



Electronic Warfare and Remote Sensing: Photonic Technology in RF Systems

Radar Receiver with Intrinsic Power Limiter Assisted by Microwave Photonics

Receptor radar com limitador de potência intrínseco assistido por micro-ondas em fotônica

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Abstract

This article presents an approach of a radar receiver that has an intrinsic power limitation based on photodetector power saturation. The radar signal power detection is implemented using optical self-homodyne detection. The proposed architecture uses a phase modulator (PM) to modulate the optical carrier and a fiber Bragg grating (FBG) to filter the spectrum and convert the phase to intensity modulation. The self-homodyne technique eliminates the optical carrier influence. It enables to reduce of shot noise influence and increases the photodetected optic power to improve the conversion gain. Moreover, the photodetection is performed at the radar pulse baseband, allowing to obtain transimpedance gain. An experimental demonstration is performed. A dynamic range of 56 dB is achieved for a pulsed radar operating at 20 GHz.

Resumo

Este artigo apresenta uma abordagem de um receptor radar que possui um limitador de potência intrínseca baseada na saturação de potência do fotodetector. A detecção de potência do sinal de radar é implementada usando detecção auto-homódina óptica. A arquitetura proposta utiliza um modulador de fase (PM) para modular a portadora óptica e uma rede de Bragg a fibra óptica (FBG) para filtrar o espectro e converter a modulação de fase em intensidade. A técnica auto-homódina elimina a influência da portadora óptica. Permite reduzir a influência do ruído de disparo e aumenta a potência óptica fotodetectada para melhorar o ganho de conversão. Além disso, a fotodetecção é realizada na banda base do pulso do radar, permitindo a obtenção de ganho de transimpedância. Uma demonstração experimental é realizada. Uma faixa dinâmica de 56 dB é alcançada para um radar pulsado operando a 20 GHz.

I. INTRODUCTION

A receiver protector is a requirement for front-end radar receivers to intentionally or not intentionally transmitted high power. Most radar receivers use some means of controlling the overall gain. This usually involves the gain of one or more stages of the intermediate frequency (IF) amplifier. This function can be implemented by sensitivity time control (STC), automatic gain control (AGC), main gain control (MGC), and logarithmic amplifier (LogAmp) [1].

Sensitivity time control circuits apply a time-varying bias voltage to IF amplifiers to control the gain of the receiver. When the transmitter works, the STC circuit decreases the receiver gain to zero to prevent amplification of any leakage energy from the transmitted pulse. At the end of the transmitted pulse, the STC voltage increases, and gradually the receiver gain till the maximum [1].

The logarithmic amplifier is an unsaturated amplifier that usually does not use special gain control circuitry. The output voltage of the logarithmic amplifier is logarithmically

proportional to the input voltage [2]. For low-amplitude signals, this amplifier has a high gain and inverse for high-amplitude signals. In other words, the linear amplification range does not end at a defined saturation point, such as in the case of normal IF amplifiers [2]. A common receiver that uses this technology is a Crystal Video Receiver (CVR). This system is known as successive detection logarithmic video amplifier (SDLVA) and presents a dynamic range of 75 dB [2].

When photonics technologies are merged with radiofrequency (RF) systems, several advantages arise such as operating at high RF bandwidth, low propagation loss, electromagnetic interference immunity (EMI), low weight, and downsize [3]. Microwave photonics (MWP) approaches for radar applications have been proposed for waveform generation, mixing, filtering, and channelization [4]. Besides, MWP approaches for radar signal receivers have been proposed to achieve wideband receivers [5]. Traditionally, a high-speed photodetector recovers the RF

signal at the photonic system output, to be amplified and detected by RF electronic-based circuit.

However, RF envelope detection can be performed directly on the photodetector using the optical self-homodyne technique [6], [7]. By using photonic RF envelope detection, the expensive high-speed photodetector at the system output is no longer needed, as well as any kind of microwave frequency electronic circuit. Additionally, when the photodetector is operating at a low-frequency baseband, it is possible to achieve transimpedance gain by increasing the load impedance output.

This work proposes a fully photonic radar signal receiver architecture based on an optical self-homodyne technique to detect radar pulse emissions. An optical single-sideband-suppressed carrier (SSB-SC) is injected into a photodetector. The result is an envelope detection of radar pulsed signals.

Combining the optical and the transimpedance gain contribution, it is demonstrated a 56 dB dynamic range for a radar frequency of 20 GHz. The system architecture implementation is quite simple using an optical PM at the RF input and a low-cost and low-speed photodetector at the output. Rather than MWP architecture that uses Mach-Zehnder (MZM) intensity modulators, the proposed architecture does not need modulator bias voltage control. As the photodetection is performed at the radar pulse baseband frequency spectrum, the only microwave electric circuit is the PM input.

II. SYSTEM CONFIGURATION AND PRINCIPLE

The principle of operating the fully photonic radar signal receiver is based on optical self-homodyne detection shown in Fig. 1. The laser light wave is coupled to the phase modulator and undergoes optical phase modulation by the RF signal. The modulated optical signal passes through an optical filter. The optical carrier and the lower sideband of the modulated signal are rejected. The upper sideband portion of the modulated optic signal is transmitted through the filter to the PD, to be converted into a baseband electrical signal by direct detection. This process is similar to the one used in [7], where the authors presented this structure as a down converter receiver.

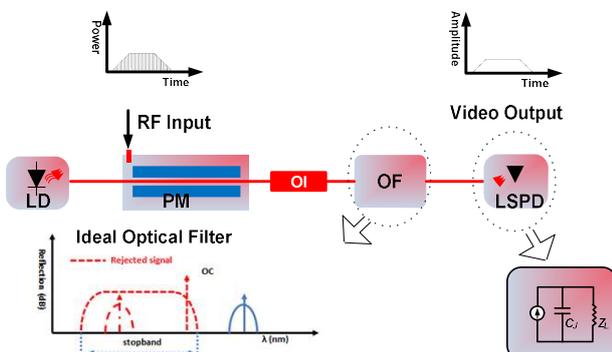


Fig. 1. Schematic diagram of the photonic ED. LD – Laser Diode, PM – Phase Modulator, OI – Optical Isolator, OF – Optical Filter, LSPD – Low-Speed Photodetector, C_J – Junction Capacitance, and Z_L – Output Load.

This optical circuit uses an optical phase modulator to modulate the carrier with the RF radar input signal, and the phase-to-intensity (PM-IM) modulation conversion technique by optical filtering [8]. Traditionally, the PM-IM conversion approach to achieve RF filtering has been

proposed using fiber Bragg grating. One approach is to use FBG as a notch filter to cut one of the optical phase-modulated sideband spectrum and produce PM-IM conversion. When the optical carrier is preserved, the beating between it and the remaining optical sideband components will result in a filtered RF signal at the photodetector output [8]. To achieve optical self-homodyne in this work, the optical carrier is tuned to be filtered together with the rejected lower sideband portion, as shown in Fig. 1. So, only the non-rejected sideband phase-modulated spectrum reaches the PD. Therefore, the beating among the optical components at the PD produces an RF radar pulse envelope detection at the system output.

The RF envelope signal is much lower than the RF frequency at the input system. For low-frequency operation, the photodetector has an equivalent circuit as a low-pass filter. This fact can be observed in Fig. 1, the photodetector equivalent circuit is composed of a current source parallel to junction capacitance and output load. Another fact is that impedance matching is not required in the output system. The transimpedance gain is possible with an increase on the output load.

When the optical carrier power of the phase-modulated signal is filtered, it is possible to increase the optical signal power at the system input without saturating the photodetector. This allows more power to be transferred from the optical signal to the RF signal envelope, increasing the dynamic range of the system.

There are two important processes to consider in the proper operation of this receiver. The first process is the radar envelope signal amplification by power transferred from the optical circuit to the RF signal envelope combined with a transimpedance gain at the output system. The second process is an intrinsic RF power limiting by photodetector (PD) saturation. This saturation occurs for an output voltage below the damaging voltage and in the vicinity of the photodetector reverse bias voltage. The envelope pulse radar maintains a time shape undistorted.

III. EXPERIMENTAL DEMONSTRATION OF THE PHOTONIC ENVELOPE DETECTOR

To demonstrate and measure the dynamic range of the photonic radar receiver, an experiment was carried out. The schematic diagram is shown in Fig. 2. A DFB laser is used as an optical source. The phase modulator operates at frequencies up to 20 GHz. A uniform FBG is used as an optical filter followed by a 1.5 GHz low-speed photodetector. The RF signal generator performs the pulse radar signal and a high-speed digital sampling oscilloscope (DSO) measures the input RF modulated signal and the output video signal, that is, the envelope of the input signal.

Figure 2 shows the right side of the rejection band optical filter, the left side is symmetric. The right edge has a roll-off starting from the total transmission and ending at the beginning of the region's maximum optical signal reflection.

The transition region between the stopband and transmission band has a roll-off of around 2.86 dB/GHz. This imposes a limitation on the RF flatness response operation band, starting at 10 GHz, considering the laser carrier tuned at the right edge frequency of the optic stopband [6].

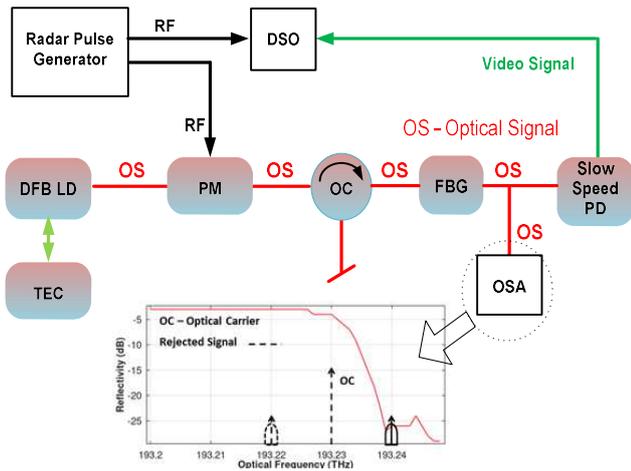


Fig. 2. Schematic diagram setup of the receiver. DFB - Distributed Feedback Laser, TEC - Thermal Electronic Cooler, PM – Phase Modulator; OI - Optical Isolator, RF - Radio Frequency, PD - Photodetector, and FBG - Fiber Bragg Grating. Right side of the rejection band optical filter, the stopband center frequency is approximately 193.20 THz.

The DFB laser operates at a frequency of around 193.23 THz by optical cavity temperature adjusting. To achieve optical self-homodyne in this work, the optical carrier is tuned to be filtered together with the rejected sideband portion as shown in Fig. 2. To achieve the dynamic range, an RF pulsed radar signal was set with a pulse width (PW) equal to 4 ms and a pulse repetition interval (PRI) is 10 ms. The dynamic range test relied on pulsed RF signals generated with the carrier at 20 GHz. The RF signal was generated with power variation from -10 to 16 dBm. A saturation process occurs from -3.3 to 16 dBm as shown in Fig. 3 (a) and (b) respectively. The RF power value of 16 dBm was chosen from the information of the maximum RF power supported at the PM input. The output voltage value was 25 V for -3.3 and 16 dBm as shown in Fig. 3 (c) and (d) respectively.

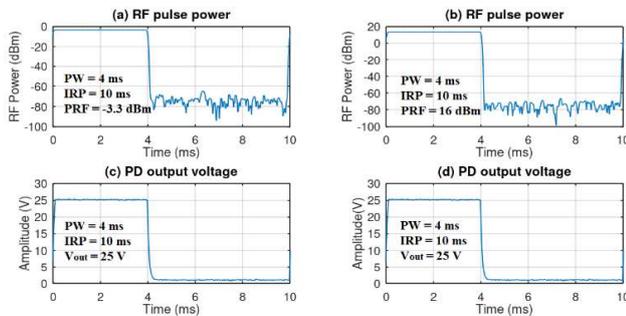


Fig. 3: Measured input and output radar pulses. RF input pulse powers at 20 GHz are shown in (a) and (b). The output PD voltage is shown in (c) and (d). The PD load resistance is 500 k Ω .

In Fig. 3 (c) and (d), the pulsed signal can be seen undistorted and with its envelope measured with the voltage value equal to 25 V. The output system voltage remains at the same value without increase. This fact shows that the system works as an RF power limiter. If the PM power handling was 30 dBm like many PMs found in commerce, the upper limit of the dynamic range would be 30 dBm.

The lower limit of the dynamic range was determined from the tangential sensitivity (TSS) concept. The TSS is the point where the top of the noise level with no signal applied is level with the bottom of the noise level on a pulse [9].

Starting the test with an RF power radar signal equal to -3 dBm, this value gradually decreased until the system

output voltage with the bottom of the signal tangent to the top of the noise is observed in the DSO as in Fig. 4. This RF power value reaches -40 dBm and it is known as the TSS and follows the 8 dB criterion as described previously [9]. The TSS measurement process is used to determine the lower limit of the dynamic range. The pulsed RF signals used in the test have the value of PW equal to 4 ms and PRI of 10 ms. The MF has the value of $V\pi$ equal to 10.5 V for the frequency of the pulsed RF signal at 20 GHz.

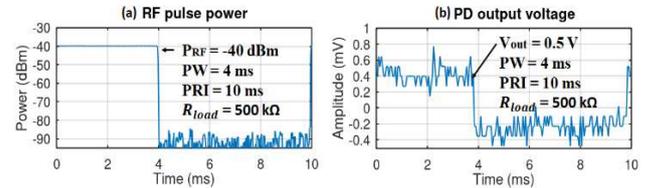


Fig. 4. Minimum RF input power measures at TSS condition. (a) is the RF input pulse power of -40 dBm. (b) is the PD output voltage for RF input pulse power of -40 dBm. The RF carrier is 20 GHz.

Two kinds of gain contributions factors are observed in the experimental approach. One is related to a photonic contribution and another is related to a transimpedance gain. A dynamic range measured reaches 56 dB, moreover, if the PM power handling is 30 dBm, the dynamic range can be 70 dB. The measured values demonstrated for a pulsed radar operating at 20 GHz, without any kind of RF amplification. Better performance can be achieved by using lower PM $V\pi$ or increasing the laser power. The SDLVA presents a dynamic range of 75 dB, but its upper limit is of around 3 dBm [2]. The photonic approach can reach an upper limit of around 30 dBm and a lower limit of around -70 dBm. For this case, the dynamic range can reach 100 dB.

IV. CONCLUSION

A new concept of a radar receiver based on Microwave Photonics has been presented. The principle is based on the optical self-homodyne technique to directly detect the envelope of the radar pulse. It uses phase-to-intensity modulation conversion by optical filtering. The optical PM modulator does not need any kind of modulator voltage bias control. The system architecture implementation is quite simple and the RF frequencies are handled only at the PM input. All other stages of the system use photonic technology and low-frequency electronic circuitry. The theoretical approach shows the PD output detected envelope radar pulse of the radar pulse at PM input. Two kinds of gain contributions factors are observed in the experimental approach. One is related to a photonic contribution and another is related to a transimpedance gain. A measured dynamic range reaches 56 dB and can reach 70 dB if the PM power handling is 30 dBm. The measured values were demonstrated for a pulsed radar operating at 20 GHz, without any kind of RF amplification. Better performance can be achieved by using lower PM $V\pi$ or increasing the laser power.

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