Optical Setups to Generate Harmonic RF Signals Using Dual Optical Loop and Phase Modulation

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***Abstract*—This work presents two new techniques to generate harmonic RF signals using optical fiber devices. Both proposed systems are efficient to generate up to 15^{th} harmonic from a 1 GHz RF signal. This systems have the advantages of simplicity, low cost of implementation and the ability to generate multiple harmonics from the frequency signal provided by a RF generator.**

Keywords - Photonics, Microwave generation, Optical loop.

I. Introduction

Microwave photonics is an interdisciplinary field that studies the interaction between microwave and optical signals. It may also be defined as the study of photonic devices operating at microwave or millimeter-waves and frequencies at Terahertz range. The main functions of the microwave photonics generation systems include photonics generation, processing, control and distribution of microwave and millimeter-wave signals (mm-wave) [1].

In the last years, various techniques have been developed for generating photonic microwave signals. These techniques has led interesting applications in various fields, such as: radio-over-fiber networks, wireless broadband networks, sensor networks, radio systems software, radar and satellite communications.

The main advantage of generating microwave signals by optical means, lies in the fact that a very high frequency signals with low phase noise can be generated by two optical signals beating with a spacing corresponding to the wavelength of a desired microwave[2]. The signals can also be transported away along the optical fiber, because they have an extremely wide bandwidth and low transmission loss. The distribution of a microwave signal or millimeter-wave along the optical fiber is the ideal solution to perform this task[3].

Numerous techniques have been proposed and demonstrated in recent years to generate low phase noise microwave or microwave signals. Therefore, it have been able to identify different scales of difficulty for each of the implementation techniques, which can be classified in five categories: 1) Heterodyne, divided into two techniques, 1.1) Optical Injection Locking, 1.2) Optical phase-lock loop (OPLL), 2) Generation of microwave using external modulation, 3) Laser Source Dual-Length wave, 4) Microwave generation based on an Electro-Optic oscillator and 5) Use of semiconductor optical amplifiers (SOA) in order to generate RF signals through the device then changes the saturation amplification gain mechanism, producing a mixing effect between the harmonics of the modulation optical signals[4].

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In Heterodyne technique, a microwave signal can be generated in the optical domain based on optical heterodyning. Such technique is the basic principle of generation of a microwave signal. It is based on the beating of two optical waves of different wavelengths on a photodetector, where the spacing of the two optical wave frequency is generated in the corresponding electric domain[5].

This technique consists in two optical waves with angular frequencies ω_1 and ω_2 which are superimposed and injected into a high frequency photodetector which converts the optical signal input to the THz frequency regime, generating an electric signal with microwave frequency from $(\omega_1 - \omega_2)$[6]. The advantage of this technique is that the bandwidth of the feedback circuit is not a limiting factor. However, a drawback is the complexity of the feedback system that must be used [7].

The main challenge in using the techniques for practical applications is the large size and the high cost to design. With advancement of photonic integrated circuit technology it will be able to offer a potential solution to miniaturize the system at a reduced cost. There are various techniques for generating microwaves, with different shapes and difficulty of implementation. Despite these techniques achieve their goals, they need special equipaments and components, and the optical projects become complex, sensitive and expensive while generating output signals with low power levels.

Our work present two optical setups able to generate harmonic RF signals using optical loops and phase modulation. This paper is organized as follows: in Section II is presented the description of two optical setups proposed by us able to generate harmonic RF signals; in Section III, the numerical results for two systems are compared and analyzed for power versus frequency for each generated harmonic RF signal from the sinusoidal RF signal of 1 GHz and the Conclusion is shown in the Section IV.

II. Optical Setups

This work proposes the simulation, analysis and comparison of two harmonics generation optical systems using the OptiSystem® tool. The proposed systems uses an optical carrier that feeds only one phase modulator (PM), which is fed back through optical coupler (beam splitter, BS). The purpose of such systems is to produce microwave signals via optical links.

Table I
Basic configuration of optical systems.

CW Laser	Optical Power: 0 dBm and 3 dBm
	Frequency: 193.1 THz
RF Generator	1 GHz
Photodetector PIN	1 A/W
Modulator	Phase
Optical Fiber (OF)	Length: 0.20 cm
	Dispersion: 16.15 ps/nm/km
	DGB: 0.2 ps/km
Beam Spliter (BS)	Coupling coefficient: 0.5

Both systems are composed by a laser, a RF generator, monomode optical fibers (OF), an PIN photodiode (PD), two BS and one PM. In the Table I is shown the settings related to each optical component. From Figures 1 and 2 we can see that the main difference between them is the position of the optical loop. In the System 1, optical loops in "series" while in the System 2, optical loops in "parallel". Therefore, the influence of the loop's position in the optical signals generated by the proposed system is analyzed, for each configuration of the injection laser power parameters for 0 dBm and 3 dBm and modulated frequency at 1 GHz. It will also be made a comparison of the amount harmonics generated and the power of each harmonic.

In the System 1 at Figure 1, there´s two optical loops in series. The first loop consists in an optical coupler in which an output is injected at its other input, thus forming a loop. The second loop is composed by a coupler and an optical phase modulator that together form a loop, and the phase modulator is fed by a radio-frequency (RF) signal.

In the System 2, Figure 2, there are two parallel optical loops. The first loop is formed by two optical couplers combined in parallel to form a loop. The second loop is composed by the second optical coupler and a phase modulator that together form a loop, and the phase modulator is fed by a RF signal. In both systems, the others input/ouput of the couplers are connected to the laser and photodiode (PD), having the PD output connected to a spectrum analyzer (SA) in order to view the signal generated by the system and the optical carrier, the circulates in optical loop, is modulated in phase by an RF signal. In both systems, the size of the two optical loops corresponde to the optical fiber size on 0.40 cm.

For data collection were carried out successive simulations, totaling 100 loops simulation interactions in software. Each loop corresponds to a moment captured on the screen of the virtual spectrum analyzer from Optisystem®. During the experiment, the laser injection power parameters were set for the two systems, in 0 dbm and 3 dbm and modulated frequency of 1 GHz for RF generator. Then, an average of the instantaneous Optisystem® signals generated by the spectrum analyzer was made by Matlab software that receives data 100 from all interactions and thus makes the averages. The purpose of doing this is so one can see a signal that most closely matches the actual signal that would be viewed by an oscilloscope.

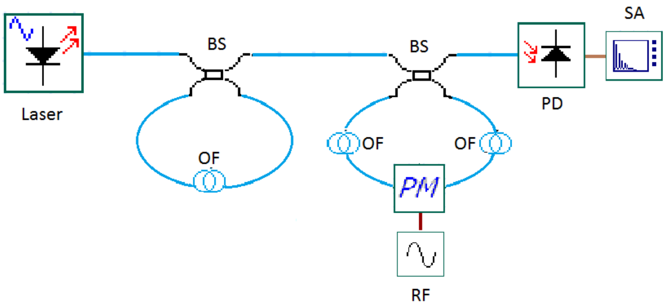

Figure 1. System 1 - Optical setup in serial loops.

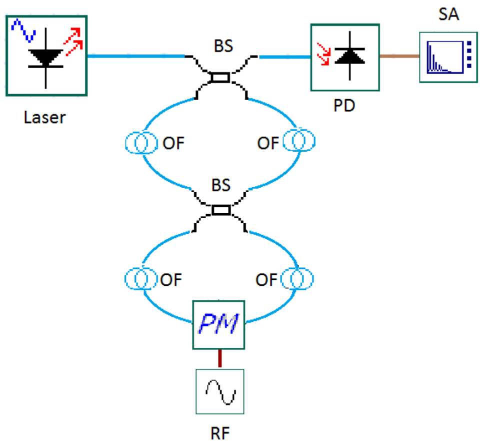

Figure 2. System 2 - Optical setup in parallel loops.

III. Results

This section presents the results and discussions about the harmonics generated in the two proposed systems in two power settings (0 dbm and 3 dbm). First, the both systems with CW laser power at 0 dBm are analyzed. In Figure 3, is made a comparison of the two signals, generating 15 harmonics. In Table 2, are observed the values of the frequencies generated by the respectives power average values.

From Figure 3, it can be observed that the System 2 generates 15 harmonics and the System 1 generates 8 harmonics. It can be seen that, in the first harmonic, the System 2 has a larger amount of power that the System 1. In the second, third and fourth harmonics, the System 1 has larger values of the power than System 2. It is observed that, from the fifth hamonic forwards, the power values of System 2 are greater than System 1.

The second review is done by comparing the two systems with laser injection power to 3 dBm. In Figure 4, the comparison of the two signals is made by drawing 15 harmonics generated. In Table 3, it is observed the values of

Table II
INJECTION LASER OUTPUT POWER IS 0 dBm

	1^{st}	2^{nd}	3^{th}	4^{th}	5^{th}	6^{th}	7^{th}	8^{th}	9^{th}	10^{th}	11^{th}	12^{th}	13^{th}	14^{th}	15^{th}
System 1	-38.86	-42.48	-45.93	-51	-57.35	-60.91	-63.69	-66.1	-	-	-	-	-	-	-
System 2	-36.97	-43.96	-49.17	-52.92	-55.72	-57.42	-60.98	-61.26	-63.82	-65.06	-66.92	-67.14	-68.25	-68.61	-68.94

Table III
INJECTION LASER OUTPUT POWER IS 3 dBm

	1^{st}	2^{nd}	3^{th}	4^{th}	5^{th}	6^{th}	7^{th}	8^{th}	9^{th}	10^{th}	11^{th}	12^{th}	13^{th}	14^{th}	15^{th}
System 1	-31.16	-36.58	-39.93	-48.1	-51.76	-54.98	-58.77	-61.53	-64.41	-	-	-	-	-	-
System 2	-32.79	-37.75	-42.31	-45.2	-50.1	-53.39	-55.36	-57.87	-59.51	-61.82	-63.05	-64.57	-65.59	-66.62	-67.2

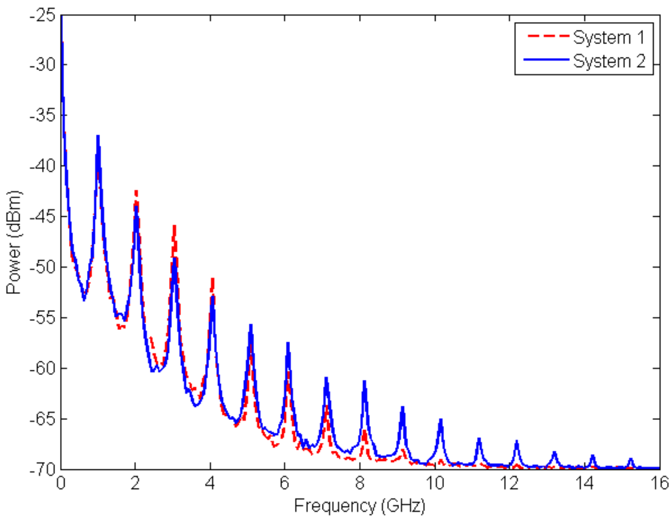

Figure 3. Generated harmonic RF signals by Systems 1 e 2 with 0 dBm CW laser power.

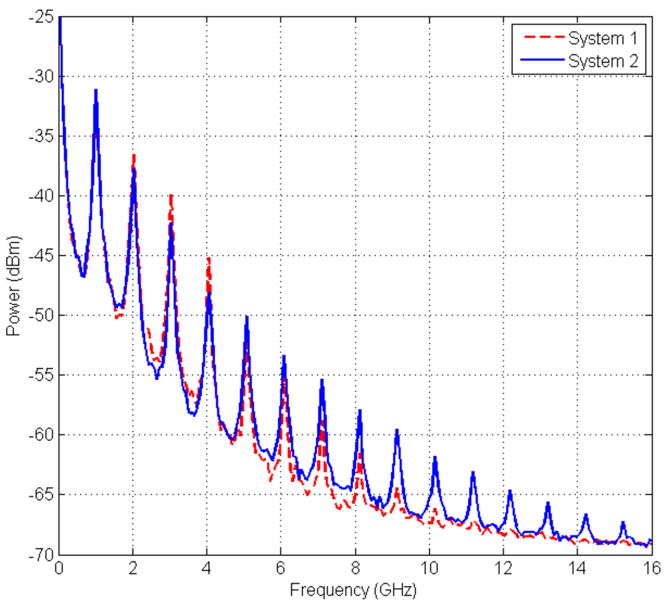

Figure 4. Generated harmonic RF signals by Systems 1 e 2 with 3 dBm CW laser power.

the frequencies generated by the respectives power average values. it can be observed that the System 2 generates 15 harmonics and the System 1 generates 9 harmonics. It can be seen that, in the first harmonic, the System 2 has a larger amount of power that the System 1. In the second, third and fourth harmonics, the System 1 has larger values of the power than System 2. It is observed that, from the fifth hamonic forwards, the power values of System 2 are greater than System 1.

IV. CONCLUSION

In this work are presented and computational simulated two photonic generation of microwave signals systems. It can be seen, for these two laser power settings that, by increasing the laser power injection the signal strength increases, but the number of harmonics do not increase. Therefore, depending on the desired application, the increase in power 0 dBm for 3 dBm will not generate major advantages. It is also observed that the System 2 generates more harmonics that the System 1 and, from the fifth harmonic, the generated signals in the System 2 has higher power values than the System 1. Analyzing the two power settings proposed, it can be concluded that the System 1 is more efficient for applications that require the firsts generated frequencies (from the first to the fourth harmonic) than System 2. But System 2 is more efficient than the System 1 for applications requiring higher frequencies, from the fifth harmonic forwards. However, both proposed systems have the advantages are: simplicity, low complexity for implementation (using a few optical components) for example if compared with the SOA system[4] that in the configuration of its system uses a laser three cascaded SOA three polarization controllers, two insulators and an optical filter, rather than to the systems proposed here also to harmonic generation by mixing of optical signals in a beam splitter.

ACKNOWLEGMENTS

This work was supported by the Brazilian agencies CAPES and CNPq via Grant no. 458867/2014-4 and INCT-IQ (Brazilian National Institute of Science and Technology for Quantum Information).

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