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# Microwave Photonics Advancements in Radar Application

**Sanchita Mittal, Vallikannu R**

***Abstract*****:** ***Microwave photonics (MWP) Technology brings Microwave and optical domains together. Due to its extraordinary capabilities and solution especially towards generation, transmission and processing of Microwave signals, the MWP field has potential to break barrier, which was not possible with RF technology alone. MWP technologies provide new opportunities in many areas like 5G networks, Advanced Radar and Internet of things. As demand for multi-functionality and reduced size is growing in every field, Radar is no exception. Radar systems capabilities in terms of functionality, precision, response time have significantly improved in past decades. MWP technologies are one of the key factors in that. With Modern photonics technologies Radar performance in terms of Speed, resolution, coverage, precise target identification has improved drastically. To understand the photonics technologies in detail, this paper is designed, which highlights the important features of Microwave photonics techniques applied in Radar and its subsystems***

***Keywords*****:** ***Microwave Photonics (MWP) Communication, Digital Signal Processing, Optoelectronic Modulators, Analog to digital conversion, MIMO Radar.***

## I. INTRODUCTION

Due to its all weather, all time, all distance capabilities, Radar systems have many applications in Military and civilian area. In simple terms, Radar detects the distance, position of target by transmitting the signal and receiving the reflected signal. Traditionally RF based Radar have limitations in bandwidth, resolution, speed & functionality. Photonics based solution has paved the way to overcome these limitation in traditional Radar with distinct features such as high range resolution, broader bandwidth, low phase noise, low electromagnetic interference and small & integrated devices. Photonics technologies have provided unique capabilities in Radar subsystems. Components such as optoelectronics oscillators, microwave photonics mixers, photonics analog to digital converters, photonics waveform generators are widely used in photonics Radar. This paper is organized in different sections. It firstly provides an overview about unique features and capabilities microwave photonics offers in Radar systems which is described in Section II. The next sections, III is dedicated to Microwave photonics techniques which are extended to Radar systems including Radar waveform generation, MWP filtering, mixers, Analog to digital conversion. Recent advancement in MIMO MWP Radar systems are described in section IV. Last section, i.e. V, discusses the possible future research directions.

## II. MICROWAVE PHOTONICS FEATURES

Microwave photonics techniques have offered many advantages to Radar system, which was not possible with traditional systems.

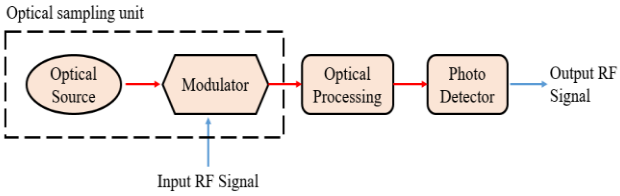


**Fig.1. Microwave Photonics principle**

Some of the Microwave Photonics features with respect to Radar systems are highlighted below

### A. High Bandwidth

Bandwidth is one of the important parameter in Radar system, which determines range resolution and functionalities. For a typical Radar system, range resolution is expressed below:

$$L_{RES}= c/2B \quad (1)$$

Where, c is speed of light in vacuum and B is signal Bandwidth [2]. This expression indicates that range resolution is inversely proportion to bandwidth; hence large bandwidth is considered to be prime factor for achieving higher resolution. The broader bandwidth also enables high-resolution imaging (2D/3D), precise target observation and multi-operations in Radar systems.

### B. Ultra-fast Signal transmission along with superior performance

Traditional Radar like array Radar, distributed Radar, remote operation Radar generally used transmission lines for signal transmission, which is now being replaced by Optical fiber due to its superior features like low transmission losses, bidirectional transmission, immunity to EMI and low cost.

### C. Multi-functionality

Due to broader bandwidth of Microwave photonics technologies, multiple signals can be processed simultaneously at transceivers, which provided a great advantage in multi-functional Radar in terms of reduced hardware equipment, hence cost.

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Even new generation electronic warfare functions, Lidars are getting integrated into Microwave photonics Radar.

### D. Compatibility

Microwave photonics technologies can be applied to one or more subsystems of Radar. Different Radar architectures such as optoelectronics hybrid system and all optical system are proposed in this regard, which enables either partial or full operations of Radar in optical domain [12]. Integrated Microwave Photonics devices have significantly improved robustness along with reduction in Size, weight, cost and power consumption of Radar systems. Field such as Silicon photonics technology are integrating active and passive photonics devices with high-speed silicon electronics.

### E. Wide applications

MWP technology has opened many new avenues for Radar application, which significantly improved Radar applications in many areas.

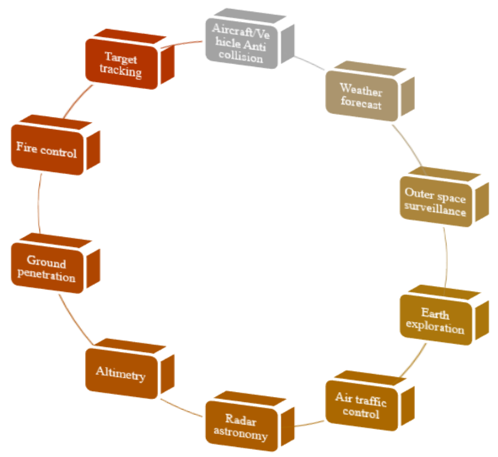


**Fig.2. Radar application in different fields**

## III. MICROWAVE PHOTONICS TECHNOLOGIES FOR RADAR SUB-SYSTEMS & PROCESSES

A number of photonics techniques are applied to Radar to make its performance better. A typical Radar system diagram is presented in Fig. 2.

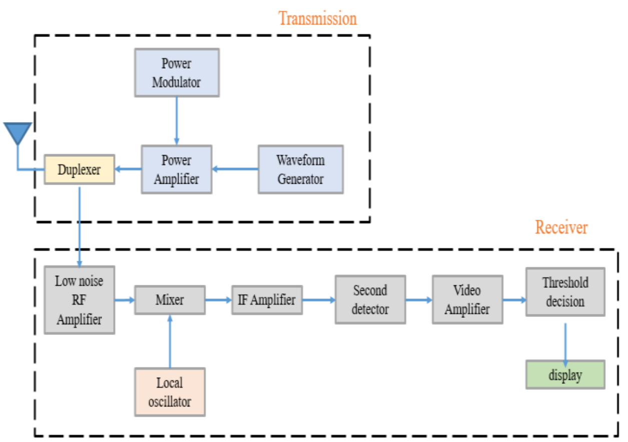


**Fig.2. Basic Radar diagram with subsystems**

### A. Signal Generation

Signal generation is essential part of Radar system. Generated reference signal is used in different process & subsystems of Radar such as waveform generation, digital to analog conversion, frequency up and down conversion, synchronization and DSP modules. Usually in traditional Radar, LO signal generation are typically based on frequency multiplication of Oscillators [10], even many resonators like those that dielectric resonators, ceramic coaxial resonators etc. also sometime employed for signal generation with low phase noise. Due to limitation on carrier frequency, signal bandwidth and noise properties, signal generation based on traditional technologies, cannot meet the requirements of high performance advanced Radar. When it comes to signal generation by Photonics techniques, many methods were applied in the past. Fig.3 shows different types of Photonics techniques used for signal generation. Based on criteria such as frequency stability, complexity, phase noise and reliability, these photonics methods tested, however few of the only meet these criteria and provide the good solution for Radar applications.

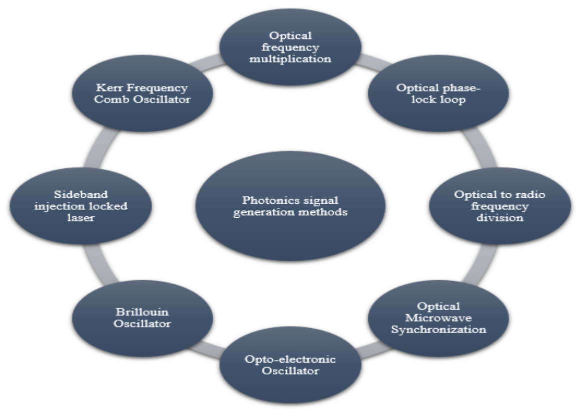


**Fig.3. Different photonics signal generation methods**

Optoelectronic oscillators are considered one of the best solution to generated low phase noise signals due to usage of long and low cost optical delay lines. Fig.4 shows basic functional block diagram of an optoelectronic oscillator (OEO). A typical OEO made of laser, an Opto-electronic modulator, optical fiber delay lines, amplifiers, photo detector and band pass filter. The OEOs system has positive feedback loops that used to create ultra-low phase noise by employing high Q-factor energy storage elements such as optical delay lines [9]. Optoelectronic oscillators (OEOs) offer a long-term phase stability compared to the conventional oscillators.

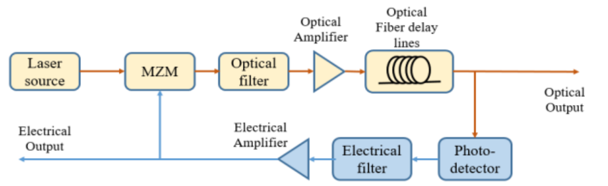


**Fig.4. Basic diagram of Opto-electronic oscillator**

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Operating frequency of OEOs can be as high as 60 GHz [21]. Current research on OEOs mainly focus to reduce size, increasing stability, enabling frequency tenability and Suppressing undesired side modes.

## B. Microwave Photonics Filtering

Filters are the crucial component of Modern Radar systems. The basic function of filters are to remove unnecessary components such as band noise, spurs and interferences. Both analog and digital filters are in use. Microwave photonics filters offer many advantages such as fast and flexible tuning, re-configurability, Broad bandwidth and filter shapes, over traditional electrical filters.

Generally, Microwave photonics filter can be implemented by two ways: Coherent and incoherent filtering operations. Incoherent filters can be further divided based on delay line configuration i.e. Finite impulse response (FIR) and Infinite impulse response (IIR) [11]. A common FIR filtering system consists of an optical laser, an Opto-electronic modulator, a delay line system and a photo detector. The Main component of this set up is optical delay line system, which can be used with different schemes like Fiber Bragg grating (FBGs), a chirped FBG (CFBG), an array waveguide or dispersive filters [13]-[16]. The optical delay lines used to generate the filter tabs. To get the desired result tabs length must be correctly set. Multiple tabs are required to improve Q factor and enhance rejection levels, however increasing tabs numbers and length make it difficult to get high accuracy. Different fiber grating arrays are used to improve system accuracy and flexibility.

## C. Optical Beam Forming Network

Microwave photonics beamforming networks (OBFN) are generally based on optical true time delay lines, which can provide low losses in the system without limiting bandwidth in Radar applications. This advantage can solve the beam squint problem of phase shifter based array. The Essential component of OBFNs are optical delay lines. A simple optical delay lines system made of a laser, optical delay element, an electro-optical modulator and photo detector. Different combinations of optical delay lines are applied and reported to establish squint free beam steering.

## D. Multi-dimensional Multiplexing

Suitable multiplexing technique play a very important role in designing Radar systems. Number of multiplexing methods such as Frequency division multiplexing (FDM), Code division multiplexing (CDM) & time division multiplexing (TDM), are well known for Radar applications. After arrival of Microwave photonics techniques, wavelength division multiplexing (WDM) are employed as suitable option, which harness tens-THz bandwidth of optical system. Another Multiplexing technique, spatial division multiplexing (SDM) is used in microwave photonics systems for signal generation, transmission, filtering & beamforming. The limitation of this technique is due to inter channel crosstalk.

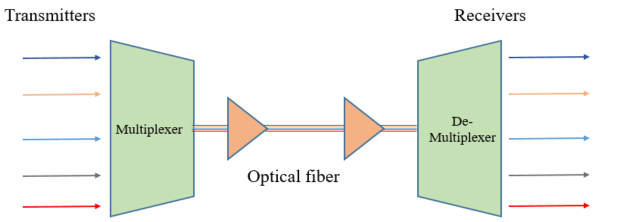


**Fig.5. Basic diagram of wavelength division multiplexing.**

## E. Microwave Photonics Mixing

Frequency mixers are important components in overall Radar systems. At the transmission end, mixers are required to up convert the Intermediate Frequency (IF) band waveform to required Radio Frequency (RF) band whereas at receiver end, mixers change the RF to IF signal to suit ADC requirement. Fig.6 shows basic structure of a mixer.

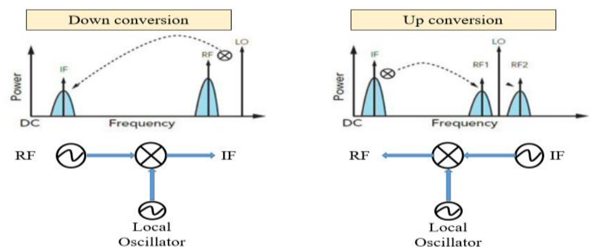


**Fig.6. Typical mixer diagram. RF: Radio frequency, IF: Intermediate frequency**

Ideal mixers should have process large bandwidth signals with low conversion loss, minimum spurious response & high dynamic range but conventional mixers have limited processing capabilities in this regard. Photonics mixers have given new ray of hope due to their advantages, such as large bandwidth, lightweight & high EMI [22].

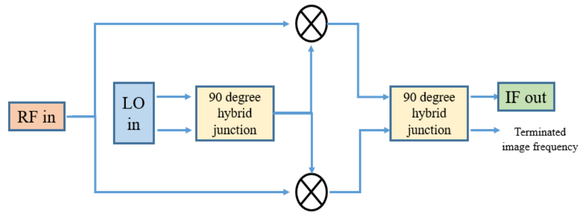


**Fig.7. Image rejection mixer diagram.**

At the output of a mixer, two frequency signals are generated, i.e, $f_{RF} + f_{LO}$ & $f_{RF} - f_{LO}$. Out of two, one is desired signal and another signal, which is called image signal, to be filtered out by special type of mixed called image- reject mixers. Basic diagram of image-reject mixer is given in Fig.7. Image reject mixers can apply wideband coherent cancellation to remove undesired signals by applying optical 90 degree hybrid or Microwave photonics phase shifters, which greatly improves Radar performance by ensuring wideband de-chirping and removing frequency mixing between Radar echoes.

## F. Arbitrary Waveform Generation

A suitable waveform applied to Radar, can make its performance batter.

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Even with advanced waveforms, the Radar systems can improve in spectrum efficiency and enable advanced signal processing. Traditionally systems generate waveforms either by usage of analog oscillators or digital systems. Digital systems offers good flexibility but has limited bandwidth. In modern Radar systems, large time–bandwidth product (TBWP) of laser source are extensively used in Microwave waveforms generation [2]-[3]. These types of waveforms are generally frequency or phase-coded by using digital domain, however, these also have limitations on the carrier frequencies.

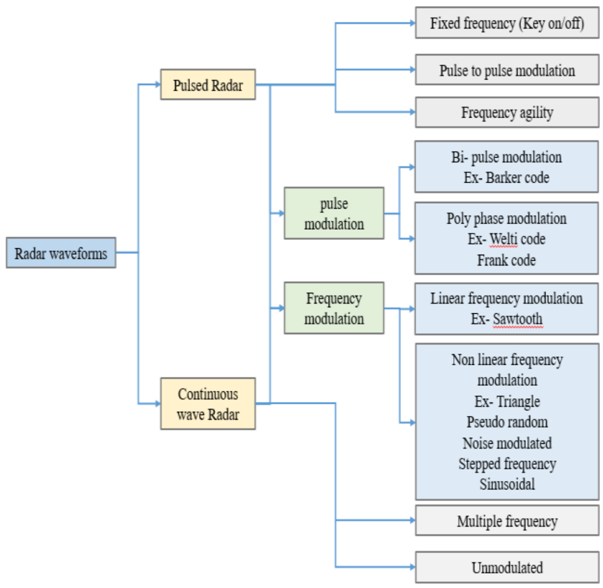


**Fig.8. Methods of Radar waveform generation**

Along with low phase noise, Photonic techniques provides very high bandwidths. Different approaches are applied to generate photonic RF arbitrary waveforms, like spatial to-temporal mapping, wavelength-to-time mapping, and Fourier synthesis based on line-by-line control of optical frequency comb [4], but these techniques also have some limitations. For wavelength-to-time and spatial-to-time mapping waveform generators, the generated waveforms are single-shot pulses, that sometimes not suitable to applications where continuous waveforms are required, whereas Fourier synthesis approach [1] has limitation in reaching low-frequency RF bands. Integrated optical Kerr frequency comb sources, or 'Micro-Combs', has shown in this regard by provide highly coherent multiple wavelength sources for RF applications [4]. Micro-Combs can improve communication system capacity and enable advanced signal processing. They have big advantage over Mode-locked lasers in terms of providing large number of wavelengths. With reduced degree of complexity and footprint, Micro-combs have big potential, which can be harnessed fully.

## G. Co-site Interference Cancellation

Since transmitter and receiver, usually placed vary close in Radar systems, a part of radiated signal from transmitter directly leaked to receiver. This effect or leakage is called co-site interference or self-interference. This leakage seriously affect Radar efficiency.

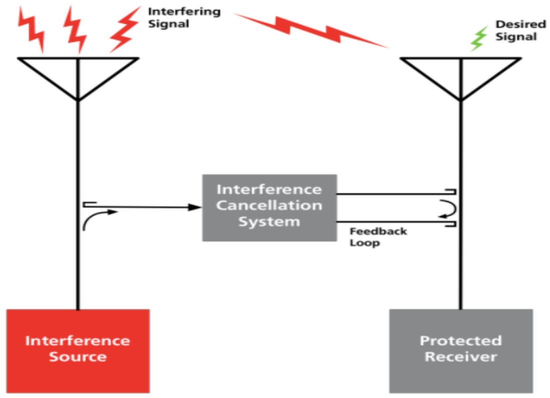


**Fig.9. Basic Interference cancellation system.**

Different systems are employed to remove Co-site interferences. One such example is coherent cancellation method. Nevertheless, these electrical domain cancellation systems, have limitations in terms of frequency and bandwidth, hence Photonics techniques applied to achieve broadband co-site interference cancellation at higher frequencies.

## H. Analog to digital Conversion

Analog-to digital converters (ADC) play a crucial role in Radar of converting the real life analog signals to digital signals in modern signal processing systems. Traditional analog to-digital conversion has mainly two functionalities: 1) Sampling and 2) Quantization. A considerable amount of techniques and research are employed in electronic ADCs (E-ADC) until now, however their overall performance is still limited by timing jitter of the clock source and power consumption in higher bandwidths applications. To overcome E-ADCs capability limitations, photonics techniques were employed. Photonic ADCs offer many advantages in terms of high-speed clocking, Minimal signal's mutual interference, broadband-based sampling and compatibility with Photonic systems [5]-[7]. Analog-to-digital conversion based on Photonics technologies can broadly be categorized into different areas:

a). Photonic assisted ADCs,
b) Photonic sampled ADCs,
c) Photonic quantized ADCs and
d) Photonic sampled and quantized ADCs

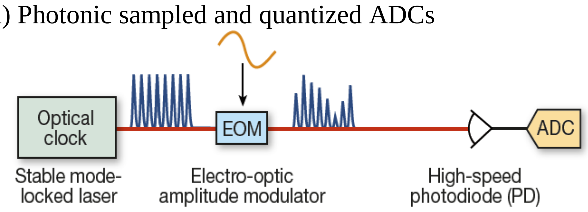


**Fig.10. Photonics assisted ADC diagram. ADC: analog-to-digital converter**

In most of P-ADCs reported until date, either sampling, quantization or both operations are performed in optical domain. However, still most of P-ADCs technologies are presently in development phase and require considerable research efforts.

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One of the most promising P-ADC technology, which has enormous commercial potential, and viability is time-stretched photonic ADCs (TS-PADC). In time stretched photonics architecture, which has generally optical frontend, an ultra-short optical pulse (Usually 100-200 femtoseconds long), that has high optical bandwidth, is time-stretched by dispersing it in a dispersive medium. Different speeds are observed for different wavelengths, when they travel in dispersive medium. Due to this, the resultant stretched pulse frequency changes with time, hence called a chirped pulse. The signal bandwidth which is to be sampled is reduced as much as the stretch factor, thus enabling sampling and quantization at lower bandwidths using E-ADCs.

## IV. RECENT ADVANCEMENT IN MICROVE PHOTONICS

MWP techniques can be applied to different Radar architectures to achieve high resolution & coverage area along with faster speed. Mainly, Radar configurations are divided into two areas, i.e. Monostatic and Multistatic Radar systems, which are widely, studied with Photonics assisted technologies. Monostatic Radar are traditional Radar where transmitter and receivers are collocated, however, different MWP monostatic Radar have been demonstrated in recent past for real time Synthetic aperture Radar (SAR) or Inverse Synthetic aperture Radar (ISAR) imaging, resolution of those systems is up to sub centimeter levels [19]. On the other side, Multistatic Radar, by definition consists of multiple and diversely located Monostatic systems with shared coverage area. Many photonics based distributed Multistatic Radar configurations are studied in the past. Due to advantages like low transmission losses, immunity to EMI and broader capabilities, photonics signal transmission via optical fibers considered the best solution for transmitting the signals between multiple sub-stations in Radar network [17].

### A. Photonics based MIMO Radar

Multiple input multiple output (MIMO) Radar is one of the subsets of Multistatic Radar. Photonics based MIMO Radar are considered a promising architecture in terms of achieving a higher resolution, better direction of arrival estimation, multiple and differently located target tracking and enhanced 2D/3D imaging, due to its signal orthogonal property [20]. Different setups of Photonics based MIMO Radar have been experimentally demonstrated in recent past [23]. The overall architecture of MIMO radar made of nTx transmitters and nRx Receivers, which is also, called MxN MIMO radar. If a target distance is u, mth antenna location is at xT,m and nth receiver location is at xR,n, then nth receiver end signal can be expressed as below:

$$y_n(t) = \sum_{m=1}^{M} x_m(t) e^{j\frac{2\pi}{\lambda}u^T(x_{T,m}+x_{R,n})} \tag{2}$$

Since, each set of values for m (m=1,2,…M) is orthogonal, the information at receiver end can easily be extracted. Signal generation and detection happens in a central unit in MIMO Radar. This centralized unit is connected with multiple remotely located sensors with WDM optical network. Same substructure at centralized units allows data fusion on the acquired signal. Fig 10. Shows a 2x2 Photonics based MIMO Radar system. Since MIMO radar has widely distributed antennas, which required signal synchronization& broader bandwidth along with long-range signal distribution, the capacities of traditional Radar structure were limited in the regard. In the Photonics based structure, generation and distribution is in optical domain, hence provided the greater frequency flexibility along with high quality and large bandwidth connectivity between remotely located sensors. Although Photonics techniques in MIMO Radar have provided wide coverage area and improved angular resolution, however there is an improvement still required in terms of low losses of SNR (Signal to Noise ratio), sensitivity, flexibility and transportability.

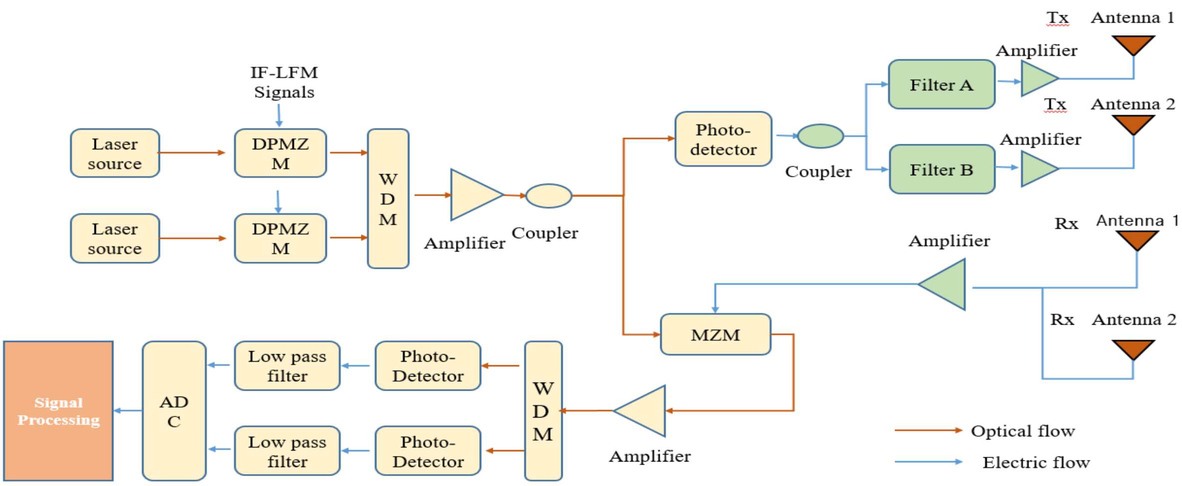


**Fig.10. Diagram of Photonics based 2x2 MMO Radar. DPMZM: dual-parallel Mach-Zehnder modulator; WDM: Wavelength division multiplexer; MZM: Mach-Zehnder Optoelectronic modulator; ADC: analog-to-digital converter.**

## V. RESULT AND DISCUSSION

Modern Radar are required to have much high resolution, consume less power, more reliable, smaller size, lighter Antenna and Versatile [18]. To meet these requirements, Photonics assisted technologies have done excellent work. Field trial of different Photonics based Radar in recent years have demonstrated following benefits 1) Broad bandwidth and large frequency enabled 2D/3D imaging with high resolution; 2) Low phase noise of Photonics based oscillators greatly improved the detection performance; 3) Generation and processing of complicated waveforms for Modern Radar possible due to re-configurability of Photonics techniques; 4) reduction in amount of data requirement in DSP due to optical analog signal processing; 5) Improvement in Signal to Noise ratio (SR) due to high coherence of pulsed laser. Microwave photonics technologies have improved the Radar system capacities a lot and these systems mostly use photonics devices, fiber based systems and optical fibers.

However, these components together with other electronic equipment makes Radar system bulky and less flexible, hence there has been a significant motivation for look for integrated solutions to make systems light weight and less costly with low power consumption. Integrated Microwave Photonics (IMWP) techniques are doing excellent work in this regard. IMWP can use different platforms such as Indium Phosphide (InP), Silicon on Insulator (SOI), Silicon Nitride (Si3N4) and Chalcogenide glass [8].

## REFERENCES


1. Lam Anh Bui. "*A Review of Photonic Generation of Arbitrary Microwave Waveforms*". Progress In Electromagnetics Research B, Vol. 75, 1-12, 2017.
2. Y.Li, A.M. Weiner. *"Recent Advances in Programmable Photonic-Assisted Ultrabroadband Radio-Frequency Arbitrary Waveform Generation*". Unpublished.
3. Jianping Yao. "*Arbitrary waveform generation*". Nature Photonics, Vol.4, Feb 2010.
4. Mengxi Tan, Xingyuan Xu, Andreas Boes, Bill Corcoran, Jiayang Wu, Thach G. Nguyen, Sai T. Chu, Brent E. Little, Roberto Morandotti, Arnan Mitchell, David J. Moss. "*Radio frequency and microwave arbitrary waveform generator based on photonics with a 49 GHz micro-comb source*". Unpublished.
5. Patrick T. Callahan, Michael L. Dennis, Thomas R. Clark Jr. "*Photonic Analog-to-Digital Conversion*". Johns Hopkins APL Technical Digest, Vol. 30, 2012.
6. Sitong Wang, Guiling Wu, Feiran Su, Jianping Chen. "*Simultaneous Microwave Photonic Analog-to-Digital Conversion and Digital Filtering*". IEEE Photonics technical letters, Vol. 30, 2018.
7. S R Abdollahi, H S Al-Raweshidy, T J Owens. "*Pipelined Photonics analog to digital converter*". Journal of Optics, 2018.
8. Reza Maram, Saket Kaushal, José Azaña, Lawrence R Chen. "*Recent Trends and Advances of Silicon-Based Integrated Microwave Photonics*". Photonics, 2019.
9. Lute Maleki. "*The Opto-Electronic Oscillator (OEO): Review and* Recent Progress". IEEE, 2012.
10. Fangzheng Zhang, Shilong Pan. "Microwave Photonics Signal Generation for Radar Applications". IEEE, 2016.
11. Jianping Yao. "*Photonics to the Rescue*", IEEE, 2015
12. Shilong Pan, Yamei Zhang. "*Microwave photonics Radar*". Light wave Technology Journal, 2020
13. S. Preussler, A. Zadok, Y. Stern and T. Schneider. "*Microwave Photonics Filters*". GeMiC, 2016
14. Jose Capmany, Beatriz Ortega, Daniel Pastor. "*A Tutorial on Microwave Photonics Filters*". Light wave Technology Journal, 2006
15. J. S. Leng, W. Zhang, and J. A. R. Williams. "*Optimization of Super-structured Fiber Bragg Gratings for Microwave Photonics Filters Response*". IEEE Photonics technology Letters, 2004
16. Ehsan Hamidi, Daniel E. Leaird, AndrewM. Weiner. "*Tunable Programmable Microwave Photonics Filters based on Optical Frequency Comb*". IEEE Transaction on Microwave Theory and Techniques, 2010.
17. Leonardo Lembo, Paolo Ghelfi, Antonella Bogoni. "*Analysis of a Coherent Distributed MIMO Photonics based Radar Network*". European Radar Conference, 2018.
18. Borowski, Tomasz, Pasternak, Mateusz, Pietrasinski, Jerzy. "*The Photonics Radar: the situation of today and the prospects of the future*". Radioelectronic Systems Conference, 2019.
19. Haojie Wang, Shangyuan Li, Xiaoxiao Xue, Xuedi Xiao, Xiaoping Zheng. "*Distributed Coherent Microwave Photonics Radar with a high precision fiber optic time and frequency network*". Optics Express, 2020.
20. Fangzheng Zhang, Bindong Gao, Shilong Pan1. "*Photonics based MIMO Radar with high resolution and fast detection capability*". Optics Express, 2018.
21. Jian Tang, Tengfei Hao, Wei Li, David Domenech, Rocio Baños, Pascual Muñoz, Ninghua Zhu, José Capmany, Ming Li. "*Integrated Optoelectronic Oscillators*". Optics Express, 2018
22. Dan Zhu, Shilong Pan. " *Photonics based Microwave image-Reject Mixer*". MDPI Photonics journal, 2018.
23. F. Scotti , S. Maresca, L. Lembo, G. Serafino , A. Bogoni, P. Ghelfi. "*Widely distributed Photonics based Dual band MIMO Radar for Harbour Surveillance*". IEEE Photonics Technology Letters, 2020


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