

# Frequency stability of a self-phase-locked degenerate continuous-wave optical parametric oscillator

P. Groß and K.-J. Boller

Faculty of Applied Physics, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands  
phone: +31 53 489 3968, fax: +31 53 489 1102, p.gross@utwente.nl

M.E. Klein

Nederlands Centrum voor Laser Research NCLR b.v., P.O. Box 2662, 7500 CR Enschede, The Netherlands

D.-H. Lee

KAIST, Center for Electro-Optics, Guseong-Dong, Yuseong-Gu, 305-701 Daejeon, Republic of Korea

**Abstract:** The properties of a self-phase-locked by-2-divider optical parametric oscillator are presented. A locking range of up to 156 MHz is measured, and the divider's relative frequency stability is shown to be better than  $6 \times 10^{-14}$ .

©2003 Optical Society of America

OCIS codes: (190.2620) Frequency conversion; (190.4970) Parametric oscillators and amplifiers

Phase-coherent division of optical frequencies by two and by three using continuous-wave (cw) optical parametric oscillators (OPOs) is of great interest for precision metrology in the near and mid-infrared spectral region [1]. In particular, all-optically phase-locked divider stages are desirable due to their potentially fast response time to phase-shifting effects.

Here, we report on the first measurement of the frequency stability of an all-optically-locked frequency-by-2 divider OPO. For an integration time of 5 s, the divider's frequency stability was measured to be better than  $5.9 \times 10^{-14}$ .

The optical frequency to be divided is given by a grating-stabilized AlGaAs-diode master-oscillator power-amplifier (MOPA) system, which provides up to 300 mW at 802 nm for pumping the frequency-by-2 divider. The divider is a triply resonant two-mirror OPO based on type-II phase matching in a 50-mm long periodically poled lithium niobate (PPLN) crystal, which provides up to 10 mW subharmonic output. Self-phase locking is achieved by mixing of the two perpendicularly polarized subharmonic waves using an intracavity quarter-wave plate (QWP) [2,3].

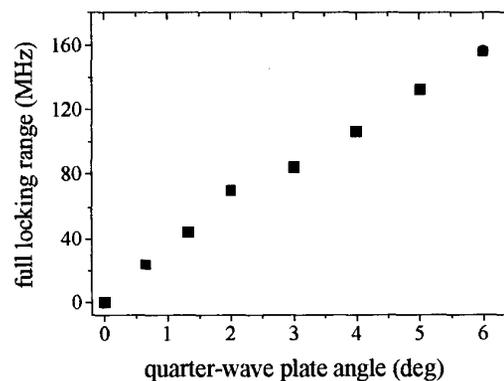


Fig. 1. Locking range as a function of QWP angle.

## CThPDB1

When tuning the OPO towards frequency degeneracy, self-phase locking occurs, if the frequency difference of the subharmonic waves becomes smaller than a characteristic value, the so-called locking range. When rotating the QWP out of the neutral, i.e. non-mixing, orientation, we observe an approximately linear increase of the locking range with the QWP angle, as displayed in Fig. 1. A maximum locking range of 156 MHz has been measured for a QWP angle of  $6^\circ$ .

To determine the frequency stability, we measured the bandwidth of the beat frequency between the two subharmonic waves using a fast photodiode and a radio frequency (rf) analyzer. To avoid the DC noise peak at zero frequency, one of the waves was frequency-shifted using an acousto-optic modulator (AOM), transferring the beat frequency to the range around 27 MHz.

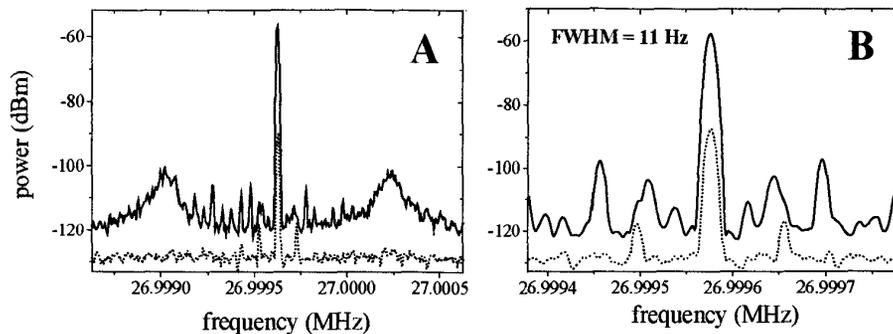


Fig.2. Beat spectra of the OPO subharmonic waves.

Figure 2 shows two examples of the measured rf-spectra, averaged over 20 measurements. The dotted curves give the electronic background signal obtained with the photodiode blocked. The main peak, which is typically 30 dB below the optical signal, is caused by rf-pickup from the AOM driver. The bandwidth of the optical beat signal is always found to be equal to the resolution bandwidth of the spectrum analyzer, even at the highest possible resolution. From Fig. 2B we obtain as an upper limit for the divider's instability a bandwidth of 11 Hz for an integration time of 5 s, which corresponds to a fractional frequency instability of  $5.9 \times 10^{-14}$ .

The wide all-optical locking range and the high frequency stability together with the wavelength flexibility of the concept due to the use of diode laser pump systems and quasi-phase matching materials demonstrate the high potential of all-optical frequency dividers for precision metrology.

## References

- [1] N.C. Wong, *Opt. Lett.* **15**, 1129 (1990).
- [2] E.J. Mason and N.C. Wong, *Opt. Lett.* **23**, 1733 (1998).
- [3] C. Fabre, E.J. Mason, and N.C. Wong, *Opt. Comm.* **170**, 299 (1999).