A Photonic Based Multiband Signal Generation, Transmission and processing for 5G ROF front-haul

C. Kavitha1, C. T. Manimegalai2*

1,2 Department of Electronic and Communication Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur 603 203, Chennai, Tamil Nadu, India
Email: 1kavithac@srmist.edu.in, 2*manimegc@srmist.edu.in

Abstract. This work proposes the generation of multi-band K-band, V-band, W-band of millimeter-wave (mm-wave) and its transmission performance through the standard SMF of various lengths. The optical frequency multiplication (OFM) principle is used for multi-band signal generation by the optical modulator's non-linear characteristic. The frequency doubling, quadrupling, and six-tupling are done for multi-band generation. The generated multi-band is modulated with downlink data at the central station and transmitted through the conventional Radio over Fiber (RoF) network. The received signal is photo-electrically converted by heterodyne mixing with the local oscillator according to the user's requirement. The transmission performance is analyzed at the receiver end for varying lengths of SMF. The simulation analysis result shows that the RoF system holds good for multi-band transmission of 30, 60, 90 GHz for about 40 km. The power penalty for 30, 60, 90 GHz signal from B-T-B to 40 km is -3.79 dB, -4.847 dB, -6.33 dB.

Keywords: Radio over Fiber, multi-band signal, optical frequency multiplication, mm-wave, optical tunable filter.

1. Introduction
Increasing data rate demands an increase in the bandwidth requirement for combating the number of customers. The evolution of new technology infuses high-quality data like HD video, interactive gaming, video conferencing. This requires high bandwidth for the upload and download of huge data rates. This gives rise to the evolution of a new network access system that supports high data rates and great flexibility.

1.1. Radio over Fiber
Potential technology enabling high data rate communication with freedom of mobility. Multiband RoF system Architecture is shown in Figure 1. The RoF is the integration of a high data rate supporting optical fiber communication and highly flexible wireless communication. The radio over fiber provides a network for high-frequency radio signal through fiber and the high-frequency radio signal transmission through an antenna to the user [1]. Each existing cell is split into a smaller cell and connected through a fiber network. The smaller cells communicate between them self through antennas and provide flexible network access to high data rate signals. The high-frequency signals are used for the data communication between the cells. Conventionally mm-wave of 60 GHz is of great
attention as 7 GHz of unlicensed bandwidth is capable of huge capacity for high data rate [2]. Thus, the RoF system enables high data rate communication flexibly to support mobile users with high bandwidth.

Figure 1: Multiband RoF system Architecture

1.2. Multiband Signal Generation
The high-speed internet access, TV broadcast, FTTH, IP telephony for home and office network organization, and other multimedia services require multiservice bandwidth. The mm-wave, which has a huge bandwidth, is capable of multiservice facility [3]. The optimum usage of mm-wave multi-band signal may ensure multiservice to the geographically distributed users by existing infrastructure, reducing the expenditure [4]. The transmission allows a single administrator to manage, program, and optimize the throughput and implement a troubleshooting algorithm for multiservice applications.

1.3. Proposed Model
The proposed system generates the multi-band signal and transmits it through the fiber to the receiving end. The multi-band generation is done at the central station (CS) by the principle of optical frequency multiplication. The local electrical oscillator is used to generate multi-band by the non-linear characteristics of the optical modulator [5]. The Mach Zehnder Modulator (MZM) is biased for the generation of frequency doubling, quadrupling, sextupling multi-band. Each band has two sidebands with suppressed carriers [6]. The data can be OSSB modulated on 1 side bands and transmitted through the network [7]. At the base station (BS), modulated data is converted into photocurrent [8] by a photo detector. The opto electrical conversion takes place by heterodyne beating between the sidebands generated. The generated data modulated electrical mm-wave frequency, transmitted [10] to the user end by the antenna [11] For analysis purposes, the signal is down-converted and evaluated based on BER, received power, and the receiver’s power penalty[12].

2. Design Schematics And Principle Of Operation
The Laser Diode (LD) with central frequency 193.1 THz is used as the optical source for multi-band generation. The optical source is fed to the MZM biased at maximum transmission point for the generation of sidebands which are doubled, quadrupled, sextupled of RF local oscillator frequency. The two sidebands with positive and negative values are generated. The multi-band is located at 193.055 THz, 193.085 THz, 193.115 THz, 193.145 THz. The upper sideband at 193.145 THz is separated by an FBG and modulated by downlink data. A PRBS generator generates the downlink data of 10 Gbps with a word length of 2^7-1. The LN-MZM is fed with downlink data, and the upper sideband is the optical carrier signal for the multi-band generation. The MZM is biased for optical single-sideband modulation, Table 1 gives the simulation parameter for the system. The bias voltage of half the switching voltage is applied at the maximum transmission point [8]. The OSSB reduces the
cross talk between the sidebands, and hence the dispersion is avoided. The modulated signal is coupled with the un-modulated sidebands with an optical coupler.

![Figure 2: Design schematic of Multiband radio over fiber system](image)

### 3. Results and Discussions

EDFA amplifies the coupled signal. Design schematic of Multiband radio over fiber system shown in Figure 2. The amplification compensates for the fiber attenuation by EDFA of 20 dB. The signal is received at the base station (BS) and converted to an electrical signal by a photodiode. The heterodyne beating of the data-bearing sideband with the un-modulated sideband generates the electrical mm-wave

| Table 1: System Configuration |
|--------------------------------|
| **Parameter**                 | **Value**       |
| Central Frequency of Laser Diode | 193.1 THz       |
| Power of Laser Diode           | 0 dBm           |
| Switching voltage of MZM1      | 4 V             |
| Bias voltage1 of MZM1          | 0 V             |
| Bias voltage2 of MZM1          | 4 V             |
| Local oscillator frequency     | 15 GHz          |
| The bit rate of the PRBS Generator | 10 Gbps       |
| Order of PRBS                  | 27-1            |
| Switching voltage of MZM2      | 4 V             |
| Bias voltage1 of MZM2          | 0 V             |
| Bias voltage2 of MZM2          | 4 V             |
| The gain of Optical filter     | 20 Db           |
| Length of the fiber            | 0-50 km         |
| Attenuation factor             | 0.2 dB/km       |
| Dispersion co-efficient        | 16.75 ps/nm/km  |
| Responsivity of photodiode     | 1 A/W           |
| The dark current of the photodiode | 10 nA         |

The electrical photocurrent is amplified and transmitted through the user end via an antenna. At the user end, the tunable band pass filter of 30 GHz, 60 GHz, 90 GHz is used to extract the desired
signal [13]. The extracted signal is coherently demodulating a tunable oscillator of 30, 60 GHz, 90 GHz for estimating transmission performance.

**Figure 3:** (a) Eye diagram at 40 km for 30 GHz (b) Eye diagram at 40 km for 60 GHz (c) Eye diagram at 40 km for 90 GHz

**Figure 4:** Received Power vs. BER for 30GHz

**Figure 5:** Received Power vs. BER for 60GHz
Figure 3 a-c shows the eye diagram for 30 GHz, 60 GHz, 90 GHz after 40 km. The eye diagram shows that the eye-opening is clearer even at a bit rate of 10 Gbps which shows the high-frequency influence in long-distance transmission. The high-frequency component gives a wide eye-opener for the same distance [14]. The distortion may occur for high-frequency components, which is evident by the upper eyelids dispersion. The power penalty for 30 GHz, 60 GHz, 90 GHz up to 40 km is given by -3.79 dB, -4.847 dB, -6.33 dB, respectively. The BER increases with a decrease in received optical power and increasing fiber length. It is also observed that the power penalty decreases with an increase in frequency [15]. The carrier suppression ratio for the higher frequency is less, which in turn improves the signal power. Figure 4, 5 and 6 illustrates the increase in BER with increased transmission distance. The higher frequency carrier is well capable of better transmission compared to the lower frequency carrier for a distance of up to 40 km. The transmission of multi-band does not include any dispersion compensation. When considering the appropriate dispersion compensation technique, the transmission quality and the transmission distance can be further improved.

4. Conclusion
RoF system for multi-band signal generation and transmission for a maximum transmission distance of 40 km is evaluated. The band of 30 GHz, 60 GHz, 90 GHz is generated by the ODSB modulation scheme. The downlink data is modulated and transmitted through SMF. The optical modulator is configured for an OSSB modulation scheme to modulate the downlink data. The OSSB modulated multi-band data is transmitted through fiber and received at the BS. Simulation analysis is used to measure the received signal's output. The proposed RoF system retains an appropriate BER for 40 kilometers, according to the report. Non-linearity is overlooked for now, although this can be modified in the future.

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