Optical generation of frequency stable mm-wave radiation using diode laser pumped Nd:YAG lasers

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ABSTRACT

Frequency locking of diode pumped YAG lasers to high finesse interferometers is discussed. Relative stability at the sub-Hz level is demonstrated and application of this work to the generation of mm-wave radiation to 115 GHz for high speed photodetector characterization is presented.

1. INTRODUCTION

Many areas of research such as wide band frequency division multiplexed communication links, or optical distribution of mm-waves for phased array radar, antenna remoting and high speed photodiode characterization require optical generation of frequency stable mm-waves. Previously, we had demonstrated < 3 Hz relative frequency stability when locking two low power (2 mW) Nd:GGG laser diode pumped nonplanar ring oscillators to a high finesse ($F = 22,000$) interferometer with an offset frequency of 6.33 GHz. We have since made improvements in this system by replacing the low power Nd:GGG sources with higher power (40 mW) Nd:YAG lasers to provide a higher signal to noise frequency discriminant. Additionally, an acousto-optic modulator was added to provide additional isolation against optical feedback. These modifications have enabled relative stability at the sub-Hz level to be achieved.

2. EXPERIMENTS

![Schematic of dual laser locking experiment. The acousto-optic light modulator (AOLM) provides additional resistance to optical feedback.](image-url)

Figure 1. Schematic of dual laser locking experiment. The acousto-optic light modulator (AOLM) provides additional resistance to optical feedback.
The experimental arrangement for frequency locking two 1.06 μm Nd:YAG lasers at the sub-Hz level is shown in Figure 1 and sometimes known as Pound-Drever locking. Laser 1 was phase modulated at a frequency of 10.9 MHz while laser two was modulated at 20.3 MHz. The two beams were mode matched into a high finesse interferometer (Newport Research Corporation Model SR-150 SuperCavity). The interferometer had a free spectral range of 6.327 GHz and a finesse of 22,000. The modulation sidebands of each laser were well outside the interferometer passband and were therefore completely reflected with essentially no relative phase shift. The polarizing beam splitter and quarter wave plate served to isolate the reflected and incident beams as well as provide resistance to optical feed back. The residual laser light that did make its way back to the sources was frequency shifted by 80 MHz upon twice propagating through the acousto-optic modulator and therefore did not cause any frequency or amplitude instability. The carrier experienced a strongly dispersive phase shift on resonance which, when mixed with the sidebands at detector D2, created a high signal to noise error signal. The error signals were amplified and fed back to the lasers to maintain frequency lock and therefore reduce frequency noise. The laser's free running short term linewidth was typically 10 kHz and therefore the loop bandwidth necessary to significantly reduce the frequency noise was only 100 kHz with a DC gain of 120 dB.

With the loop closed and the lasers locked on adjacent axial modes of the interferometer, a very stable microwave signal at 6.3277 GHz resulted. The optically generated microwave signal was detected at detector D1 and mixed down to the audio regime for frequency domain analysis using a Hewlett-Packard model 3561A dynamic signal analyzer. The resultant 0.33 Hz heterodyne beatnote linewidth is shown in Figure 2. These experiments have demonstrated to us that the Nd:YAG diode laser pumped solid state laser can be frequency stabilized to the sub-Hz level for applications in the areas of metrology, communications or optical distribution of mm-waves.

![Figure 2. 330 mHz heterodyne beatnote linewidth obtained by locking two Nd:YAG lasers to a high finesse interferometer. The beatnote frequency was 6.3277 GHz.](image)

### 3. PHOTODETECTOR CHARACTERIZATION

At New Focus Inc., we have recently implemented this capability of frequency locking YAG lasers to characterize our 60 GHz high speed InGaAs and GaAs photodetectors. The servo requirements in this application are even further simplified since the goal was to optically generate mm-wave radiation for photodiode characterization and not to stabilize the lasers at the sub-Hz level. The photodiode test set is shown in Figure 3. The lasers are frequency modulated at frequencies $f_1$ and $f_2$ which are typically 160 and 250 kHz. With such a low frequency of modulation the locking technique can best be described as the "dither and lock" technique. The interferometer free spectral range was 1.00 GHz. On resonance,
the first derivative of the reflected intensity with respect to frequency is zero so the component of the reflected intensity at the modulation frequency is also zero. Any shift away from resonance causes a component at the modulation frequency to be generated which can be detected using a lock-in technique. Through temperature tuning of the YAG lasers we were able to generate stable mm-wave modulation of the optical beam to 57 GHz by locking to successive axial modes of the cavity. The linewidth of the lasers under long term (> 10 s), locked conditions was typically 100-200 kHz and the frequency stability of the mm-wave signal was therefore as high as $3 \times 10^6$. This was more than adequate for an accurate characterization of the frequency response of the photodiodes and a typical frequency response for an InGaAs detector is shown in figure 4.

![Figure 3. Optical generation of mm waves for visible and IR photodiode characterization.](image)

![Figure 4. Frequency response for model 1011 with 400μW of input power at 1.06μm](image)

The GaAs photodiodes developed by New Focus operate in the visible region of the spectrum and therefore the optically generated mm-wave signal needed to be frequency doubled. In this application, the same photodiode test set could be used by placing a nonlinear doubling material (KTP) into the cavity. Locking of the lasers to adjacent axial modes of the cavity therefore enabled us to generate mm-waves...
while also simultaneously doubling the 1.06 μm lasers with high doubling efficiency. The lasers were orthogonally polarized and at 45° to the crystal axis and therefore the sum frequency between the two lasers was suppressed. Typically 30 mW of 1.06 μm radiation from each laser is incident on the cavity and 1-2 mW of 532 nm is generated. As high as 4 mW of green has been observed but over time the performance has degraded. No conclusive explanation for this behavior is given. The doubling process not only enabled characterization of visible photodetectors but also the generation of mm-wave radiation to 57 x 2 = 114 GHz. The frequency response for a GaAs detector is shown in figure 5.

![Figure 5](image)

Figure 5. Frequency response for model 1001 with 325μW of input power at 532nm

4. CONCLUSIONS

The ability to frequency control diode laser pumped Nd:YAG lasers has enabled them to be frequency stabilized at the sub-Hz level and also to be used to optically generate frequency stable mm-wave radiation to 114 GHz. Future applications of this ability will lead to phase locking of the lasers with offset frequencies to 120 GHz and stability significantly below 1 Hz for metrological and communications work.

5. REFERENCES


3. Lightwave Electronics model 120.
