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A Survey on Photonics Radar Technology

Asha Shendge, G.H. Raisoni Institute of Engg. and Tech. Pune India, asha.shendge@raisoni.net
A A Brazil Raj, Defence Institute of Advanced Technology, Pune India
G. Unnikrishanan, Defence Institute of Advanced Technology, Pune India

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Abstract:
As the frequency increases, due to limited bandwidth and high noise, processing the microwave signals using the digital components such as frequency synthesizers, analogue-to-digital converters and RF up/down converter, becomes highly difficult. Today's fully digitized radar systems works in sync with other subsystems only up to few GHz. Further, generation of extremely stable RF signals particularly at upper–side of radar frequency band with available technology is almost impossible today or highly expensive. Thus, the development of a new technology, based on photonics, to generate a wide spectrum of highly-stable RF signals (up to mm waves) and transport, detect/measure ,and process those microwave signals is very much essential to mitigate the limitations of existing RF technology. In this survey paper, we reported the outcome of a thorough literature survey on the up-to-date worldwide developments in the field of photonics radar technology. The reported survey address the maturity of photonics radar technology in four different aspects namely (i) generation and transportation of RF signal, (ii) processing of microwave signal in photonics domain, (iii) detection and measurement of photonics microwave signal and (iv)Photonics radar architecture(v) Photonics based software defined radar (vi) Photonics based MIMO radar; to explore/understand the full-potential of the photonics radar technology to meet the demand of neat-future next generation radar requirements.

Keywords: *RF system, Photonics Radar, Micro Wave Systems, Machzehnder modulator(MZM)*

I. Introduction

It is well known that there are following types of conventional Radar System available such as Continuous wave radar (CW) , Pulsed Doppler radar, Moving Target Indicator (MTI) Radar, Frequency Modulated-CW radar, Phased Array Radar , Bi Static and Multi Static radar, Synthetic Aperture Radar, Passive Radar, Multimode Radar which are used for different purposes as per application demands . However, it needs to tackle the challenges of realizing ultra wideband transformer and quadrature filters, programmable microwave phase shifters, phase array beaming true time delay elements , continuous tunable filtering, switching operation of mixers etc.

The prologue of photonics in microwave systems is setting novel concepts as well new paradigms in radar design. Photonics technology is proficient to overcome many of the shortcomings of conventional radar for example it generates a stable radio frequency signal of millimeter wavelength and arbitary waveform using analog to digital conversion. This generated signal is detected by using precise degitalization with good immunity towards electromagnetic interference and without any down conversion. Furthermore photonics allows RF signals from the transceiver to the antenna site using the fiber based distribution and thus delivers signal with negligible distortion and low losses. This signal carries larger bandwidth and very low jitter. Photonics has ability to receive multiple of signals concomitantly. Photonics is thus expected to transform approach to radar systems to communication system. It has benefit of high resolution and high performance in terms of consumption, size and cost.

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Current research in the field of photonics has covered generation of microwave millimeter and Terahertz waves, tunable, adaptivemicrowave photonics filtering, broadbandoptical beam forming for phased array antennas and tunable microwave phase shifting across a broad range. Forphased array antennas and tunable microwave phase shifting across a broad range. For developing nation such as India , in overview quick security checks , pilotless automobiles and unmanned aerial vehicles is essential need which can be fulfill by that photonics radar system.

II. Literature Survey Photonics Radar

This section presents a comprehensive analysis of photonics radar system based on different expert's experimental studies. These studies mainly elaborated remarkable improvement of photonic technology in comparison with electronics impede both its practical as well as theoretical limits. The limits such as power consumption, miniaturization performance software methodology.

Fangzheng Zhang et al., have demonstrated a real time and high resolution inverse synthetic aperture radar (ISAR) imaging system by means of photonics-based radar experimentation. This radar utilizes generationand de-chirp handling technique of broad band LFMCW signal in optical domain. In the transmitter section, an electrical signal is applied to a single integrated electro-optical modulator, and it generates a broad band LFMCW signal. The methodology followed is frequency quadrupling of a low speed converter. At the receiver side , these LFMCW is de-chirped to low frequency signal. The optical reference is phase modulated for this purpose. After de-chirping optical filtering of this low frequency signal is carried out. This photonics de-chirp method could directly process signals with large bandwidth and high frequency without any frequency alteration .These de-chirped signals can be used in real time application after being sampled by a low speed Analog to Digital Converter (ADC) [1].

Fangzheng Zhang et al**.,** have proposed photonics based LFM signal generation technique as well as processing of high resolution and real time broadband LFM signal based radar with frequency modulation. In modern radar applications, these real time and high resolution LFM signals can be used for target detection. A broadband LFM signal is produced in the transmitter section using photonic frequency quadrupling. The echo received is de-chirped at the receiver into a low frequencysignal.
To overcome the shortcomings of current radar related to operational bandwidth and processing speed, the work presented in [1] can be a reliable solution. It is positively used in upcoming radars for real time target detection and imaging with higherresolution.[2]

Paolo Ghelfiet al., have studied various aspects of the radar system by field experiments using Phonics approach. He developed a transceiver system which summarizes a Photonic Radar project demonstrator. In their project demonstrator they proposed a high frequency carrier radar system with unique frequency flexibility aspects, high resolution receiver with quality signals at the receiving end. This radar system is tested in the real time environment [3].

Filippo Scotti et al., have developed complete scheme of fully digital coherent radar of the first photonics based system in real word. The projected design relies on a original flexible photonics transceiver based on the software-defined radio model. The fully digital coherent radar is proficient of generating and receiving signals with arbitrary carrier frequency and waveforms. Francesco Laghezza et al., have discussed optical methods used for Synthetic Aperture Radar (SAR) systems. The paper specifically elaborate history of Radar system's remarkable developments from the long time. Here novel and higher-performance electronic

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devices and subsystems with new radar architectures are also discussed. The author has explained SAR radar used for most complex and sophisticatedremote sensing system applications. Their optical methodology utilizes data collection on aircraft and spacecraft.

A. Bogoni et al., have presented the results obtained during the field trial experiments of the photonics-based radar system demonstrator in a real maritime environment [4-10].

Reza Maram et al., have discussed photonics applications for microwave engineering known as microwave photonics (MWP). He proposed extraordinary processing speed for generation and handling of random and arbitrary microwave waveforms in various application of photonic technology.

The combination of complex passive and active photonics devices is possible by utilizing photonics technologies. So it is highly capable of dealing with high speed silicon electronics monolithic integration of MWP and allowed understanding main functionalities of the highly complex systems. Recently, this developing field has accepted the integrated photonics technologies to build up microwave photonics systems with superior strength as well as with a major diminution of size, cost, weight, and power utilization. In these papers, authors have presented a review of current work on MWP functions developed on the silicon platform in particular reference to newly reported designs for signal modulation, arbitrary waveform generation, frequency measurement, beam steering, filtering, phase shifting and true-time delay [11,12].

III. State of Art of Photonic Radar

This section covers (i)the generation of phonics based RF signal (ii)processing of photonics microwave signal (iii) detection and measurement of RF photonic signal.

A. Generation and Transportation of RF Signal

The main area of study in photonics technology is the photonic generation of microwave, millimeter and terahertz wave. Photonics based techniques can also be applied in generation, distribution and processing of microwave signal, construction of high performance radar and distributed antenna for non-contact measurement of objects.

The methodology of generating a RF signal from a optical source is shown in **Fig.1.**The direct generation of linear frequency modulation (LFM) signal is done using a direct digital synthesizer (DDS). Then this LFMCW signal is passed through a 90˚ hybrid before applying to MZM. This hybrid produces two signals which have phase difference of 90˚. These two hybrid signals are fed to the RF port of MZM signals. The LFMCW signals are used to drive the MZM. The constant light from laser diode an optical source is modulated by dual parallel MZM. Then using anoptical coupler these MZM signals are been split into two equal branches and sent to the photo diode using single mode fiber (SMF). Photonic RF generation deals with detection of optical signals in a Photodiode .The conversion of optical signal from optical to electrical signal is done by passing it through a photo detector (PD). The RF signal is passed through electrical amplifier and then fed to transmitting antenna.

It in turn produces a current relative to the square of the input optical signal. Since the bandwidth of electro optical signal is above 40GHz, photonics allows the RF **signals generation** in the range of mmW.

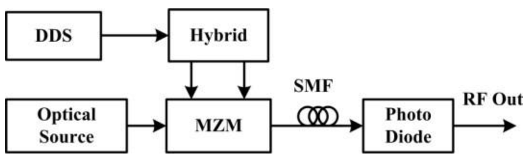

Fig.1 Generation and Transportation of RF Signal

B. Processing of Microwave Signal in Photonics Domain

The second section in photonic radar deals with processing of photonics signal. Traditionally, photonics has focused only in signal transmission. Due to the unique advantages of signal processing concerned with photonics such as it enables high-resolution, reconfigurable microwave signals due to capability to process wideband signals together, it has paved way for many applications. The unique advantages related with photonics are parallel signal processing, inherent speed, low-loss delay, immunity to EMI interference and high frequency sampling. **Fig. 2** describes microwave signal processing in optical domain where the RF modulated optical signal. RF modulated Optical signal comes from Phase Modulator (PM) which modulates the optical signal according to the RF signal received from the receiver antenna.

This signal processing consists of forming of optical beam using coupler, amplification, phase shifting of optical frequency and then filtering. As per wavelength requirement wavelength dependent element such as fiber link is used and finally optical signal outputs to Photo detector.

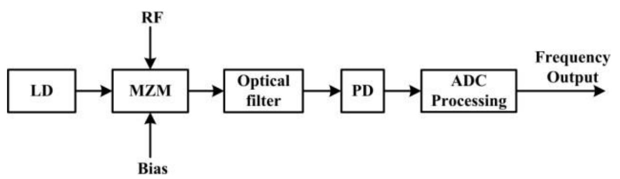

Fig.2 Microwave Signal Processing in Photonics Domain

C. Detection and Measurement of Photonics Microwave Signal

The optical measurements concerned with the microwave signal deals with measurement of power, noise, spectrum, bandwidth, frequency etc. of contact object. The photonics signal can be used for non- contact measurement such as detection of position, velocity and arrival of an object in a microwave medium. Fig. 3 shows the measurement systems based on the principle of power monitoring of photonic radar. For measurement of the various parameters of microwave signal , the signal is converted into the optical domain using a modulator. This modulated optical signal is given to a optical processing module consist of LD, MZM, Optical filter. Optical modulator converts measured parameters to optical change detector and filters high frequency interference. A photo detector (PD) extracts the final amplitude information. A large range of signal wavelength is either absorbed or rejected by the optical modulator. ADC signal processor in this system plays a significant role. It helps to increase transmission capability and help in increase of bit rate wavelength channel.

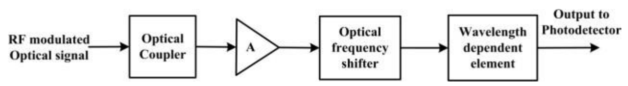

Fig.3. Microwave frequency measurement system using optical power monitoring

IV. PHOTONICS RADAR ARCHITECTURE

This section briefs the working and architecture of photonics radar. **Fig. 4** shows the overall Photonics radar architecture of the projected photonics-based broadband radar.As elaborated in figure laser diode emits continuous- wave light which is modulated by a dual-parallel Mach-Zehnder modulator (DPPMZM). The DPMZM is driven by an intermediate frequency (IF)-band LFMCW signal. This signal is generated by a low-speed electrical signal generator. The DPMZM is composed of three sub-MZMs, among which two sub- MZMs i.e. MZM-a or MZM-b are embedded in each arm of the main modulator which is MZM-c. Before being applied to DPMZM, the IF-LFMCW signalis passed through a electrical hybrid which produces two signal with phase difference of 90^0 . These signals are sent to the RF port of sub- MZMs i.e. MZM- a and MZM-b. Serial of even order optical side bands are generated by simply biasing these two sub-MZMs at its upper limit transmission points. Thus sequential even order optical side bands are generated. A optical coupler then splits the set wo signals into equal branches. The lower branch signals are used as a reference that would de-chirp the receiver radar echoes and the upper branch optical signals are converted into electrical signals using the photo detector. After PD1, frequency quadrupled LFMCW signal is acquired.

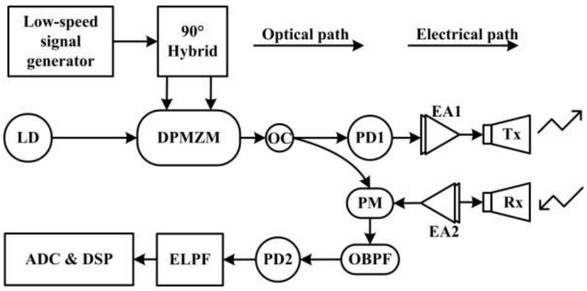

Fig.4. Photonics Radar Architecture [1]

The generated LFMCW signal is amplified by a broad band electrical amplifier1 (EA1). This signal is then emitted to the free space through the transmitting antenna helping in target detection. The receiving antenna collects the echoes from target. The collected echoes signals are amplified by electrical amplifier 2(EA2). After amplification the received signals are applied to the electro-optical phase modulator (PM). The PM modulated the reference optical signal and this modulated signal is sent to another photo detector PD2 after passing through optical band pass filter (OBPF) for optical to electrical conversion. At this point photonic de-chirping is implemented. An electrical low pass filter of preferred band width is selected for removal of high frequency interference. Selecting an appropriate de-chirp rate from the detection range, signal can have low frequency (e.g. lower than 50Hz) and can be simply digitalized by a ADC with lower number of bits. This digitized signal can be handled in a digital signal processing (DSP) unit based on mature ISAR imaging algorithms. Larger bandwidth selection helps in higher range resolution. The projected radar avoids the utilization of high speed ADCs and multistage electrical frequency conversion, thus enabling processing and generation of broadband radar signals.

V. Contemporary Photonics Radars

A. A photonics-based Software defined coherent radar In this section construction and working of coherent radar is discussed. The photonics-based fully digital coherent radar system demonstrator architecture depends on new photonic transceiver which is based on software-defined radio (SDR) pattern. It is proficient of generating and receiving signals with random carrier frequency and waveforms.

In this radar system, the crystal oscillator that generates the clock signal for the whole system acts as the first module. The photonic transmission and reception module exhibits a pulse of 1ps long and operates at a reception rate of 400MHz from a laser which is used as a semiconductor in the module. The core part of the system is the mode-locked laser(MLL). Inherent phase and amplitude stability property of the mode locked laser add up as an advantage in the system. This property of MLL not only generates high quality carrier over broad frequency range but also directly digitalizes high frequency signal with exceptional precision.
Photonic transmitter is the second optical module. It is obligatory to calculate and record the small Doppler deviations in the frequency of the back scattered echoes. Therefore , the transmitter has a doubled structure to provide both the radar pulses and a reference signal of continuous wave. The filtration of the signal from MLL is done by the special filter. Followed by Erbium doped fiber amplifier (EDFA) this amplifies the signal. This amplified signal is filtered with an optical band-pass filter with a bandwidth of 0.3nm. Filtering is done in order to reject the spontaneous and amplified noise from the selected lines from the spectrum. The optical bandpass filter (OBPF) rejects spontaneous emission noise, and final

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signal is sent to two MZMs. A two channel direct digital synthesis (DDS) using digital technology produces a continuous wave at a IF of 100MHz and a phase modulated wave of 100MHz. Photodiodes detects the modulated optical signal. The RF filters operating at MHz bandwidth finally selects the photonic generated radar signals as well as the reference signals at a frequency ofGHz.

Low noise amplifiers amplify these RF signals and then multiply it with a gain of 30dB to compensate conversion losses. The noise figure of 1.2 dB is also added. The spectrum of the generated carrier shows a spurious free dynamic range close to 100 dB. The environmental interference can be eliminated using a properly design electromagnetic interference shield.

At last the final signal-to-noise-and-distortion-ratio (SNDR) can calculated over a spectrum of 40MHz. It obtains a value of 58 dB.

The photonic receiver is the third module of the system. It samples both the reference signal and the echoed radar signal coming from the RF receiver stage. The incoming radar signal is sampled in a 20 GHz bandwidth MZM by the optical pulses The reference signal is under gone analog processingin the second identical receiver. ADC samples the two received signal at a rate of 80msps. ADC realizes a nominal precision of 14 bit and an effective number of bits (ENOB) of 10 bit. The Fast Fourier Transform (FFT) is used in the calculation and analysis of the sampled signal.[4]

B. A photonics-based multiple-input-multiple-output (MIMO) radar

Multiple-input Multiple-output (MIMO) radars outstands the traditional radar concepts. MIMO acts as a standalone and a local system and thus is considered as a breach in radar world. This type of radar is proposed and demonstrated based on wavelength- division-multiplex broadband microwave photonic signal generation and processing. MIMO with its larger bandwidth could achieve ultra-high range resolution. In comparison with mono static radar system, improved radar performance can be achieved with the MIMO architecture for multiple targets detection and multiple beam forming. Real time signal processing with low speed electronics is possible with this architecture. In complex target detection those are having high variability of the radar cross section in consideration of angle, stealth targets and scattering RF light in more than one direction, MIMO technique can be used in order to illuminate it. The fiber connected communication or sensor networks incorporation is possible with the photonics-based MIMO radar for used in wildly separated antennas. This property may lead to novel applications such as radar communication fusion and ultra-high resolution remote sensing. The involvement of photonic technology is predictable to progress the performance and slow down the hardware requirements. The photonics-based MIMO-ISAR has various applications such as 2D/3D imaging, multi- target detection and velocity measurement, etc., Moreover, distributed MIMO radars permits high resolution in the orthogonal direction to the radar-target line (cross-range resolution)[14].

VI. Conclusion

This paper briefs state-of-the-art on technicality of the different aspects of conventional radar system in comparison with Photonics Radar. The paper contents review of the system elements, principle of operation, and study made by various experts in photonic radar field. It can be concluded that photonics radar is the next generation technology. This technology can be utilized for remote sensing applications, harbor surveillance, Disaster and crisis management, Borderline, coastline and pipeline surveillance, Continuous imaging of critical infrastructure, Traffic and traffic infrastructure monitoring ,Traffic ability of maritime routes sea ice, icebergs, tomography and holography.

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