A Photonic Phased Array Using Frequency Quadrupling without Optical Filtering

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***Abstract* - This work demonstrates a millimeter-wave photonic phased array where the input millimeter-wave is generated by a frequency quadrupling technique. The array consists of an external dual-parallel Mach-Zehnder modulator (DPMZM), an optical amplifier and a wavelength-division-multiplex (WDM) coupler. A wavelength-division-multiplexed optical signal from multiple lasers is inputted into the DPMZM and modulated with a 15-GHz radio-frequency (RF) signal to produce a 60-GHz modulation, in which more than 20 dB on optical harmonic distortion suppression ratio is realized without optical filtering. The modulated signal is propagated over an optical fiber is then divided into each feeder of the array by the WDM coupler and de-modulated by photo diodes. This system provides sufficient phase difference without distortion effected by chromatic dispersion of the fiber. The phases are controlled by changing the wavelength of the lasers. A beam shift from -30 degree to 30 degree is achieved by using this system.**

***Index Terms* — Radio-over-Fiber, Beam steering, Array-antenna.**

1. Introduction

Millimeter-wave applications attract much attention to meet the increasing demand for radars and wireless communications. Phased array antennas are necessary for the applications due to the direct and lossy propagation of the millimeter-wave propagation and require true time delay phase shift for beam forming. Optical delay line is an effective means because it can provide broadband signal propagation with low deterioration [1].

On the other hand, some issues limit the use of the optical delay lines for millimeter-wave applications. The first one is that millimeter-wave signal must be converted into optical signal but few modulators can modulate signal over 40 GHz and they are expensive even if possible. In addition, the chromatic dispersion in optical fibers deteriorates the quality of the modulated radio-frequency (RF) signal when the modulation frequency is high. To solve the problems, several millimeter-wave signal generation schemes based on Mach-Zehnder modulator (MZM) have been proposed [2]-[5], where the degradation of millimeter-wave propagation due to the fiber dispersion is avoided.

In this paper, we will demonstrate a photonic phased array antenna based on a wavelength-division-multiplexing (WDM) optical delay line by using one of these schemes. The WDM source is modulated by an external dual-parallel Mach-Zehnder modulator (DPMZM) for quadrupling RF signal. A 15-GHz RF signal is put into the modulator to generate 60-GHz modulation with a harmonic distortion suppression ratio higher than 20 dB without optical filtering. The modulated signal is propagated over an optical single-mode fiber (SMF) is then de-multiplexed into an antenna array and is detected by photo diodes. This system provides sufficient distortion-free delays which are controlled by changing the wavelength of the lasers. A beam shift from -30 degree to 30 degree is achieved by using this system.

2. Concept of Photonic Phased Array Using Optical Frequency Quadrupling

Figure 1 shows the configuration of the proposed photonic phased array. A WDM source is modulated by RF signal and is propagated through a SMF to generate delay. The scheme of the modulation is shown in Fig. 2 [2], where a 15-GHz RF signal is supplied to the two arms of a DPMZM with 90 degree phase difference and two optical signals with opposite phase with each other are combined. This scheme up-converts the RF signal from 15 GHz to 60 GHz where the 15-GHz signal is cancelled out without any optical filter. The optical spectrum is piloted by an optical spectrum analyzer (OSA).

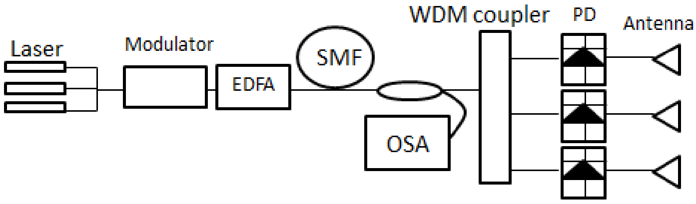

Fig. 1 Photonic phased array system.

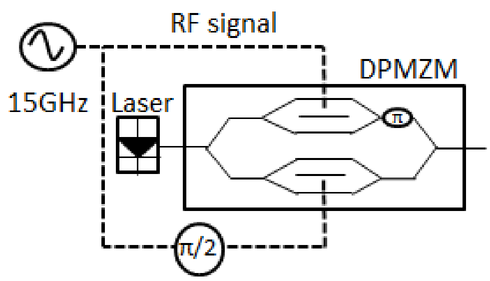

Fig. 2 Modulator with millimeter-wave generation scheme.

The up-converted signal is amplified by an Erbium doped fiber amplifier (EDFA) and propagated over a 20-km single-mode fiber (SMF) whose chromatic dispersion is 20 ps/nm/km so that the delay can be tuned by the wavelength of the input laser by which a change of 0.01 nm makes a shift of 4 ps on RF signal. The up-converted signal is de-multiplexed by a WDM coupler into individual elements of an antenna array and is optic-electric-converted by photo diodes (PDs) and is fed to the array.

To confirm the tunable operation of the system, an array antenna shown in Fig. 3 is fabricated on a liquid crystal polymer (LCP) substrate which has quite low loss at millimeter-wave frequencies. The antenna consists of 3 layers of ground, feeding circuit and patch antennas. 4 lanes of patches are constructed along *x*-axis with each lane consisting of 5 series patches along *y*-axis is fed together via apertures on the ground between the patch-layer and the feeding-circuit-layer [6]. Phase difference between the lanes is produced by lasers with different wavelength and distance between the adjacent lanes is 2.65 mm. In this manner, the radiation beam can be only tuned on *xz*-plane which the radiation directs to z-axis on *yz*-plane at 60 GHz.

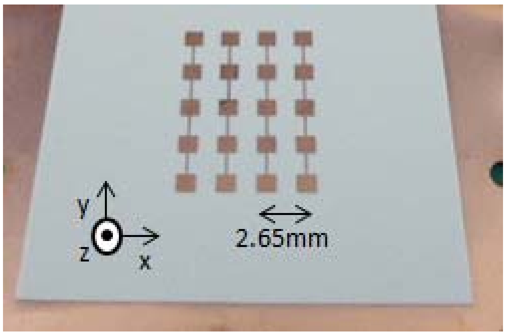

Fig. 3 Fabricated array antenna.

3. Experimental Results

At first, the millimeter-wave generation scheme is demonstrated by measuring the optical spectrum of the modulated optical signal with the OSA, as shown in Fig. 4. A 15-GHz RF signal is put into the modulator to be quadrupled to 60-GHz modulation. It is verified that the optical harmonic distortion suppression ratio exceeds 20 dB for any optical sources. This ratio is high enough that the millimeter-wave signal does not suffer from the fiber dispersion.

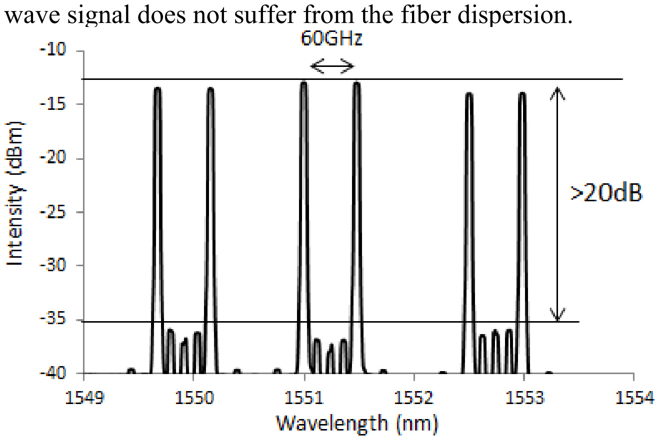

Fig. 4 Optical spectrum of millimeter-wave generation.

With this modulation scheme, the up-converted millimeter-wave signals on multiplexed optical source get a true delay through the SMF and are de-multiplexed by the WDM coupler. The divided signals are optic-electric-converted by PDs and fed to the antenna. Lasers are adjusted to have uniform power to be supplied to the antenna and the bias of the DPMZM is adjusted to keep high suppression ratio. Figure 5 shows the radiation patterns by changing the wavelength of the lasers and quite a good shift on main beam from -30 degree to 30 degree is confirmed.

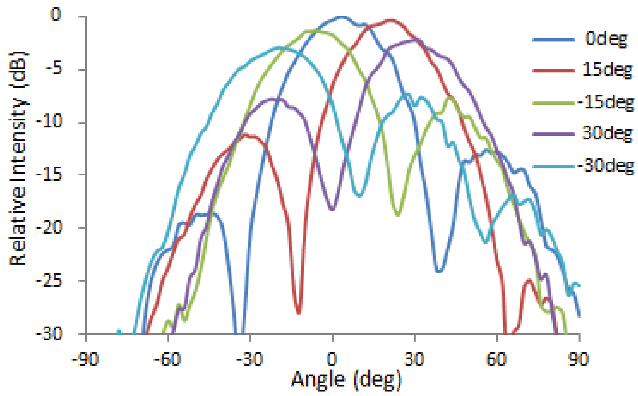

Fig. 5 Radiation pattern of photonic phased array.

4. Conclusion

In this paper, we have demonstrated the millimeter-wave photonic phased array using frequency quadrupling without optical filter. The optical harmonic distortion suppression ratio exceeds 20 dB for any inputted wavelength and little deterioration on quality due to the fiber dispersion is observed. A radiation beam shift from -30 degree to 30 degree is realized by changing the wavelength of the lasers.

References

[1] J. L. Corral, J. Marti, J. M. Fuster, and R. I. Laming, "True time-delay scheme for feeding optically controlled phased-array antennas using Chirped-fiber gratings," *IEEE Photon. Technol. Lett.,* vol. 9, no. 11, pp. 1529-1531, 1997.

[2] C. T. Lin, et al., "Optical Millimeter-Wave Up-Conversion Employing Frequency Quadrupling Without Optical Filtering," *IEEE Trans. Microw. Theory & Tech.*, vol. 57, no. 8, pp. 2084-2092, 2009.

[3] J. Ma, J. Yu, C. Yu, X. Xin, X. Sang, Q. Zhang, "64GHz optical millimeter-wave generation by octuping 8GHz local oscillator via a nested LiNbO3 modulator," *Opt. & Laser. Tech.,* vol. 42. pp. 264-268, 2010.

[4] Z. Zhu and et. al., "A radio-over-fiber system with frequency 12-tupling optical millimeter-wave generation to overcome chromatic dispersion," *IEEE J. Quant. Electron.*, vol. 49, no. 11, pp. 919–922, 2013.

[5] J. Beas, G. Castañón, I. Aldaya, A. A. Zavala, and G. Campuzano, "Millimeter-wave frequency radio over fiber systems: a survey," *IEEE Comm. Surveys & Tutorials*, vol. 15, no. 4, pp. 1593-1617, Fourth Quarter 2013.

[6] D. M. Pozar, "Microstrip antenna aperture-coupled to a microstripline, " *Electron. Lett.*, vol. 21, no. 2, pp. 49-50, 19