Ain ShamsUniversity
Faculty of Engineering
Electronics and Communications Department

Optical stabilized oscillators

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Degree in Electrical Engineering

Submitted by:
Mohamed Mousa Sayed Emam

Supervised by:
Prof. Dr. Mahmoud Hanafi Ahmed
Assoc. Prof. Dr. Kamel Mohamed Mahmoud Hassan
Assoc. Prof. Dr. Mohamed AbdelhamidAbouelatta

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Statement

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Electrical Engineering (Electronics and Communications Engineering).

The work included in this thesis was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

Name: Mohamed Mousa Sayed Emam

Date: 10/1/2017

Curriculum Vitae

Name: Mohamed Mousa Sayed Emam

Date of Birth: 22/05/1989

Place of Birth: Cairo, Egypt

First UniversityDegree: B.Sc. in Electrical Engineering

Name of University: Future University

Date of Degree: June 2011

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ABSTRACT

The target of the research in this thesis is to produce a high quality microwave signal using optical techniques. In the literature systems that generate such a signal using optical loops have been suggested. Signals with quality factor of order 10^8 are produced. Here, in this research a different course is suggested to achieve the same target. An optical filter is adopted to improve the quality of a microwave signal. The quality of such signal has reached 10^{10}, an improvement of two orders of magnitudes over the existing systems.The optical filter consists of a Brillouin/ semiconductor optical amplifier (SOA) ring oscillator fitted with an intensity optical modulator and an optical coupler that feeds an optical detector. The RF signal feeds the modulator while an avalanche photodetector (APD) retrieves it after being fitted through the optical loop. The optical filter linewidth is determined by the Brillouin oscillations which is less than 1 Hz and its free spectral range (FSR) is determined by the length of the optical fiber used in the loop. At a fiber length of 6.6 Km the FSR is 30.3 KHz. The 6 dB bandwidth of the cavity modes is measured to be 780 mHz typical of Brillouin lasers.The gain of the SOA balances out most of the losses in the ring which is mainly due to the RF modulator. The modulated optical signal beats at the APD. The optical loop acts as a cavity filter to the RF signal. A jitter in the cavity resonances due to temperature varaitions is completely eliminated from the output beat signal. The output low frequency noise below 1 KHz is reduced about 10 dB from that of the input. However, there is a 10 dB increase in the phasenoise at the FSR frequency and its harmonics. The setup has been tested with signals generated by different sources and to frequencies up to 10 GHz, the limit of the APD used. Sources with RF linewidth less than the optical FSR produces one output mode with sub-hertz linewidth. For

larger linewidth signals more than one RF frequency is produced, separated by the FSR, each showing the Brillouin linewidth.A theoretical study has been conducted also in this work via considering the detailed dynamics of the active optical components of the system, the Brillouin amplifier, the SOA, and the optical modulator. It is found that the quality of this system depends on the operating conditions of these components. The upper frequency limit that can be fitted through this scheme seems to be limited by the carrier lifetime τ_c of the SOA, which is, in our experimental work, 40 ps giving a limit of 25 GHz. In recent literatures τ_c of 10 psec has been obtained which extends the range of our system to 100 GHz. The produced filtering capacity of our system depends on a fine control of the relative gain ratio of the Brillouin amplifier to that of the SOA.

Keywords: Optoelectronic oscillator (OEO), Brillouin amplifiers, High quality microwave signal, semiconductor optical amplifier (SOA).

SUMMARY

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ThesisTitle: **“Optical stabilized oscillators”**
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Microwave generation utilizing optical circuits produces signals with quality factor of order 10^8. This is due to employing several kilometers of optical fiber in the circuit taking advantage of its low attenuation and relatively small size. In the literature several systems that utilize this principle are suggested. They, however, suffer from tunability and/or stability problems. Here, in our work we present a different approach that separates generation from quality control. The generation uses the usual electronic techniques. The quality of the generated signal is then improved by filtering through an optical circuit. The advantage of this system is that it is environmentally robust and utilizes ordinary optical components.

This proposed setup is based on Brillouin/ semiconductor optical amplifier(SOA) fiber ring laser which generates very narrow Brillouin cavity modes separated by FSR of the loop and within the Brillouin gain linewidth. The SOA gain is adjusted to be just below the threshold gain for oscillation and Brillouin gain is adjusted just to start oscillation. The generated Brillouin beam contains many of Brillouin cavity modes (which are very narrow), separated by the FSR of the optical resonator within the Brillouin gain linewidth which is of order 20 MHz. The linewidth of these resonances is less than 1 Hz, typical of Brillouin oscillators. A microwave is injected into the

loop through an intensity modulator. Then inject a microwave signal into the loop through an intensity modulator. The loop acts as a very narrow filter to the input microwave signal. The input signal produces a modulation side modes separated from each other by the modulating frequency.At the detector all of these modes beat with each other and produces back the modulating frequency signal after being filtered through passing into the loop. If the input signal linewidth is smaller than the FSR of the loop it will produce only single narrow signal at the output. If the input linewidth is greater than the FSR it will generate more than one narrow signal at the modulating frequency separated by the FSR.

The environmental effects cause the resonances of the optical loop to jitter. This jitter is canceled out when they beat in the APD used at the output. The system is experimentally investigated. The generation of the Brillouin beam is confirmed by an optical spectrum analyzer (OSA) utilizing the fractional power reflected from the 2x2 coupler that feeds the fiber with power from the pump laser and which also collects the reflected Brillouin beam generated in the fiber. A shift of 10.87 GHz is observed in the generated beam from the reflected pump laser frequency. This is typical of the Brillouin shift in single mode optical fibers at 1.55 μm.The linewidth at 6 dB of optical cavity resonances hasbeen measured, by an RF spectrum analyzer at the output of the APD, to be 780 mHz.several input RF signals from different sources have been applied at the input of the optical modulator. The frequency of these signals changed from 1 GHz to 10 GHz, limited by the BW of the APD used. All the outputs show the sub-Hertz BW, irrespective of the input signal BW.

In this work a theoretical study has also been conducted taking into considerations the dynamics of the optical active components in the circuits. The SOA saturated, unsaturated gain in the case of the input time variations (which is adjusted to be just below the threshold gain) and effect of the carrier lifetime τ_c and its effect on the frequency limit of the filter. It is found that the upper frequency limit that can be fitted through this scheme seems to be limited by the carrier lifetime τ_c of the SOA, which is, in our experimental work, 40 ps giving a limit of 25 GHz. In recent literatures τ_c of 10 psec has been obtained which extends the range of our system to 100 GHz. The Brillouin amplifier modeling which describes the Brillouin saturated and unsaturated gain and shows that in our case Brillouin gain is heavily saturated. This also shows the effect of keeping the Brillouin amplifier gain is just to start oscillation. The optical modulator modeling and taking into account the input variations with time and show that it can be neglected as the input microwave frequency to the modulator is greater than the Brillouin gain as it will propagate but not oscillate inside the optical loop, as it will take only the SOA gain which is just below threshold.

This model shows the importance of fine control of therelative gain ratio of the Brillouin amplifier to that of the SOA.As the ratio between them as this ratio effects on the amplitude feedback parameter R which in turn control the Brillouin linewidth narrowing ratio of the Brillouin stokes relative to the pump power laser linewidth, the possibility of increasing the FSR of the loop through using shorter fiber length and the importance to keep the gain ratio the same to get the same large narrowing ratio K and get a very narrow Brillouin stokes and filtered microwave signals. The next step in this model is including the fiber losses effect which in turn effects on the generated stokes linewidth and in the output filtered signal linewidth.

CONTENTS

LIST OF FIGURES