

A 1 GHz OPTICAL-DELAY-LINE OSCILLATOR DRIVEN BY A DIODE LASER

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Abstract: Experimental results are presented on a hybrid optical/electronic oscillator which uses an optical delay line to generate high spectral purity microwave signals. At Fourier frequencies above 10 kHz, the single sideband (SSB) phase noise spectrum decreases as roughly $1/f^2$ attaining a value of -138 dB below the carrier in a 1 Hz bandwidth (dBc/Hz) at 20 kHz offset. The origin of this noise is in part the fundamental shot noise on the light itself, although other optical noise sources such as double Rayleigh scattering and stimulated Brillouin scattering also appear to be important under certain operating conditions. The frequency stability over several hours is dominated by changes in the fiber ambient temperature with a coefficient of about $10^{-8}/\text{K}$ originating mostly from changes in the fiber refractive index with temperature.

Introduction

Stable S-band and X-band oscillators play a role in numerous applications ranging from precision metrology to optical communication systems. There are several traditional methods of generating low phase noise oscillation at these frequencies. Bulk acoustic wave (BAW) oscillators, oscillating at 5 or 10 MHz can be multiplied up to GHz frequencies. Although the initial BAW oscillator may be extremely stable, the multiplication process usually adds substantial additional noise, particularly at frequencies far from the carrier, which seriously degrades the original performance of the oscillator. Surface acoustic wave (SAW) oscillators have been used to directly generate oscillation in the frequency range of 100 MHz to a few GHz with somewhat inferior close-in phase noise performance than low frequency BAW oscillators. For even higher frequencies, up to tens of GHz, dielectric resonator

oscillators (DRO's) are most often used; sapphire is the dielectric material of choice for obtaining the lowest phase noise. While these methods have been, on the whole, successful, particularly in producing signals with extremely low phase noise, their lack of tunability and difficulty of fabrication limit their usefulness in many critical applications.

Recently, a novel hybrid optical/electronic approach to this problem was proposed [1, 2]. This uses an optical fiber delay line to achieve phase noise performance competitive with the best commercially available synthesizers. These optical-delay-line oscillators (ODLO's) or light-induced microwave oscillators also have a number of highly desirable features not available in other oscillators: they are highly tunable; have oscillation frequencies which can potentially range from hundreds of kHz to tens of GHz; can have moderately low phase noise; have both optical and electronic inputs and outputs facilitating their integration with other optical systems; and can be constructed with no precision components other than commercially available optical fiber. Another important aspect of these oscillators is that their phase noise performance is independent of oscillation frequency making them excellent candidates for generating microwave signals above 10 GHz. Recent experimental results for an 800 MHz oscillator [3, 4] have demonstrated a SSB phase noise of less than -140 dBc/Hz at 30 kHz frequency offset and many future improvements seem likely.

The Optical Delay Line Oscillator

The ODLO takes advantage of the extremely low loss and long delay times which can be achieved in optical fibers in order to provide the frequency discrimination necessary for low phase noise oscillation. A diagram of one of the oscillators built at NIST is shown in Figure 1. An electronic signal is first translated into amplitude modulation on an optical carrier generated by

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