MILLIMETER WAVE GENERATION BY OFF-LOCKING OPTICAL INJECTION IN A DFB LASER DIODE

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ABSTRACT

We injected CW light from a single-mode laser into the cavity of a second one, with a frequency detuning outside the locking range. After detection with a fast photodiode we observed beat notes, in the 15-45 GHz range, narrower than 100 kHz, i.e. much less than the 2.2 MHz natural beat note linewidth, observed in the absence of injection.

INTRODUCTION

Microwave carrier generation by beating of mutually coherent laser lines is attracting continuous interest for the wide range of attainable frequencies and for the ease of low loss transport via optical fiber. Several schemes have been proposed so far, among which sideband injection-locking of Fabry-Perot laser diodes [1], RF driven two mode DFB laser diodes [2] and optically filtered mode-locked laser diodes [3]. Unfortunately, most of those solutions lack continuous tunability; on the other hand an almost ideal tunability is achievable by beating together two independent laser diodes which can be easily temperature or current tuned. In this case a major drawback is the poor linewidth characteristic of the beat note.

In this work we report on the preliminary observation of a substantial beat-line narrowing obtained by injecting CW light from a high purity (~100 kHz linewidth) master laser into an unmodulated DFB slave laser, outside of the optical locking range.

EXPERIMENT

In the experimental set-up sketched in fig. 1, CW light at 1.55 µm from a single-frequency external-cavity laser (ECL) diode (Radians Innova mod. Intun 1500) was amplified by a variable gain erbium-doped fiber amplifier (EDFA) and then injected into one facet of the temperature-stabilized DFB slave cavity, by means of a tapered fiber. A two-stage isolator inside the ECL, input and output isolators inside the EDFA and an external isolator with >30 dB isolation prevented backward injection into the master, as well as unwanted reflections from the fiber connectors. All components were connected via non-polarization preserving fibers, therefore a manual polarization controller was inserted to ensure proper polarization matching in the slave cavity. Light generated

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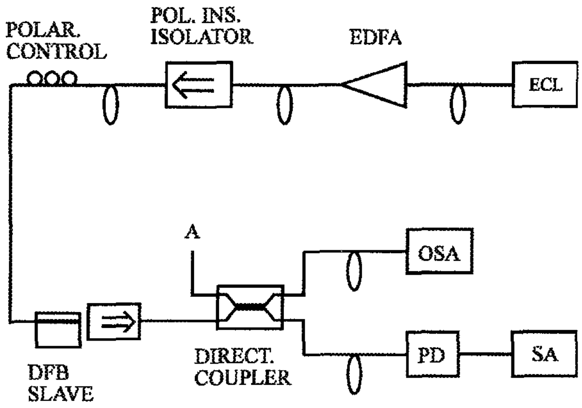

Fig.1. Experimental set-up. ECL: 1.55 μm external cavity laser, OSA: optical spectrum analyzer, PD: p-i-n photodiode, SA: 50 GHz spectrum analyzer. Both the ECL and the DFB were driven CW.

by the slave laser, superposed to the master light passing through the slave waveguide itself, was collected at the opposite slave facet via another isolator and a fiber collimating lens. With the aid of a 3 dB optical directional coupler both the optical spectrum, and the RF spectrum of the beat note were obtained simultaneously. A p-i-n photodiode (New Focus mod. 1014) with a responsivity of 10 V/W and a 3 dB cutoff frequency of 45 GHz, was used as photo-detector.

With the slave biased at 2.7 times its threshold current, and a ratio of injected master power to emitted slave power in its range 0.1 to 0.5, the optical locking range was approximately 15 GHz wide. Under these conditions, whenever the frequency detuning between master and slave was chosen outside the locking range, two separate spectral lines were present in the slave output field, thus generating a microwave beating [4]. It is worth stressing that the beat frequency differs from the free-running frequency detuning because the injection induces a change (pulling) in the average optical frequency of the slave lasing field. For both positive and negative detuning and for beat frequencies ranging from 15 to 45 GHz we observed on the spectrum analyzer a narrow beat linewidth of less than 100 kHz between -3dB points. The upper frequency limit of 45 GHz appeared to be set only by the limited bandwidth of the photodiode, since no major change was observable when approaching that limit.

The medium term drift of the center frequency was in the order of a few tens of MHz in a 5 minutes period, i.e. of the same order of magnitude as in the free-running case. For practical applications some kind of feedback stabilization loop, e.g. acting on the bias current of the slave, could be easily implemented in order to cancel this drift.

In fig. 2 we report the RF spectrum obtained at 40 GHz detuning; very similar spectra were observed for the whole RF frequency range mentioned above.

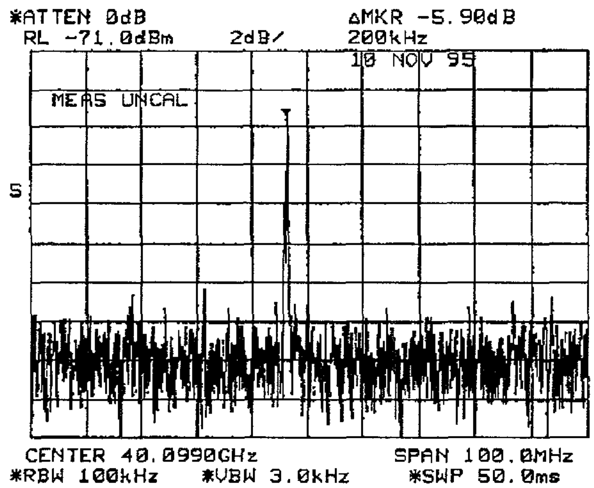

Fig.2. RF beat line at photodetector output. The medium term stability of the beat frequency was a few tens of MHz in a 5 minutes time interval. The corresponding optical spectrum impinging on the photodetector is reported in fig. 3.

The corresponding optical spectrum, measured with the optical spectrum analyzer set at the minimum resolution bandwidth of 12.5 GHz, is shown in Fig. 3. A 10.8 dB power imbalance between the two lines was present, but optical intermodulation products had negligible amplitude. In previous papers [4] the beat note was analyzed in the time domain, in which case a 0 dB power imbalance was achieved, corresponding to a nearly 100% beating modulation depth.

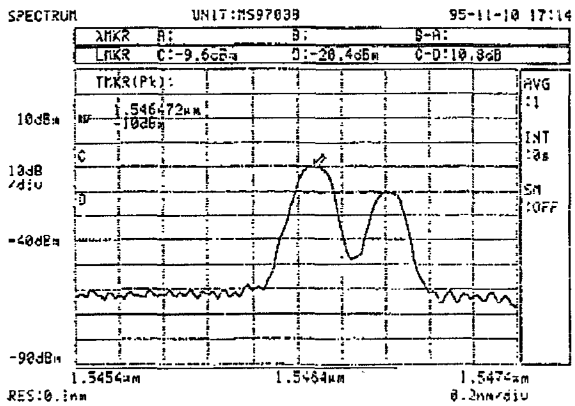

Fig.3. Optical spectrum with the master line (right) 40 GHz apart from the slave line (left). The resolution optical bandwidth was 12.5 GHz.

DISCUSSION

For immediate comparison with the standard free-running case, we disconnected the output of the EDFA from the isolator and plugged it into the available port "A" of the directional coupler. In this way we observed the natural beat note (reported in fig. 4) between the free-running lasers. The measured linewidth in this case was 2.2 MHz, mostly due to the slave laser. It is therefore evident that, by traveling through the same laser cavity, the master and slave lines gain an increased mutual coherence leading to a narrower beat line. Work is currently in progress to clarify the physical mechanism leading to such coherence increase. At present the possible explanation [5] that we are considering as most likely relies on the consideration that the major source of line broadening in a semiconductor laser stems from the refractive index dependence on carrier density. The main effect of each individual event of spontaneous emission inside the laser cavity is to alter the carrier density through the perturbation generated on the field intensity. The subsequent perturbation of refractive index modulates the cavity resonant frequency, eventually broadening the laser line by generating phase-noise. The broadening due to the amplitude noise normally is negligibly smaller than the above one. In our configuration the master light also happens to travel across the slave laser cavity, thus experiencing a phase modulation strongly correlated with that undergone by the slave field, since those modulations originate from a common carrier density perturbation. Such a correlation might be responsible for the observed increased mutual coherence.

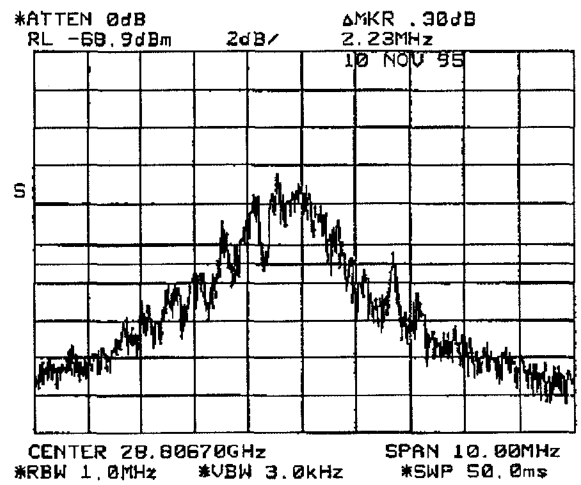

Fig.4. RF beat line between free running lasers, driven at the same DC biases used in fig. 2.

In conclusion, we presented preliminary experimental evidences of a promising and simple technique for obtaining narrower beat signals from a pair of matched laser diodes. The most interesting feature demonstrated is the capability of truly continuous tuning over at least the 15-45 GHz range, with constant RF amplitude.

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REFERENCES

[1] L.Goldberg, A.M.Yurek, H.F.Taylor, and J.F.Weller, "35 GHz microwave signal generation with an injection-locked laser diode," *Electron. Lett.*, vol. 21, pp. 630-631, 1985.

[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 and Techn.,* vol. 43, pp. 2270-2276, 1995.

[3] D.Novak, Z.Ahmed, R.B.Waterhouse, and R.S.Tucker, "Signal generation using pulsed semiconductor lasers for application in millimeter-wave wireless links," *IEEE Trans. Microwave Theory and Techn.*, vol. 43, pp. 2257-2262, 1995.

[4] H.Burkhard, S.Mohrdiek, H.Schöll, H.Hillmer, S.Hansmann, and A.Mattheus, "Effects of injected light and optical feedback on directly modulated MQW lasers and OTDM multigigabit-per-second system performance," *Proc. SPIE* 2399, paper 69, 1995; H.Schöll, H.Burkhard, "Ultra high repetition rate optical pulse generation by continuous light injection into a CW operated DFB laser," *Jap. Journal of Appl. Phys.*, Part 2, Vol. 34. n. 10B, pp. L1358-L1361, 1995.

[5] A.Sapia, *private communication.*