

Multi-Band Radio-over-Fiber System using Single Phase Modulator to Support Fixed and Mobile End Users

Jitender Kumar¹, Manisha Bharti², Yogendra Singh³
^{1,3}M.Tech Scholar, ECE Department, AIACTR, Delhi, India
²Assistant Professor, ECE Department, AIACTR, Delhi, India

Abstract- We propose a bidirectional Radio-over-Fiber (RoF) system with multi-band signals generation technique using a single phase modulator (PM). At central office (CO), a PM is used to modulate optical carrier and generated signal is transmitted through a single mode fiber (SMF). At base station (BS), three different signals are generated from the received optical signal, including 60 GHz millimeter wave (MMW) signal, 24 GHz microwave (MW) signal and baseband (BB) signal. Bidirectional transmission is achieved by reusing downlink optical carrier for uplink data transmission, which eliminates the need of optical source at BS. An error-free transmission of 3 Gb/s data through 60 km SMF, is achieved for all the signals. Electrical and optical domain representations are shown at different points and the variations in min. log of BER against received optical power (ROP) are plotted on graph.

Keywords- Radio-over-Fiber; multi-band signals; single optical source; single phase modulator; wireless and wired distribution; millimeter wave signal; hybrid networks.

I. INTRODUCTION

Need of high data rate signals for both wireless and wireline distribution arises to support high-definition video-based services. RoF seems to be the possible solution to distribute these signals through optical fibers. Fig.1, shows a basic RoF system configuration [16], which provides a bidirectional transmission to support full-duplex communication [1]-[2]. Furthermore, millimeter wave technology is an attractive candidate to support multi-gigabit services [3]-[4]. It provides a wide frequency band to distribute high data rate signals. To support different networks the need of hybrid access networks (HAN) arises [5]-[8]. These networks integrate different RoF and fiber to the home (FTTH) architectures to a single distributed infrastructure and enable this system to transmit both radio frequency (RF) and BB signals through a single fiber. In addition, multi-band signals generation techniques further improve RoF and HAN configurations [11]-[15]. These configurations have unique potential to deliver multi-gigabit services to different wireless and wireline applications. In [11], multi-band signals are generated by cascading a PM and a Mach Zehnder Modulator (MZM) with an

assistance of an optical signal-to-noise ratio (OSNR) enhancement circuit for both fiber-to-the-X (FTTX) and RoF networks.. In ref. [13], dispersion-tolerant MMW, MW and BB signals are generated using a dual-port MZM, this dispersion tolerance is achieved by the subcarrier cross-selection. Ref. [14] generated multi-band signal with dispersion-tolerant transmission by utilizing vestigial sideband filtering in combination with optical carrier suppression.

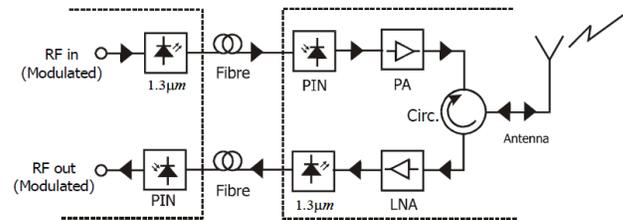


Fig.1: Radio over Fiber system concept

In this work, a bidirectional RoF system, which generates downstream multi-band signals using a single PM is proposed to support different wireless and wireline services. To achieve bidirectional operation, upstream data is transmitted by re-modulating the downlink optical carrier. At CO, downstream data is used to modulate radio frequency (RF) carrier, modulated RF signal is then combined with another RF local oscillator (LO) signal. Combination of these signals is then used to modulate optical carrier with the help of a PM. Generated optical signal is transmitted through a SMF. At BS, received optical signal is used to generate three different signals, including 60 GHz MMW, 24 GHz MW and a BB signal. MMW and MW signals are further used for wireless distribution from BS to mobile unit (MU). Symmetric upstream data is transmitted from BS to CO by re-modulating the optical carrier of downlink signal with the help of MZM. Therefore, there is no need of an additional light source and wavelength management at the BS. This scheme efficiently integrates the new 60 GHz wireless band with 24 GHz wireless and BB wireline services, allowing a system not only to provide multi-gigabit data

and video distributions but also a compatibility to different services.

II. PRINCIPLE OF OPERATION

To generate multi-band signals downstream data is used to modulate an RF carrier (RF1) as shown in fig.2. This RF modulated signal is then combined with another RF LO signal (RF2) using electrical power combiner, which is used to modulate optical carrier (frequency= f_0) with the help of a PM. This modulation generates two pair of sub-carriers, in which two sub-carriers are data sub-carriers at frequencies $f_0 \pm RF1$. These sub-carriers contain data because these sub-carriers are generated by RF modulated signal of frequency RF1 and simply mentioned as $(\pm RF1)$. Other two sub-carrier at frequencies $f_0 \pm RF2$, do not contain any data, because these two sub-carriers are generated by a LO signal of frequency RF2. Generated optical signal is then amplified using erbium doped fiber amplifier (EDFA) and transmitted from CO to BS through a SMF.

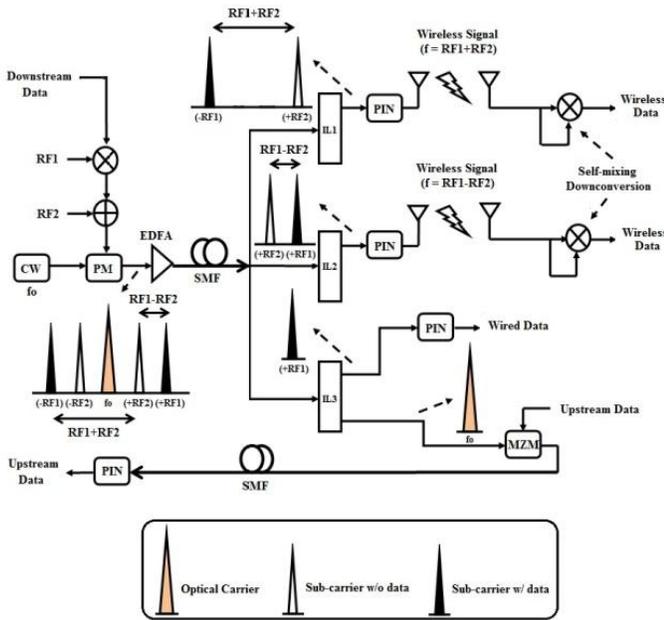


Fig.2: Schematic diagram of multi-band signals generation

At BS, optical signal is received and split into three signal using an optical power splitter. First signal is used to generate a signal of frequency $RF1+RF2$ by filtering $(-RF1)$ data sub-carrier and $(+RF2)$ sub-carrier, which provides a separation $RF1+RF2$ in optical domain. This signal is applied to PIN photodiode, which converts this optical signal into electrical RF

signal of frequency $RF1+RF2$. Electrical signal is then used for wireless distribution. At MU, wireless signal is received and down-converted using self-mixing down-conversion. Similarly, second signal is used to generate a signal of frequency $RF1-RF2$ by filtering $(+RF1)$ data sub-carrier and $(+RF2)$ sub-carrier, which provides a separation $RF1-RF2$ in optical domain. The process from PIN detection to down-conversion is similar as discussed above. From third signal, we separated $(+RF1)$ data sub-carrier and optical carrier at upper and lower port of interleaver (IL3). Data sub-carrier is used for direct BB signal generation and applied to PIN photodiode, which converts this signal into electrical BB signal for wireline distribution. Optical carrier is used for upstream data transmission and applied MZM with symmetric upstream data at its electrical input port. This signal is transmitted from BS to CO and direct detection is used for its demodulation at CO.

III. SYSTEM DESCRIPTION

Fig.3, shows simulation setup of our proposed scheme. The setup is simulated using OptiSystem software. Here, 3 Gb/s downstream data is used to modulate a 42 GHz (RF1) RF carrier, which is then combined with a 18 GHz (RF2) LO signal. This signal is used to modulate optical carrier ($f_0 = 193.1$ THz) with the help of PM. Data sub-carriers are generated at frequencies $f_0 \pm 42$ GHz and the frequencies of without data sub-carriers will be $f_0 \pm 18$ GHz. This optical signal is transmitted through 60 km SMF.

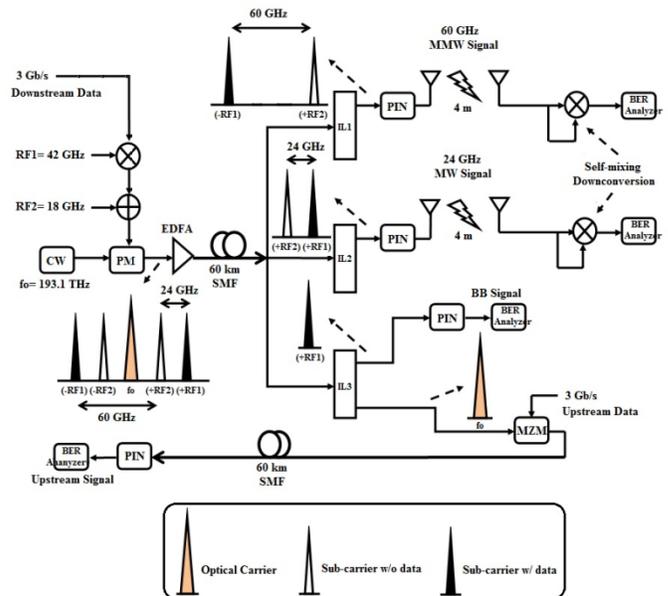


Fig.3: Simulation setup

At BS, optical signal is split into three signals; first signal is used to generate 60 GHz MMW signal by filtering f_o-42 GHz data sub-carrier and f_o+18 GHz sub-carrier, which provides 60 GHz separation in optical domain. PIN diode is used to convert this signal into electrical 60 GHz MMW signal for wireless distribution. Signal is then transmitted for 4 m wireless distance, we used an electrical attenuator of 0.1 dB to represent wireless link (@ 25 dB/km, for a distance of 4 m). At MU, signal is demodulated by self-mixing down-conversion. Similarly, second signal is used to generate 24 GHz MW signal by filtering f_o+42 GHz data sub-carrier and f_o+18 GHz sub-carrier, which provides a separation of 24 GHz in optical domain. Signal is converted into electrical 24 GHz MW signal with the help of PIN photodiode. The process for wireless distribution of this signal is same as discussed above. Third signal is used to filter f_o+42 GHz data sub-carrier and optical carrier at upper and lower port of IL3. Signal from upper port is used to generate BB signal for wireline distribution and applied to PIN diode, which directly converts this data sub-carrier into electrical BB signal. Optical carrier from lower port is applied to MZM with 3 Gb/s upstream data for uplink transmission. Direct detection is used at CO to convert upstream signal into BB data.

IV. RESULTS AND DISCUSSION

Fig.4, shows the output of PM, in which we mentioned the frequencies of optical carrier and four required sub-carriers. The frequencies of unwanted signals are not mentioned here. The sub-carriers we used in this work, are first harmonics generated by the 42 GHz and 18 GHz RF signals. Generation of 60 GHz MMW signal is shown in fig.5. In fig.5(a), 60 GHz separated sub-carriers including f_o-42 GHz and f_o+18 GHz are shown. This is an optical domain representation of signal just before PIN photodiode. When this 60 GHz separated signal is applied to PIN diode, PIN diode converts this signal into 60 GHz electrical MMW signal. The electrical domain representation of generated 60 GHz MMW is shown in fig.5(b). Optical spectrum for generation of 24 GHz MW signal is shown in fig.6(a). 24 GHz separated sub-carriers are shown in this fig. including f_o+42 GHz data sub-carrier and f_o+18 GHz sub-carrier. This optical signal is applied to PIN diode, which converts this signal into electrical 24 GHz MW signal, as shown in fig. 6(b). Fig.7 shows the generation of BB signal, in which f_o+42 GHz data sub-carrier is filtered for direct detection by PIN diode. This data sub-carrier is applied to PIN diode, which converts it into a BB signal, as shown in fig.7(b). Optical carrier of downstream signal is filtered for upstream data transmission as shown in fig.8(a). This optical carrier of frequency f_o , which we

used for downlink transmission, is applied to MZM with upstream data. At CO, optical carrier is applied to PIN diode which converts it directly into BB signal. Electrical spectrum of generated data signal from upstream carrier is shown in fig.8(b).

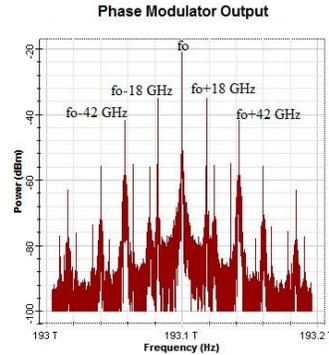
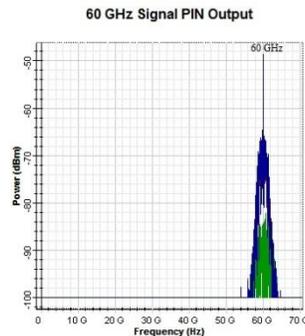
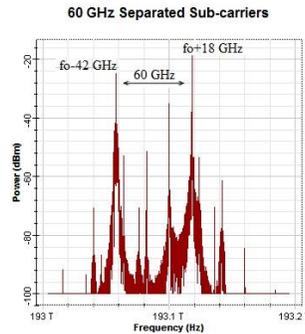


Fig.4: Phase modulator output



(a) (b)

Fig.5: 60 GHz signal (a) Separated sub-carriers (b) PIN output

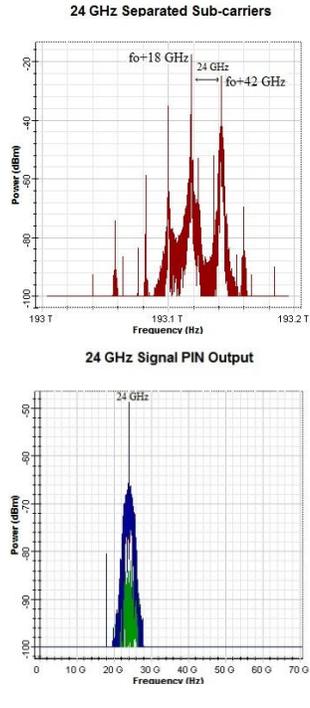


Fig.6: 24 GHz signal (a) Separated sub-carriers (b) PIN output

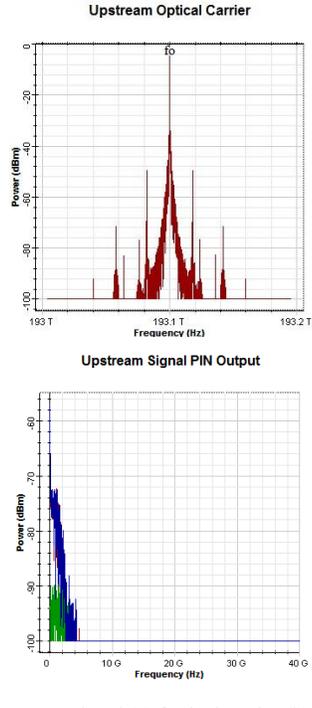


Fig.8: Upstream signal (a) Optical carrier (b) PIN output

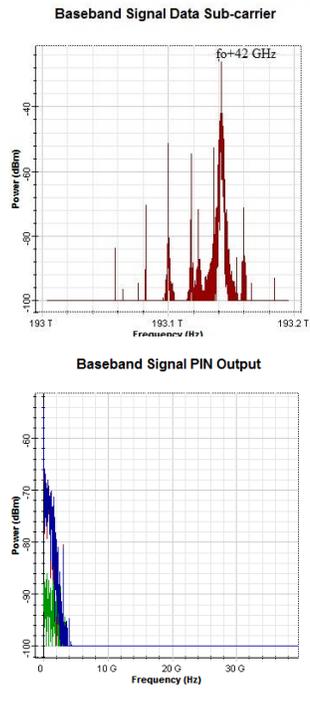


Fig.7: Baseband signal (a) Data sub-carrier (b) PIN output

Variation of min. log of BER against received optical power for all of these signals is shown in fig.9. The values of min. log of BER for 24 GHz MW and BB signals are better than that of other two signals. Also, the slope of 60 GHz curve is minimum, which indicates the min. variation in the value of min. log of BER for the 60 GHz signal in the given range of received optical power.

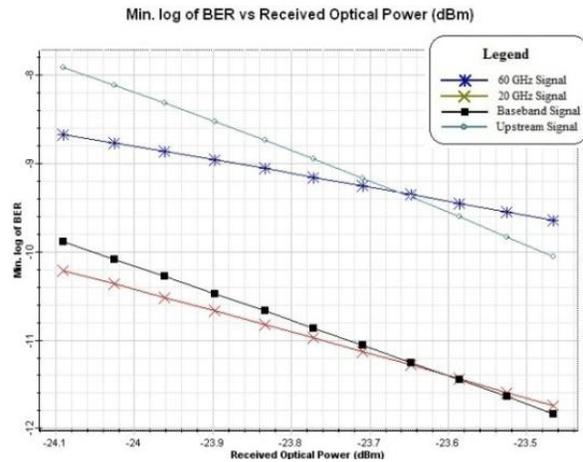


Fig.9: Min. log of BER vs Received optical power

V. CONCLUSION

We propose a bidirectional RoF system using a single PM, to support both wired and wireless services. In this

scheme, high data rate signals are distributed in different frequency bands and serve both fixed and mobile end users. The proposed scheme completely eliminates the need of light source and wavelength management at BS. At BS, downstream multi-band signals are generated by filtering required sub-carriers and uplink data is transmitted by remodulating optical carrier of downlink signal. Successful transmission of downstream 3 Gb/s multi-band signals including 60 GHz MMW, 24 GHz MW and BB signal and symmetric upstream data through 60 km SMF is achieved. The results show that this architecture has an ability to simultaneously feed different applications with high bandwidth, multigigabit signals in future hybrid optical-wireless integrated networks.

REFERENCES

- [1] C. Ye, L. Zhang, M. Zhu, J. Yu, S. He, G. Chang, "A Bidirectional 60-GHz Wireless-Over-Fiber Transport System With Centralized Local Oscillator Service Delivered to Mobile Terminals and Base Stations," *IEEE Photonics Technology Letters*, Vol. 24, No. 22, pp. 1984-1987, November 15, 2012.
- [2] Z. Jia, J. Yu and G. Chang, "A Full-Duplex Radio-Over-Fiber System Based on Optical Carrier Suppression and Reuse," *IEEE Photonics Technology Letters*, Vol. 18, No. 16, pp. 1726-1728, August 15, 2006.
- [3] J. Yu, M. Huang, Z. Jia, T. Wang and G. Chang, "A Novel Scheme to Generate Single-Sideband Millimeter-Wave Signals by Using Low-Frequency Local Oscillator Signal," *IEEE Photonics Technology Letters*, Vol. 20, No. 7, Pp. 478-480, April 1, 2008.
- [4] L. Chen, S. Wen, Y. Li, J. He, H. Wen, Y. Shao, Z. Dong and Y. Pi, "Optical Front-Ends to Generate Optical Millimeter-Wave Signal in Radio-Over-Fiber Systems With Different Architectures," *Journal Of Lightwave Technology*, Vol. 25, No. 11, pp. 3381-3387, November 2007.
- [5] S. Fan, H. Chien, Y. Hsueh, A. Chowdhury, J. Yu and G. Chang, "Simultaneous Transmission of Wireless and Wireline Services Using a Single 60-GHz Radio-Over-Fiber Channel by Coherent Subcarrier Modulation," *IEEE, Photonics Technology Letters*, Vol. 21, No. 16, pp. 1127-1129, August 15, 2009.
- [6] C. Lin, P. Shih, J. Chen, P. Peng, S. Dai, W. Jiang, W. Xue and S. Chi, "Cost-Effective Multiservices Hybrid Access Networks With no Optical Filter at Remote Nodes," *IEEE Photonics Technology Letters*, Vol. 20, No. 10, pp. 812-814, May 15, 2008.
- [7] Z. Jia, J. Yu, G. Ellinas and G. Chang, "Key Enabling Technologies for Optical-Wireless Networks: Optical Millimeter-Wave Generation, Wavelength Reuse, and Architecture," *Journal of Lightwave Technology*, Vol. 25, No. 11, pp. 3452-3471, November 2007.
- [8] C. Lin, J. Chen, P. Peng, C. Peng, W. Peng, B. Chiou and S. Chi, "Hybrid Optical Access Network Integrating Fiber-to-the-Home and Radio-Over-Fiber Systems," *IEEE Photonics Technology Letters*, Vol. 19, No. 8, pp. 610-612, April 15, 2007.
- [9] V. Urlick, F. Bucholtz, P. Devgan, J. McKinney and K. Williams, "Phase Modulation With Interferometric Detection as an Alternative to Intensity Modulation With Direct Detection for Analog-Photonic Links," *IEEE Transactions On Microwave Theory And Techniques*, Vol. 55, No. 9, pp. 1978-1985, September 2007.
- [10] F. Zeng and J. Yao, "Investigation of Phase-Modulator-Based All-Optical Bandpass Microwave Filter," *Journal Of Lightwave Technology*, Vol. 23, No. 4, pp. 1721-1728, April 2005.
- [11] C. Y. Li, H. S. Su, C. H. Chang, H. H. Lu, P. Y. Wu, C. Y. Chen and C. L. Ying, "Generation and Transmission of BB/MW/MMW Signals by Cascading PM and MZM," *IEEE, Journal of Lightwave Technology*, Vol. 30, No. 3, pp. 298-303, February 1, 2012.
- [12] H. Chien, Y. Hsueh, A. Chowdhury, J. Yu and G. Chang, "Optical Millimeter-Wave Generation and Transmission Without Carrier Suppression for Single- and Multi-Band Wireless Over Fiber Applications," *IEEE, Journal of Lightwave Technology*, Vol. 28, No. 16, pp. 2230-2237, August 15, 2010.
- [13] Y. Hsueh, Z. Jia, H. Chien, J. Yu and G. Chang, "A Novel Bidirectional 60-GHz Radio-Over-Fiber Scheme With Multi-band Signal Generation Using a Single Intensity Modulator," *IEEE Photonics Technology Letters*, Vol. 21, No. 18, pp. 1338-1340, September 15, 2009.
- [14] Z. Jia, J. Yu, Y. Hsueh, A. Chowdhury, H. Chien, J. Buck and G. Chang, "Multi-band Signal Generation and Dispersion-Tolerant Transmission Based on Photonic Frequency Tripling Technology for 60-GHz Radio-Over-Fiber Systems," *IEEE, Photonics Technology Letters*, Vol. 20, No. 17, pp. 1470-1472, September 1, 2008.
- [15] K. Ikeda, T. Kuri and K. Kitayama, "Simultaneous Three-Band Modulation and Fiber-Optic Transmission of 2.5-Gb/s Baseband, Microwave-, and 60-GHz-Band Signals on a Single Wavelength," *Journal of Lightwave Technology*, Vol. 21, No. 12, pp. 3194-3202, December 2003.
- [16] N. Anthony, "Radio-over-Fibre Technology for Broadband Wireless Communication Systems," Eindhoven, June 2005.