Relative Intensity Noise Suppression for RF Photonic Links

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***Abstract*—We propose and experimentally demonstrate a novel technique to reduce laser relative intensity noise (RIN). A RIN suppression servo is usually implemented by inserting an intensity modulator in the optical path and controlling measured light intensity with a closed-loop servo system. We utilize the intensity modulator already present in a photonic link to perform the task of RIN suppression as well as encoding the optical signal with the microwave subcarrier. This technique provides suppression of 10 to 50 dB of laser RIN over a bandwidth of 10 MHz. Furthermore, we implement this technique in an optoelectronic oscillator, significantly improving its phase noise performance due to the reduced effect of RIN on the phase noise of the oscillator.**

***Index Terms*—Optoelectronic oscillator (OEO), phase noise, photonic link, relative intensity noise (RIN).**

I. Introduction

RECENTLY, the optoelectronic oscillator has emerged as an excellent low noise source that rivals the best microwave oscillators over broad offset frequencies. These oscillators have the potential to improve the performance of a wide range of applications, such as advanced civilian and military radar, communications systems, and test measurement applications. The low noise of the OEO comes from the extremely high quality factor (Q) achieved by use of a long optical fiber as a delay-line resonator [1]. A typical OEO, as shown in Fig. 1, consists of a laser serving as a source of light, an electro-optic modulator (EOM) to amplitude modulate the light with a microwave signal, the optical fiber delay line, a photodetector (PD) to demodulate the microwave signal, a bandpass filter for mode selection, a phase shifter, and an amplifier to compensate for any losses around the oscillator loop. Appropriate gain and phase conditions inside the loop result in the generation of stable and sustained oscillations.

Several factors contribute to the overall noise of the OEO and limit its performance. In addition to the classical noise sources that contribute to the overall output noise of a feedback oscillator [2], the OEO contains a photonic link. This link enables low loss transmission through long optical delays and consists of a laser, an EOM, the optical fiber, and a photodetector [3]. The laser carrier itself has both intensity and phase noise, which can translate to the subcarrier and thus can also appear at the output of the OEO [4]. Laser amplitude, or relative intensity noise (RIN), can become OEO amplitude noise if loop components are not operating in saturation [5]. Laser phase noise can also convert to RIN after traveling through a dispersive fiber delay line [6], [7]. The PD contributes flicker noise as well as shot noise [8]. At higher optical powers the laser interacts with the fiber and optical components, producing noise from several different scattering and interference effects [9], [10].

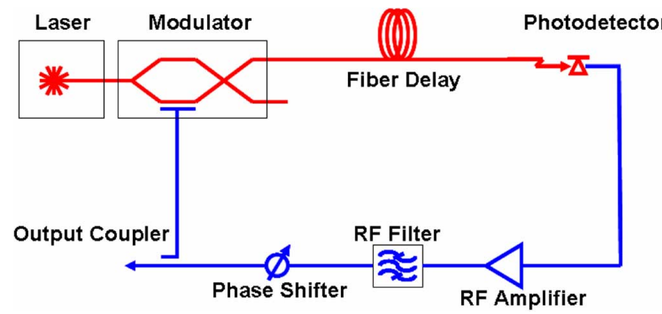

Fig. 1. Basic configuration of an optelectronic oscillator.

In this letter, we propose and experimentally demonstrate a technique to reduce RIN in the laser, one of the major sources of noise that degrades the performance of a photonic link. This letter also cites preliminary results on the improved PM noise performance of an OEO obtained with the implementation of this new technique.

II. Laser RIN and Photonic Link Noise Measurements

In order to measure the noise of a photonic link, a 1-W fiber laser with a 3-kHz linewidth was chosen as the optical source. The laser was configured as a master oscillator power amplifier (MOPA) consisting of a distributed Bragg reflector (DBR) erbium fiber laser and an erbium-doped fiber amplifier (EDFA). An operating wavelength of 1550 nm was needed to exploit the minimum loss in single mode fiber (SMF). To generate the amplitude modulated subcarrier on the optical signal, a lithium niobate Mach–Zender interferometer with a low $V\pi$ of 1.9 V at 10 GHz and optical insertion loss of 9 dB was selected.

The phase noise spectrum of the photonic link showed excess noise that exhibited a structure similar to the RIN of the laser. To study this correlation, laser RIN and photonic link noise were measured. The setup of the link phase noise measurement is shown in Fig. 2. A residual measurement was not performed; instead, a simple heterodyne measurement between two low noise 10-GHz references, using a digital phase noise measurement system, was utilized [11]. The link phase noise, shown in Fig. 3, indicates excess noise at 8 kHz, which correlates well with the laser RIN shown as the upper curve in Fig. 4. In this case, the

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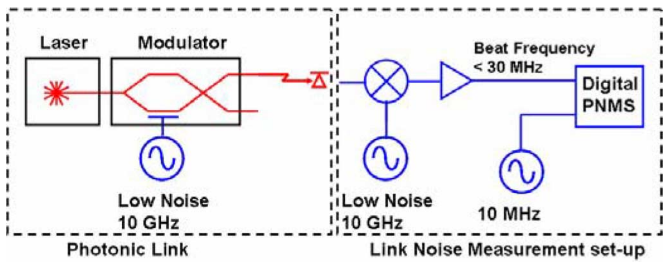

Fig. 2. Experimental setup for noise measurement of photonic link. PNMS: phase noise measurement system.

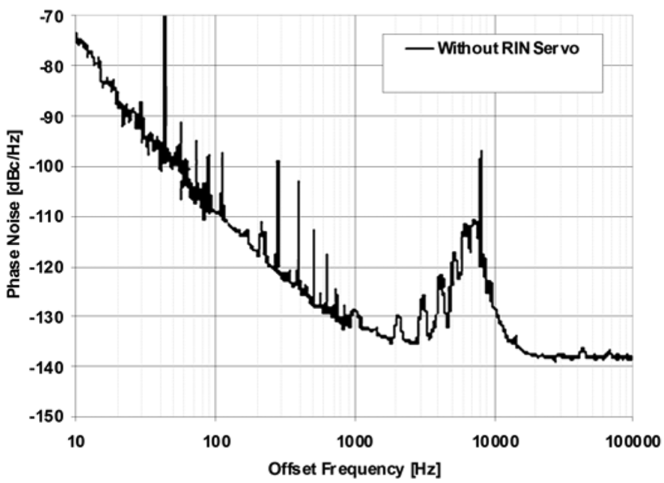

Fig. 3. Phase noise measurement between two low noise 10-GHz oscillators, one being passed through the photonic link. The link noise is dominant above 1 kHz, while source noise dominates at frequencies below.

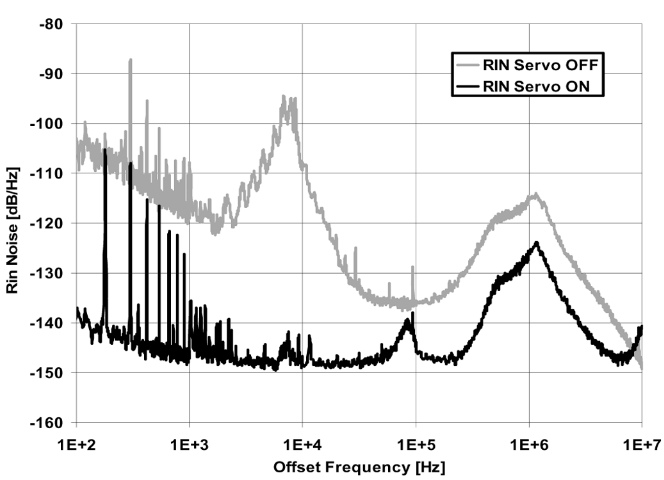

Fig. 4. Relative intensity noise of 1550-nm laser with and without the RIN suppression servo. Note that the structure around 8 kHz is identical to that of the link noise in Fig. 3.

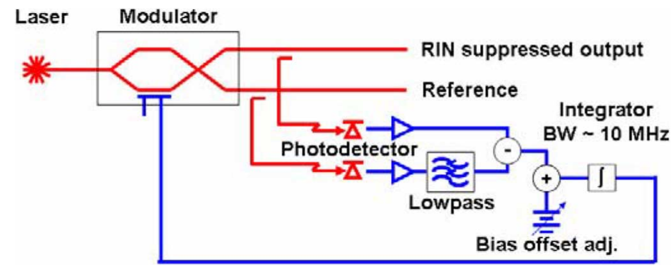

Fig. 5. Modulator bias and wideband RIN suppression servo. As well as keeping the modulator bias at quadrature, this servo also reduces the RIN of one output, at the expense of increasing the RIN of the other.

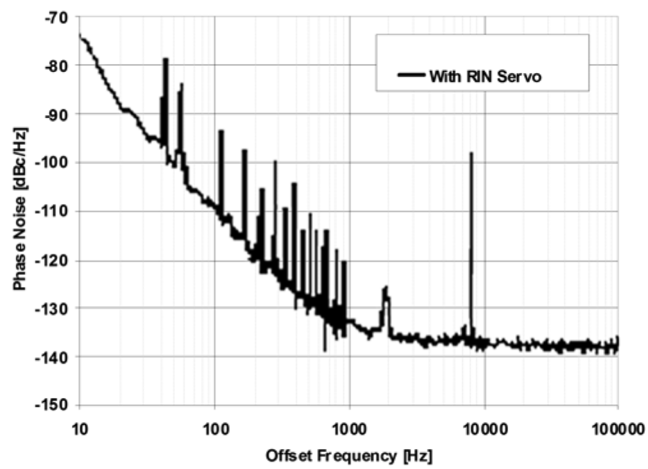

Fig. 6. Improvement in link phase noise after the RIN suppression servo is used.

conversion of laser RIN to RF phase noise in the photonic link is primarily attributed nonlinearities in the photodetector [12].

III. Wideband RIN Suppression Servo

For maximum AM modulation efficiency the Mach-Zender modulator needs to be biased so that the average optical powers in its two outputs are equal. To maintain this power balance, a servo can be implemented by detecting the power in both outputs and adjusting the modulator bias to equalize them. This bias servo can also be made to function as a RIN suppression servo, as shown in Fig. 5. A small amount of light is coupled from each arm of the balanced modulator and detected in transimpedance-amplified photodiodes. One of these signals is filtered with a low cutoff frequency, creating a low noise dc voltage that is proportional only to the dc laser intensity. This reference voltage is then subtracted from the other channel, creating an error voltage that can be integrated to provide the modulator bias voltage. An adjustable offset voltage is summed prior to the integrator to allow for small adjustments of the bias point. At very low offset frequencies, the signal power tracks the reference power, providing the proper AM modulation bias; however, outside the bandwidth of the low-pass filter the circuit acts to suppress RIN. The bandwidth of the integrator is set as high as possible to suppress wideband RIN. The RIN of the laser after suppression is shown as the bottom curve in Fig. 4. A bandwidth of about 10 MHz, as well as 50 dB of RIN suppression at 8 kHz, was achieved. The improved link phase noise with the RIN suppression servo is shown in Fig. 6.

IV. Effect of RIN Suppression on PM Noise of OEO

The phase noise of an OEO, operating at 1.25 GHz with a fiber length of 6 km, was studied in detail. This operating frequency allowed for oscillation without the use of a loop microwave amplifier, as shown in Fig. 1, thus eliminating its noise

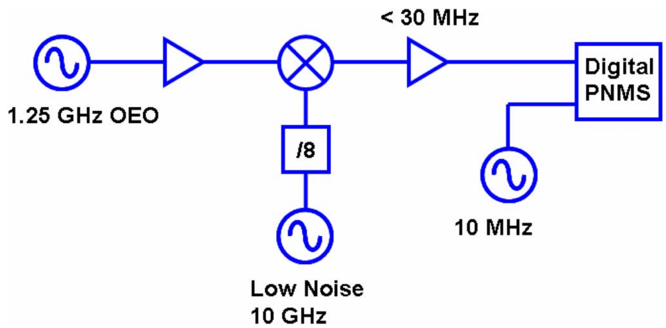

Fig. 7. Setup for OEO phase noise measurement at 1.25 GHz.

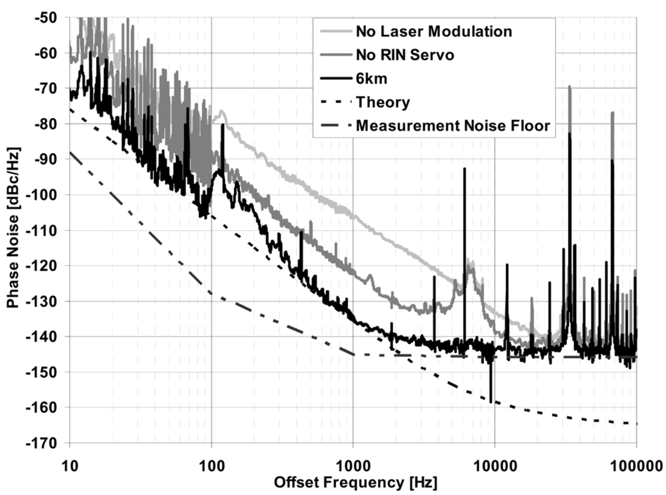

Fig. 8. Phase noise of a 1.25-GHz OEO with 6-km-long fiber. Theory is from Leeson's equation using the photodiode as the dominant flicker source.

contribution. In order to measure the phase fluctuations of the OEO without phase locking it to a reference, the output of a low noise 10-GHz oscillator, divided by eight, was used to downconvert the OEO's output to a beat frequency that can be measured with a digital phase noise system. The phase noise measurement configuration is shown in Fig. 7. This method allows for very accurate measurements close to the carrier but has a moderately high measurement system noise floor above offset frequencies of a few kilohertz. The OEO phase noise under several operating conditions is shown in Fig. 8. The OEO performed about 20 to 30 dB above its theoretically expected level [2] when the laser was operated without frequency modulation. The addition of laser frequency modulation at 6 kHz improved the performance by about 15 dB. The vast improvement provided by frequency modulation of the laser signal can be attributed to suppression of interferometic noise [10], stimulated Brillouin scattering [9], and/or further reduction of RIN [13]. Activation of the proposed RIN suppression servo improves the performance of the OEO by 10 dB for offset frequencies between 10 Hz to 10 kHz. Also, theoretically expected performance is achieved at an offset of 1 kHz. Deviations from the expected values below 1 kHz are attributed to vibration and temperature fluctuations on the fiber spool.

V. Conclusion

We discuss a novel technique to significantly reduce wideband laser RIN in photonic links. A second wideband servo is implemented by modifying the existing modulator bias-stabilizing servo already present in such a link. The Mach–Zender modulator already being utilized to encode the optical signal can also be used simultaneously to suppress the RIN of the optical signal. This eliminates the insertion loss of using a separate intensity modulator for RIN suppression. A suppression of 10 to 50 dB of laser RIN over a bandwidth of about 10 MHz is achieved with this approach. Implementation of this technique in an optoelectronic oscillator can significantly reduce its phase noise, by reducing the amount of laser RIN that can be converted to RF phase noise by circuit nonlinearities.

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