Single-Loop Opto-electronic Oscillator at 10.4 GHz with a cascaded Microstrip Bandpass Filter Configuration

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***Abstract*—The opto-electronic oscillator is a well-known microwave photonic device that produces high-frequency signals in the microwave range. One of the main advantages of the opto-electronic oscillator is that it produces high-frequency signals with low phase noise thanks to the resonator's properties. In most cases the opto-electronic oscillator faces the problem of generating side modes besides the oscillation signal due to non-ideal filtering. In this paper we propose a solution for the additional suppression of these undesired harmonics using a combination of two slightly detuned bandpass microstrip filters. We report an improvement for the side-mode suppression ratio about 8.3 dB with a single-loop 90-m-long opto-electronic oscillator at 10.4 GHz.**

Keywords—opto-electronic oscillator, side modes, electrical bandpass filter, cascaded filter connection, side-mode suppression ratio

I. Introduction

An opto-electronic oscillator (OEO) is a high-frequency oscillator that can be used in a variety of applications where a stable oscillator with a low-phase-noise signal is needed [1-3]. In addition the OEO can be used to provide low phase noise signal in the optical domain for radio-access-networks [4]. The main advantage of the OEO is that the phase noise is independent of the oscillator frequency, which means that by increasing the nominal frequency of the OEO, the oscillator phase noise will not increase. A typical configuration of the microwave OEO is shown in Fig.1.

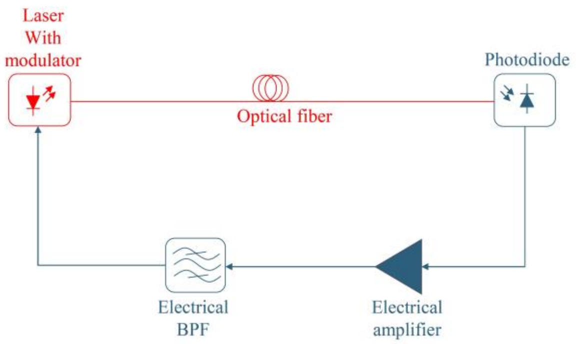

Fig. 1. Basic configuration of the single-loop OEO.

It consists of electrical components, electro-optical components and optical fiber. One of the main components of the OEO is the electrical bandpass filter (BPF), which is used to determine the frequency where the OEO oscillates. One of the main problems of the OEO is the multi-mode operation of the OEO due to the non-ideal filtering of the electrical BPF [5]. Side modes are undesired modes of the oscillation frequency and they are not suitable for applications that require an oscillator signal. The main reason for the side modes is the bandwidth of the filtering. The side-mode suppression ratio (SMSR) is the power difference between the main frequency and the closest spurious mode in the power spectrum.

Several papers describing solutions for SMSR improvement have been presented. For example, the authors in [6-8] describe a dual-loop or multi-loop configuration of the OEO. There is another solution called injection locking [9], which also increased the SMSR. We have also presented some basic results regarding the SMSR suppression based on a single-loop OEO in [10]. However, all previously reported improvements have the disadvantage of increasing the complexity of OEO set-up. Therefore, in this paper we examine a very straightforward design idea for increasing the quality of oscillator loop.

One of the main requirements of the OEO is to have an electrical filter to suppress the side modes and determine the oscillating frequency. There are optical and electrical domain solutions for a single-loop OEO. However, while there are some optical-based filters reported [11-12], electrical filters are more commonly adopted due to the maturity of microwave design techniques. A straightforward solution is to adopt a microstrip bandpass filter (BPF) to eliminate the side modes. However, this solution has limited utility, as microstrip filters have very low quality factor at microwave frequencies and OEOs having a free spectral range (FSR) that is very narrow due to the use of a long delay line to achieve a low phase noise [5], [13].

This paper describes work on a more efficient technique for suppressing undesired modes through the adoption of cascaded microstrip coupled-line BPFs. The approach of cascading -filters to modify filter response is well-known [14-15]. Examples of its application in microstrip filter design

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include [14] where they cascade a low-pass filter and a high-pass filter to make a bandpass filter [BPF]; and [15] where the cascaded connection of microstrip parallel-coupled filters was used to achieve trisection and quadruplet responses. In this work, we cascade two bandpass filters, with center frequencies at 10.250 GHz and 10.725 GHz. By cascading the two filters, we are able to increase the Q-factor of the resulting filter network, to decrease the bandwidth (BW), and consequently, to suppress the side modes more efficiently.

II. THE IDEA OF THEORY AND DESIGN OF THE CASCADED MICROSTRIP FILTER

The proposed technique involves cascading two microstrip coupled-line bandpass filters with slightly different centre frequencies (f_{c_1} and f_{c_2}) to achieve an overall filter response with centre frequency at (f_{c_0}), a narrower bandwidth and higher selectivity. The technique works by exploiting the multiplicative effect of cascading to achieve increased attenuation at frequencies outside the region of overlap. Effectively, the cascaded filter network can be modeled by the multiplication of the transfer function of the individual filters that form the network.

$$H(s)_0 \approx H(s)_1 \times H(s)_2 \tag{1}$$

Where $H(s)_0$ is the overall frequency response and $H(s)_1$ and $H(s)_2$ is the frequency response of filters with centre frequencies f_{c_1} and f_{c_2} respectively. This is shown in Fig. 2.

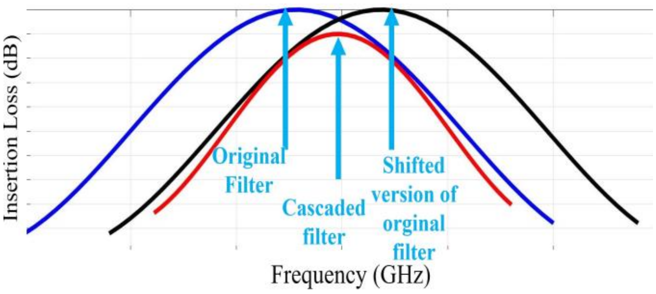

Fig. 2. Response of two bandpass filters with slightly different centre frequencies. The blue line shows the original filter, while the black line shows the shifted version of the original filter, and the red line is the cascaded filter of these two filters.

The main demerit of this technique is that the insertion loss (IL) of the cascaded filter is significantly higher as it is a multiplication of the IL of the two filters forming the network. Fig. 3 shows the design of the BPF using Keysight's Advanced Design System (ADS), while Fig. 4 shows the simulated response.

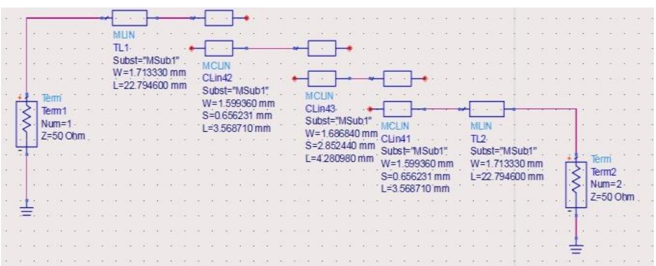

Fig. 3. Design of the single original filter using ADS software.

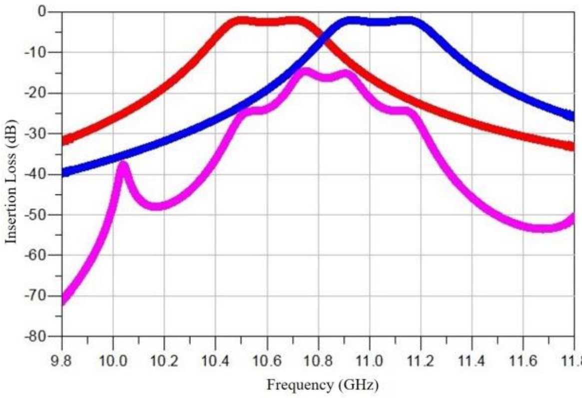

Fig. 4. Simulation results for S21. The red line shows the original filter, while the blue line shows the shifted version of the filter, and the purple line shows the cascaded version of these two filters

The coupled-line microstrip BPFs were implemented using a chemical etching process on a Rogers RO4350B substrate with dielectric constant of 3.48 and thickness of 0.76 mm [16]. The fabricated filters are shown in Fig 5.

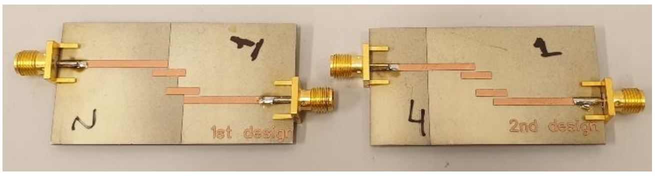

Fig. 5. The Photograph of the fabricated filters.

The individual filter responses and the response of the cascaded network were measured using HP 8510B Vector Network Analyzer (VNA). Table 1 and Fig. 6 show the experimental results of the IL of the microstrip filters from 10.250 GHz to 10.725 GHz.

TABLE 1: EXPERIMENTAL MEASUREMENT RESULTS ON 3-dB BANDWIDTH AND INSERTION LOSS

Measurements	**1st Filter**	**2nd Filter**	**Cascaded Connection**
Central frequency	10.250 GHz	10.725 GHz	10.400 GHz
3-dB Bandwidth	500 MHz	510 MHz	260 MHz
Insertion Loss	6.5 dB	6.1 dB	17.8 dB
Q-factor	20.5	21	40

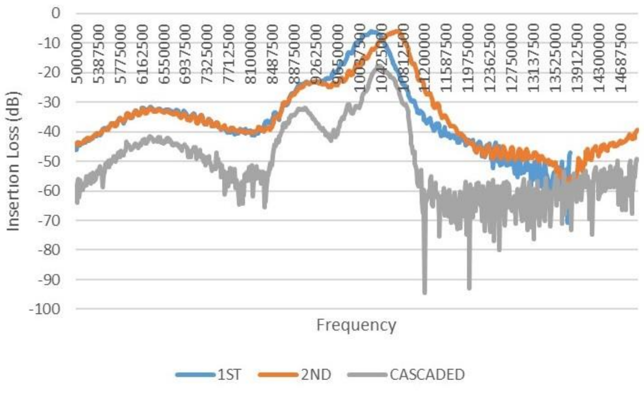

Fig. 6. Experimental measurements of the IL for filters in separate and cascaded versions using a VNA.

The difference in the IL between individual filters and cascaded connection is due to the compounded attenuation across the entire operating frequency of the cascaded filter. At the point of overlap, the IL of the individual filters is approximately around 9 dB, hence, the cascaded filter has a IL of 17.8 dB, the product of the two filter's IL.

III. Implementation of the Cascaded Bandpass Microstrip Filter into the OEO

In the experimental setup, we measured the SMSR of the single-loop OEO at 10.4 GHz under two conditions. First, we measure the SMSR with individual BPFs, after which we measure the SMSR with the cascaded filter network. The measurement setup is shown in Fig.7.

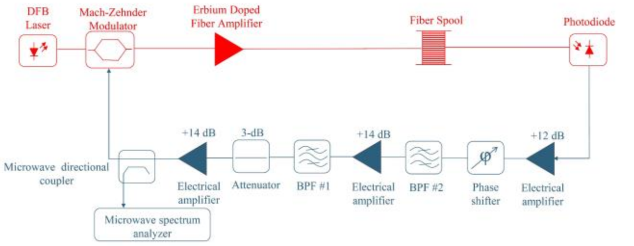

Fig. 7. Schematic of the test system.

The measurement setup consists of several optical and electrical components. The length of the delay line is 90 meters, measured by an optical time domain reflectometer. The electrical amplifiers and the electrical filters are used in the OEO loop. A phase shifter is used to modify the frequency of the oscillation to ensure that Barkhausan conditions are met. Due to the 10-dB increase in the IL from the cascaded connection, we added an extra electrical amplifier in the single-loop OEO. While taking measurements with single individual filters, we add a 6-dB attenuator to provide same power for the oscillating signal.

The experimental setup consists of a single-loop OEO with an electrical bandpass filter and electrical amplifiers. A Mach Zehnder Modulator (MZM) and distributed-feedback (DFB) laser is used to generate the optical signal. The MZM is biased in the quadrature point, while the laser is temperature stabilized. The electrical amplifiers are used to compensate for the conversion loss (optical to electrical) and the IL of the electrical bandpass filter. Fig. 8 shows a photograph of the experimental setup to measure the SMSR of a single-loop OEO in a single-filter and a cascaded-filter configuration at 10.4 GHz.

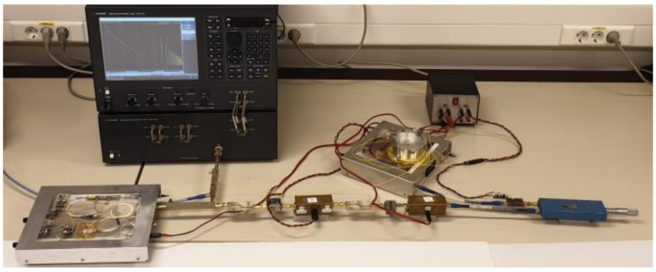

Fig. 8. Experimental setup of a single-loop OEO to measure the SMSR.

The effect of filters were tested in three different configurations (Fig. 9). The first configuration is for only BPF#1, and in order to provide the same power output for the output signal, we introduced a 6-dB attenuator to compensate for the IL of the BPF#2. In the second experiment we have used the same setup, only exchanging BPF#1 with BPF#2. In this setup also the 6-dB attenuator is implemented to compensate for the IL of BPF#1. In addition we have decreased the laser output power to have a precise output power of the carrier frequency. In the third setup we use both BPF#1 and BPF#2.

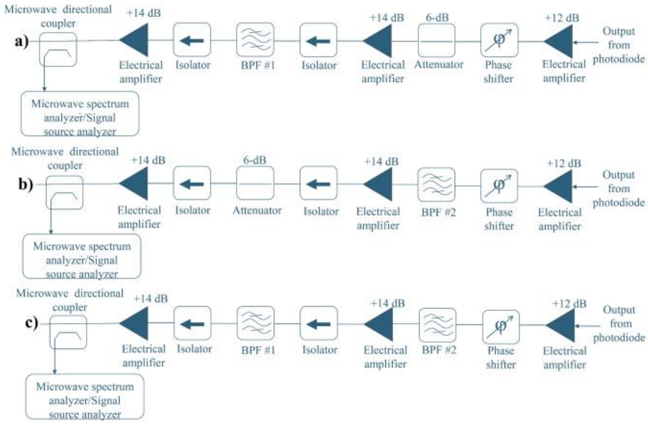

Fig. 9. Three configurations of the experimental setup for the microwave part of a single-loop OEO.

Fig. 10 shows the measurement results for a single-loop OEO with single filters and cascaded filters via spectrum analyzer.

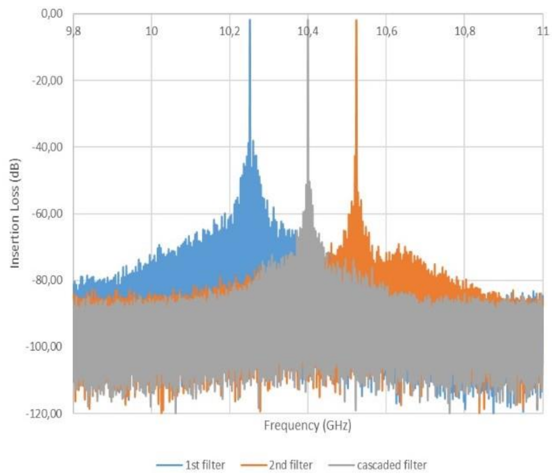

Fig. 10. Frequency domain of the filter, filter with frequency shifted, and cascaded version of the two filters.

In order to see the comparison on the SMSR with a cascaded and single-filter configuration of the single-loop OEO we have inserted the measurements from signal source analyzer (SSA). Fig. 11 and Fig. 12 show the experimental result on the SSA.

We observed an improvement of about 8.3 dB for the SMSR with a cascaded connection compared to the single-filter connection. This improvement is considered significant, as the FSR of the OEO is about 2.11 MHz. Higher levels of performance improvement would be gotten in systems with higher FSR. More importantly, the result demonstrates the potential of the described technique in achieving improvement in SMSR in the OEO system.

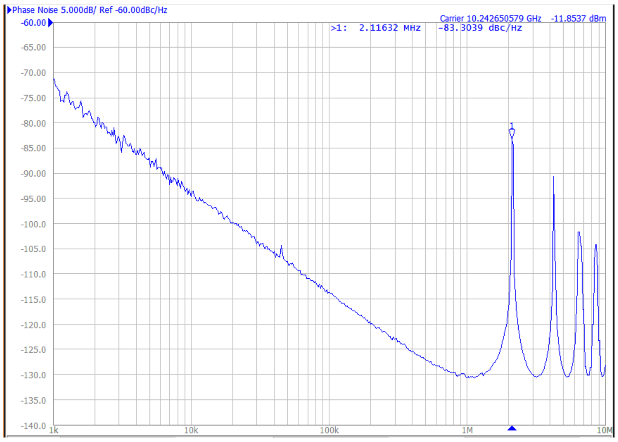

Fig. 11. The phase noise measurement of the single-loop OEO with a single-filter configuration.

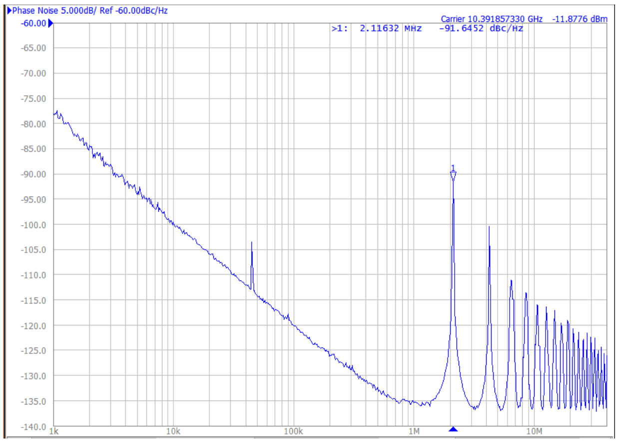

Fig. 12. The phase noise measurement of the single-loop OEO with a cascaded-filter configuration.

IV. CONCLUSION

In this paper we introduced a new cascaded microstrip BPF configuration in order to have a narrower electrical filter so as to improve the SMSR of a single-loop OEO without increasing either the cost or the complexity of the OEO. We observe about 8.3 dB improvement in the SMSR when a cascaded network of two microstrip BPFs with slightly different center frequencies, was introduced in a 90-m-long fiber loop in the OEO at 10.4 GHz. The obtained SMSR improvement does not increase the complexity of OEO. We are planning to continue our research in the directions of short, single-loop OEO configurations towards integrated solutions.

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