Microwave Photonics

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Abstract -- **Optoelectronics/photonics is integrated with microwave signals for their transmission and processing because low loss wide bandwidth capability of optoelectronics system has become an attractive technology for microwave transmission. The microwave photonics can be defined as the study of optoelectronics devices and system operating at microwave frequency. The key components require for microwave photonics applications include optical sources which can be modulated by high frequency, high speed photo detector, optically control microwave devices and suitable transmission media. Directly modulated semiconductor lasers are used to modulate frequency upto 40 GHz whereas external modulator are used for modulator frequency upto 100 GHz while photo detector operating at 10 THz modulation frequency has been realized. The modulation and transmission in the frequency band between 100 GHz and 10THz is the area of interest. The transmission in microwave band has lot of loss and it can be compensated by using optical communication modulated by microwave frequencies. So combination of radio wave technology and photonics has become a necessity.**

Government of India has installed a national broadband facility in which optical fiber communication is used to transmit data from National Capital to 6000 block centers passing through State head quarters and various cities but there is no solution to connect blocks with Panchyat in various villages. Microwave photonics can provide the above connectivity solution by transmitting data from block centers to various Panchyat through radio waves.

Keywords: Optoelectronics, Microwave, Photonics

I. INTRODUCTION

MICROWAVE signal is modulated using optical carrier frequency for low loss wideband transmission. The signal at the transmitted end is again converted into radio waves & transmitted or else, microwave signal can be transmitted directly to the receiver using single mode/multimode optical fibers.

In one case, the radio waves at receiver end are detected & sent using optical fiber cables over long distances and reconverted at the end into audio/video/data. In another case, the optical carrier is directly sent at receiver end & reconverted into required output such as audio/video/data & text. The block diagram of basic structure of system of microwave photonics is given in figure 1.

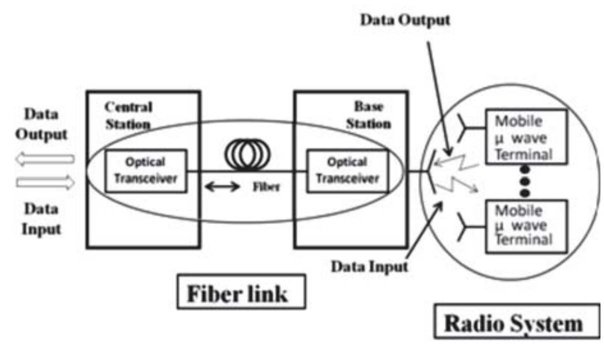


Figure 1. Basic block diagram.

Typical radio-wave application system is illustrated in Fig. 2. Wireless communication link consists of a transmitter (Tx) and a receiver (Rx) as shown in Fig. 2(a), and some kind of object is placed between the Tx and Rx in applications to measurement, testing, and sensing as shown in Fig. 2(b). Now, what happens when we introduce photonic technologies in Tx and Rx?

Figure 3 shows a block diagram of MWP-based transmitter, that is, a photonically assisted radio-wave transmitter. First, the optical (O) signal, whose intensity is modulated at microwave (MW) and/or millimetre-wave (MMW) frequencies, is generated by the optical MW/MMW signal source, and is

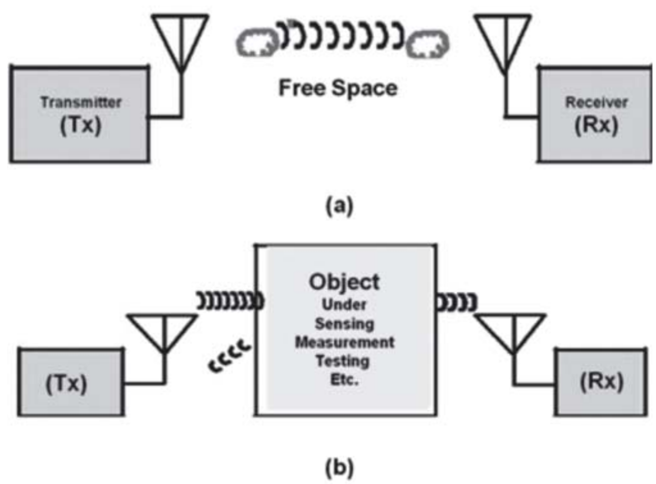


Figure 2. Radio-wave system (a) communication and (b) measurement.

delivered through optical fiber cables, and converted to the electrical (E) signal by a high-frequency O-E converter such as a photodiode. The converted signal is followed by a power amplifier and/or a frequency multiplier, and is finally radiated into free space by an antenna. The antenna unit can be separated and remotely controlled by optical fiber cables.

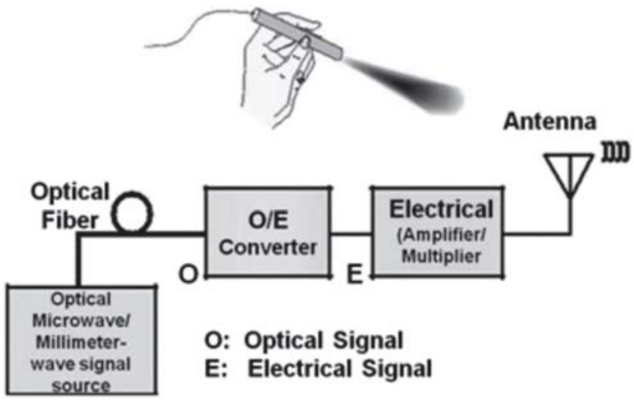


Figure 3. Photonically-assisted MW/MMW Transmitter.

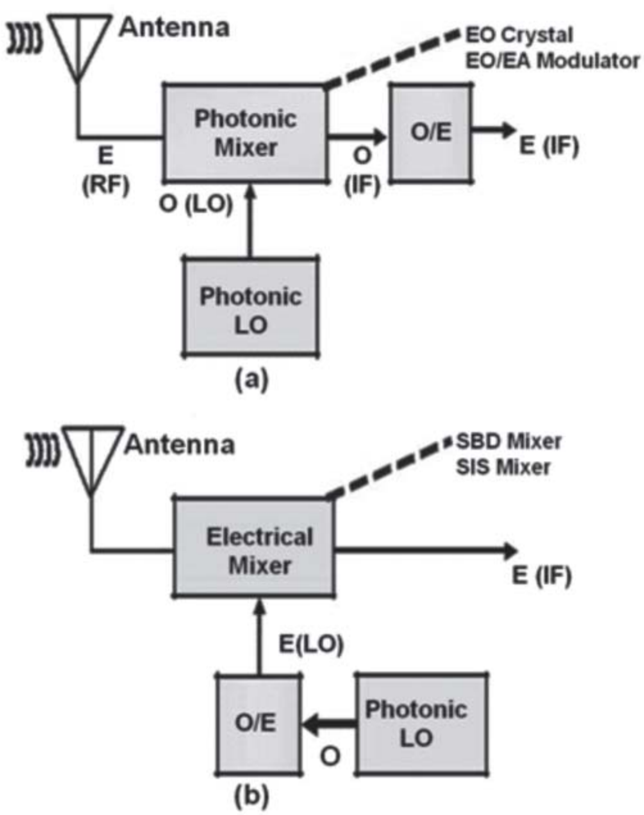


Figure 4. Photonically-assisted MW/MMW receiver.

Figure 4 shows two types of photonically-assisted radio-wave receivers; one employs a photonic mixer pumped by photonic local oscillator (LO) signals. Typical photonic mixer is a bulk electro- optic (EO) crystal, and optical modulator devices such as a $LiNbO_3$ waveguide EO modulator and a semiconductor electro-absorption (EA) modulator. Here, the optical intermediate frequency (IF) signal is converted to the electrical IF signal by a slow photodiode. The other type is based on a nonlinear electrical mixer such as a Schottky-diode mixer, and a superconducting (SIS) mixer. The LO signal is generated by a high-frequency photodiode followed by the optical MW/ MMW signal source, as is used in the transmitter (Fig. 3).

II. ENABLING DEVICE TECHNOLOGIES

As for the optical MW/MMW source in Fig. 3, there are lots of options such as optical heterodyning using two frequency-tunable laser diodes, optical heterodyning using two modes filtered from a multi-frequency (wavelength) optical source or optical frequency comb generator (OFCG), the combination of a continuous-wave (CW) laser with an external modulator, and semiconductor mode-locked lasers (Fig. 5). Low-phase-noise and frequency-tunable optical MMW generators based on the optical heterodyning technique is shown in Fig. 6 [2].

Method	Frequency	Tunability	Stability/ noise
Heterodyning two LDs	Excellent >10 THz	Excellent >10 THz	Bad *frequency drift large linewidth*
CW LD + External modulator	Fair <100 GHz	Fair <100 GHz	Excellent *determined by electronics*
Mode-locked laser diode (passive/active)	Good Passive >1 THz Active 240 GHz	Bad <1 GHz	Excellent *only for active*
Optical comb (OFCG) + Filter	Excellent > 1THz	Excellent >1 THz	Excellent *determined by electronics*

Figure 5. Comparison of CW optical MW/MMW sources.

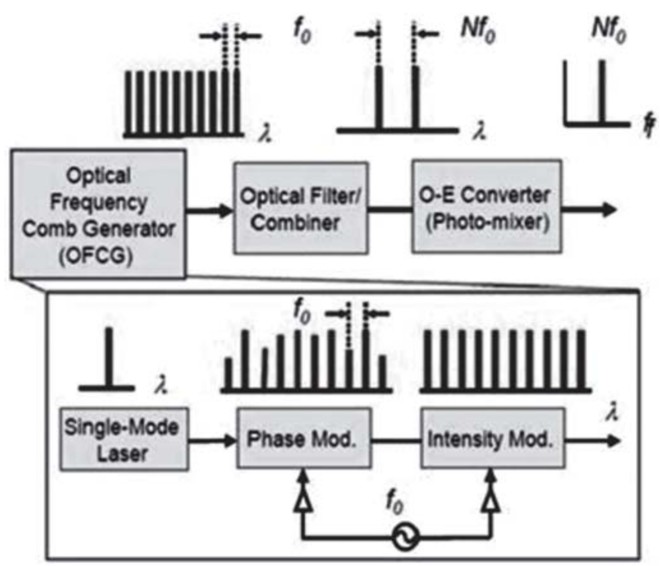


Figure 6. Example of Optical Heterodyning Techniques.

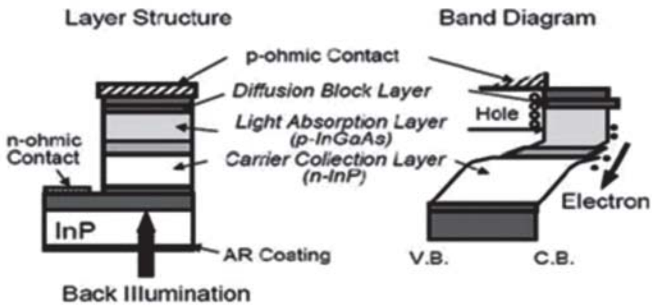


Figure 7. Structure of UTC-PD.

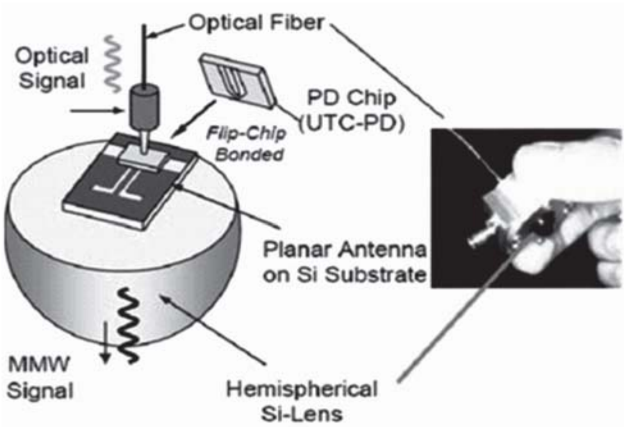


Figure 8. Example of Photonic MMW Emitter.

An O-E converter is a key device in the system. Since optical amplifiers with a high gain of over 30 dB and a large bandwidth of over 1 THz are now readily available, a high-power O-E converter to boost the signal generator performance is needed. An ultrafast photodiode called a uni-traveling-carrier photodiode (UTC-PD), whose band diagram is shown in Fig. 7 [3] is used. Fig. 8 depicts an example of photonic MMW emitter, where the UTC-PD and the antenna are integrated [4].

As a good example of the photonic MMW receiver or detector, the electro-optic (EO) sensor made of a bulk EO crystal offers the largest bandwidth extending to the terahertz frequency region. The operation of the EO sensor is analogous to that of the down-converter in the electronic mixer operation as shown in Fig. 9(a). Fig. 9(b) shows the EO sensor attached to the optical fiber [5]. Highly sensitive EO materials used at an optical wavelength of 1.55 μm are CdTe and DAST. This EO sensor is also applicable to microwave regions, and is proven to be useful in the specific absorption rate (SAR) measurement at cellular phone frequency (1.5 GHz ~ 2 GHz) [5].

III. SYSTEM APPLICATIONS

The photonic MMW transmitter is applied to the 120-GHz-band wireless link system to realize a 10-Gbit/s transmission capacity [6]. Fig. 10 shows a block diagram of the wireless link. A high-gain Cassegrain antenna is used for a long distance (> 1 km) transmission. The wireless link can support the optical network standards of both 10 Gb/s (10.3 Gbit/s) and OC-192 (9.95 Gbit/s) with a bit error rate of 10^{-12}. The above is successful demonstrated in the wireless transmission of 6-channel uncompressed high-definition television (HDTV) signals using the link.

The ultralow-noise characteristics of the photonically generated MMW/THz-wave signal have been verified through their application to the LO for superconducting mixers in receivers used for radio astronomy. Radio-astronomical signals from the universe have been successfully observed using a 97.98-GHz photonic LO [7].

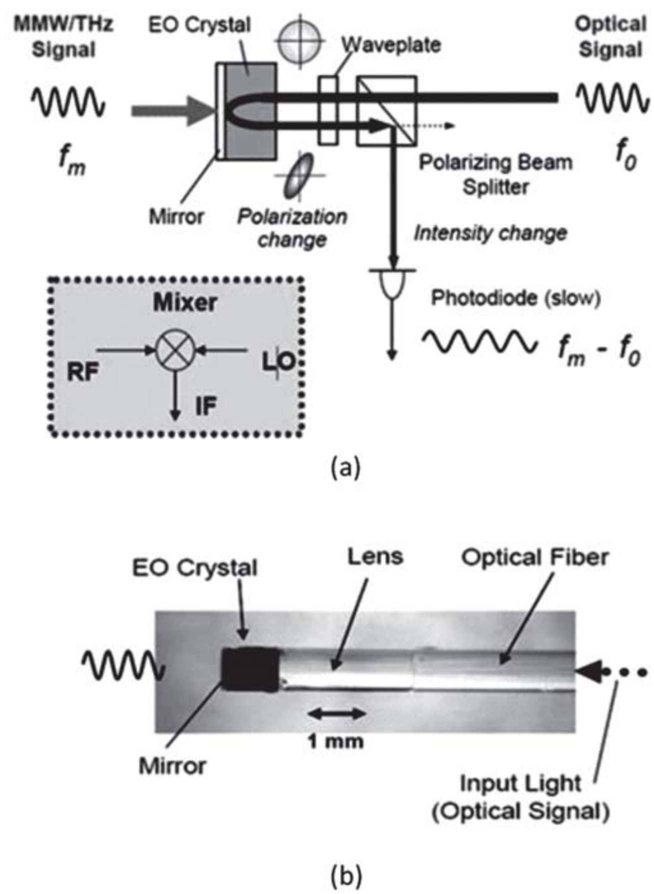
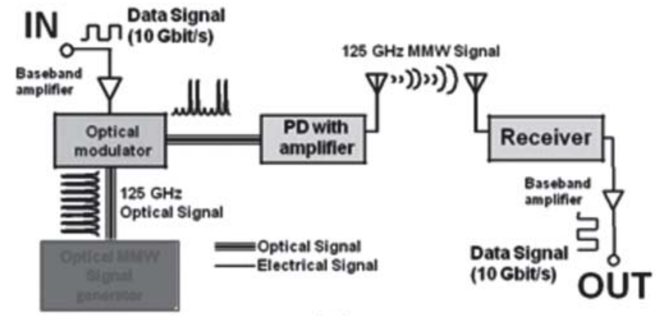
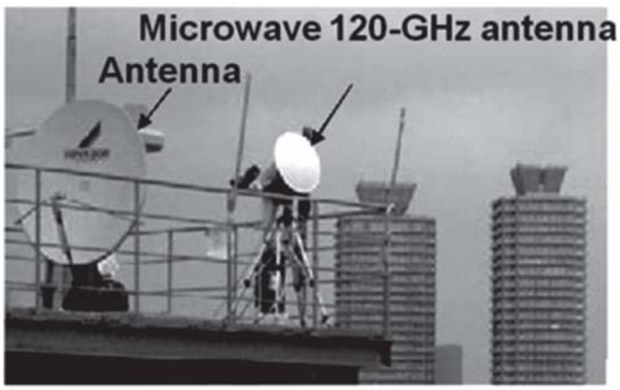


Figure 9. Electro-optic sensor as photonic MMW down-converter, (a) block diagram, (b) example of EO sensor.

A great advantage of photonic LOs in spectroscopic measurement systems is their wide tun-ability. For this purpose, a wideband receiver has been tested with the same combination of superconducting mixers and a photonic LO at frequencies from 260 to 340 GHz [8]. MMWs/THz waves generated by the optical heterodyning using the OFCG and UTC-PD are successfully applied to the spectroscopy measurement [9, 10].



(a)



(b)

(c)

Figure 10. (a) Block diagram of 120-GHz-band wireless link. Photographs of (b) field trial and (c) application scene.

IV. CONCLUSION

A brief overview of microwave and millimeter-wave photonics systems is described alongwith key devices incorporated in the system. The fusion of wireless and optical-fiber-based wired telecommunications technologies will continue to steadily advance in a form that will support the need for high speed communications. Technology for the optical generation and detection of radio waves will become essential for various fields of measurement, as it facilitates the handling of ultra-high-frequency radio waves, which has been difficult with previous technologies.

V. REFERENCES

[1]. A. Seeds, Development of Microwave Antenna at 120 GHz, *IEEE Trans. Microwave Theory and Tech.*, Vol. 50, 2002, pp 877-887.

[2]. A. Hirata *et al.,* Integration of Microwave and photonics Technology, *IEICE Trans. Electron.*, Vol. E88-C, 2005, pp 1458 -1464.

[3]. H. Ito *et al.*, Long Range Communication using optical fibers and RF wave Technology, *IEEE J. Lightwave Technology*, Vol. 23, 2005, pp 4016 - 4021.

[4]. A. Hirata *et al.*, Microwave and Millimeter wave Communication link using photonics, *IEEE Trans. Microwave Theory Tech.*, Vol. 49, 2001, pp 2157 -2162.

[5]. H. Togo *et al.*, Spectroscopy Measurement at RF and MM Wave Frequencies, *IEICE Trans. Electron.*, Vol. E90-C(2), 2007, pp 436 - 442.

[6]. A. Hirata *et al.*, Limitations of Microwave Technology in Long Range Communication, *IEEE Trans. Microwave Theory Tech.*, Vol. 54, 1937 - 1944, 2006.

[7]. S. Takano *et al.*, Traffic Optimization in WDM Optical Networks, *Publ. Astron. Soc. Japan*, Vol. 55, 2003, pp L53 - L56.

[8]. S. Kohjiro *et al.*, trends in Optical Communication in Terahertz Frequency Range, *Tech. Digest of Intern. Workshop on Terahertz Technology*, 18B-6, 2005, pp 119 -120, Osaka.

[9]. H.J. Song *et al.*, Advancements in Microwave Photonics, *Tech. Digest of IEEE/LEOS Summer Topicals 2007*, TuC4.3, July 2007.

[10]. N. Shimizu *et al.*, Convergence of Microwave & Photonics Technology, *Tech. Digest of IRMMW/THz 2007*, Sept. 2007, pp 895- 896.

Prof. (Dr.) S.C. Gupta is a reputed professional in the field of Electronics and Communication. He was awarded PhD from Delhi University and completed Post Doctoral Research from University of HULL, England. He was leader of PPC team deputed by Hindustan Aeronautics Ltd. at Ferranti Ltd, UK in 1980 and 1982. Served in leading industrial public sector undertakings for more than two decades and was Founder Director of Northern India Engineering College, Delhi for 10 years before joining RKGIT as Director (Academics).

Authored four engineering books and published 66 research papers. Successfully developed nine instruments that are being used in India and Europe. Received various awards for outstanding contribution in optoelectronics and excellence in education.