. A. Khawaja *et al*, “Study of Millimeter Wave Phase Shift in 40 GHz Hybrid Mode Locked Lasers”, *IEEE Microwave wireless comp. Lett,* vol. 19, no. 3, pp. 182-184, March 2009
[7] J. B. Georges *et al.*, “Simultaneous Fiber-optic Transport and RF Phase Control of Narrow-Band Millimeter-Wave Signals Using Multicontact Monolithic Semiconductor Lasers”, *IEEE Photonics Tech Lett.*, Vol. 8, No. 7, pp. 953-955, Jul 1996
[8] R.Kaiser *et al.*, “Monolithic 40-GHz Mode-Locked MQW DBR Lasers for High-Speed Optical Communication Systems”, *IEEE J. Quantum Elec*, vol. 13, no. 1, pp. 125-135, Jan 2007.
[9] R. Adler, “A study of locking phenomena in oscillators,” *Proc. IEEE*, vol. 61, pp. 1380–1385, Oct. 1973
[10] A. E. Siegman, *Lasers*, Oxford University Press — University Science Books, 1986
[11] B. A. Khawaja *et al*, “A Millimeter Wave Phase Shifter Using A Wireless Hybrid Mode Locked Laser”, *Accepted for Publication in OFC 2009,* 22 – 26 Mar, 2009, San Diego, California, USA