

New Schemes for Improved Opto-Electronic Oscillator

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The opto-Electronic Oscillator (OEO) [1,2] has already demonstrated superior spectral purity as a for microwave and millimeter wave reference signals. Experimental results have produced a performance characterized by noise as low as -50 dBc/Hz at 10 Hz and -140 dBc/Hz for a 10 GHz oscillator. This performance is significant because it was produced by an oscillator that was free running. Since the noise in an OEO is independent of the oscillation frequency, the same performance may also be obtained at higher frequency. The recent work in our laboratory has been focused in three areas: 1) realization of a compact OEO based on semiconductor lasers and modulators, 2) reduction of the close-to-carrier noise of the OEO originating from the $1/f$ noise of the amplifier, and 3) miniaturization of the OEO. In this paper we report on progress made in these areas, and describe future plans to increase the performance and the efficiency of the OEO.

It has been previously pointed out [3] that the OEO has a fundamentally generic architecture based on an electro-optic feedback loop, and can operate with essentially any light source and modulation scheme. This feature allows the realization of the OEO based on integrated laser-modulator elements.

We have recently developed such a device, which also includes a small microwave amplifier, and a unique dielectric loaded filter, with the requisite high Q, and in a small package. The laser-modulator element is an integrated device comprising of a DFB laser and a semiconductor Mach-Zehnder modulator. The laser's RIN is -110 dBc/Hz at 10Hz, and -135 dBc/Hz at 10KHz, and is the

limitation to the phase noise performance of the OEO.

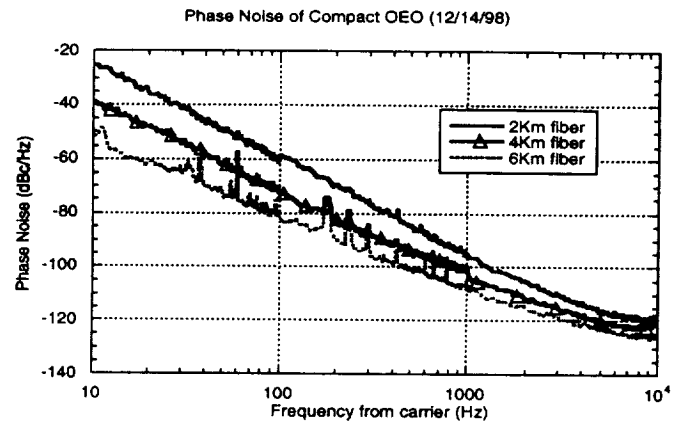


Fig.1

A key element in the electro-optic feedback loop of the OEO is the filter that allows a single mode operation of the oscillator at the selected frequency. Since the noise performance of the oscillator improves with the fiber delay length in the loop, a high spectral purity requires a long length of fiber, which in turn yields closely spaced modes of oscillation. So a high performance OEO will require a very narrow band filter at microwave frequency for single mode selection. This requirement is particularly difficult to meet if the size of the filter is also required to be small. We approached this problem by developing a unique dielectric resonator loaded filter by placing a $8.7\text{mm} \times 4\text{mm}$ high dielectric constant ($\epsilon=35$) ceramic cylindrical disc at the center of an aluminum cavity whose size is three times larger than the DR disc. The filter was optimized for both mode matching, and for insertion loss and external Q. The bandwidth of the filter was measured to be 2 MHz at 9.56 GHz, with 6dB insertion loss, and Q was about 5,000. This filter allows to use up to 6

km of fiber in the OEO loop, while maintaining a side mode suppression between the oscillating mode (9.56GHz) and adjacent side modes of 50 dB.

The noise performance of the compact OEO using the elements described above is shown in Fig. 1. Here the spectral density of the phase noise, as a function of frequency away from the carrier, is plotted for fiber lengths of 2, 4, and 6 km. The longest length fiber has produced 20-dB lower phase noise at 10 Hz than any of our previous oscillators.

In order to reduce the $1/f$ phase noise of the oscillator even further, we developed a novel carrier suppression technique. The technique is based on the use of a long fiber delay in place of the high Q cavity, which is ordinarily used to implement this scheme. The carrier suppression technique pioneered at JPL [4,5] has been successfully used in microwave oscillators to reduce close-to-carrier phase noise resulting mainly from the $1/f$ noise of an amplifier in the oscillator loop[3]. Here we report the first application of the carrier suppression technique in an opto-electronic oscillator (OEO) to reduce the phase noise, which result not only from the amplifier, but also from the laser relative intensity noise (RIN).

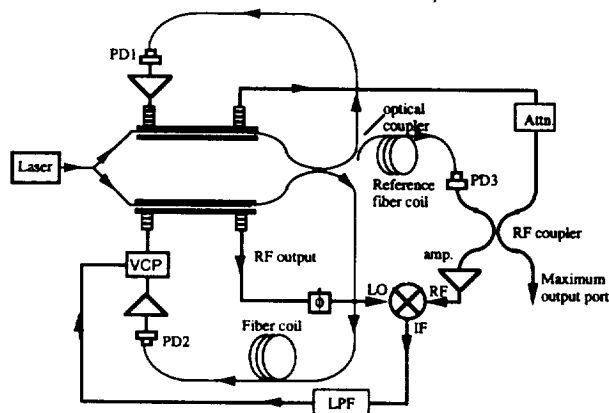


Figure 2.

Our preliminary experimental results indicate an extra 10 to 20 dB phase noise reduction of the OEO with this novel technique. Improved circuit designs and longer reference fiber is

expected to further reduce the oscillator noise beyond this level.

A double loop OEO incorporating the carrier suppression technique is shown in Fig. 2. The long loop consists of a polarization beam splitter (PBS), a fiber coil having a long length of fiber, a photodetector (PD2), an RF amplifier, a bandpass filter, and a voltage controlled phase shifter (VCP). The short loop consists of a short length of fiber, a photodetector (PD1), a RF amplifier, and a bandpass filter. In one implementation of the fiber optic carrier suppression scheme, part of the light is coupled out from the short loop and is delayed by a reference fiber coil of 2-km length. The delayed light signal is then received at a third photodetector (PD3) and converted to RF signal. This signal is then made to interfere with the RF output of the OEO at a RF bridge consisting of a 3-dB coupler, a variable attenuator, and a variable phase shifter. The variable attenuator and the phase shifter are adjusted such that one of the output ports (port 1) of the bridge has a minimum output power, while the other port (port 2) has the maximum. The signals from the minimum output port is then amplified and mixed with the signal from the RF output port of the oscillator. The relative phase between these two signals is adjusted to be at 0 or π by another variable phase shifter. The error signal from the mixer is then amplified, filtered, and feedback to the VCP to control the frequency of the OEO.

In this configuration, the fiber coil acts both as a high Q phase storage component for the oscillator, and as a frequency discriminator for the carrier suppression bridge. The frequency discriminator converts the frequency jitter of the OEO into amplitude jitter out of the bridge. This amplitude jitter is then detected by the mixer, and then amplified, filtered, and feedback to the VCP to suppress the frequency noise of the OEO.

Because the carrier suppression scheme is insensitive to the amplitude noise of the signal source, the relative intensity noise (RIN) will not affect the frequency noise measurement

with the RF bridge, and thus will not mask the phase noise contribution from the RIN.

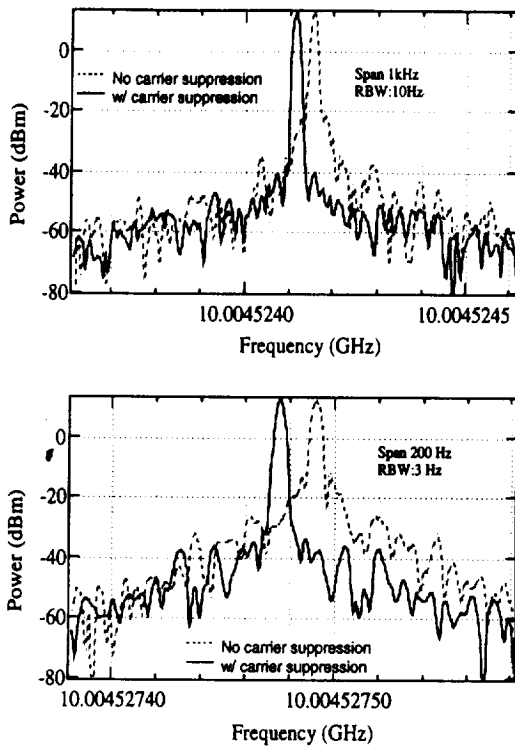


Fig. 3.

The RF spectra of the 10 GHz OEO with and without carrier suppression are shown in Fig. 3a and Fig. 3b. The spectra were taken with an HP8563E spectrum analyzer. The span and resolution bandwidth of the spectrum analyzer were set at 1 kHz and 10 Hz respectively for Fig. 2a and 200 Hz and 3 Hz for Fig. 3b. It is evident that the spectral purity of the OEO was improved significantly (~ 20 dB) with the carrier suppression circuit active.

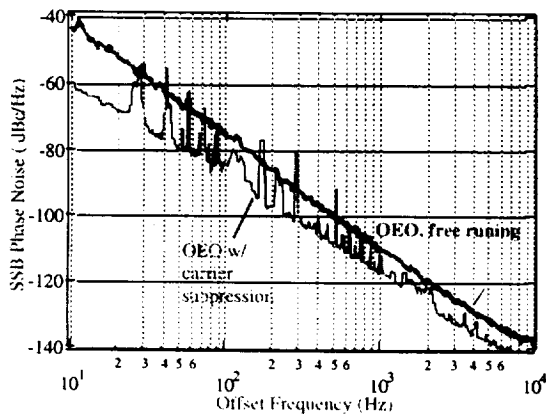


Fig. 4.

Fig. 4 shows the phase noises of an OEO with and without carrier suppression noise reduction. A phase noise reduction close to 20 dB at 10 Hz is evident.

Finally, we have made progress towards replacing the fiber delay length with a microspherical resonator. These sub-millimeter resonators have been shown to have Q's in the range of 10^7 to 10^{10} for optical frequencies. A Q of 6.28×10^9 corresponds to an energy storage time of 10 μ s, which is equivalent of a two-kilometer of optical fiber. We have demonstrated an OEO with a microsphere, and have developed a scheme for direct coupling of light to the microsphere with a short length of fiber.

In summary, we have demonstrated a compact OEO with integrated laser and modulator, and miniature amplifier and filter, have successfully implemented a carrier suppression noise reduction technique with an optical fiber delay line, and applied the technique to reduce the close-to-carrier $1/f$ noise in a double loop OEO. Finally, we have demonstrated an OEO with a sub-millimeter microspherical resonator in place of kilometers of fiber delay. Further improvements of these techniques are expected in the near future.

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