Frequency sextupling millimeter wave generation by using lithium niobate mach zehnder modulator without an optical amplifier

P K Anand Prem 1*, C Pranit Jeba Samuel 2, S Nagaraj 1, Subhashree G R 4
S Albert Alexander 5

1Assistant Professor, Department of Electronics and Communication Engineering, Sri Venkateswara
College of Engineering & Technology, Chitoor, Andhrapradesh, India.
2Assistant Professor, Department of Electrical and Electronics Engineering, K.Ramakrishnan College
of Technology, Trichy, Tamilnadu, India.
4Associate Professor, Department of Physics, M.G.R University, Chennai, Tamilnadu, India.
5Associate Professor, Department of Electrical and Electronics Engineering, Kongu Engineering
College, Perundurai, Tamilnadu, India.

*Email: anandprem.2008@gmail.com

Abstract. The millimeter wave (mmw) based optical networks have been considered as the most
promising solution to increase the capacity, coverage, bandwidth and decreasing cost for next
generation access networks. The optical fiber technology utilizing mmw band is an attractive way to
provide higher signal bandwidth and overcome congestion. In the present era the frequency having less
bandwidth is used in the communication technology which increases the time delay. The proposed
scheme is used to generate mmw with an applied voltage of 7 V for a distance of 50 km and data rate of
6 Gbps is achieved by using a Lithium niobate Modulator without an optical amplifier and filter. The
carrier suppression scheme used in the LiNbO3 modulator act as a optical filter so that the complexity
of the system is reduced. As the modulator helps to increase the frequency of the input signal to achieve
a long distance transmission through an single mode optical fiber the number of optical amplifiers can
also be reduced. To verify the robustness of the setup the visualizers are used which ensure the data
quality.

Keywords: Millimeter Wave Generation, Carrier suppression scheme, Sextupling, LiNbO3 modulator,
Optical Filters, Single mode optical fiber, Visualizer

1. Introduction
Nowadays demand for high broadband data transfer between devices is ubiquitous and hence requires
specialized communication techniques [1]. Optical communication (OC) seems to be a promising
candidate to support the ever increasing demand for broadband connectivity [2-4]. OC is preferred over
other communication methods due to its tolerance to lightning, electro-magnetic interference (EMI) and its flexibility to extend the bandwidth for data transmission [5]. OC fibers can transmit data in the form of light for long distance without using any active optical taps hence data loss will be less[5]. Even when multiple optical fibers are employed in parallel, the possibility of cross-talk is less compared to others [6-8]. It is evident that conversion of electrical signals into optical signals is mandatory for data transmission through optical fibers. Hence generation of optical millimeter wave (mmw) from RF wave is a potential area for research. Wide frequency tenability, system reliability and high spectral purity are the advantages of mmw [9]. The features of the optical signal generated can be appraised by means of optical visualizers. The objective of the proposed work is to design robust and cost effective models which generate optical sextupling mm wave frequency with low cost, reliability and ease of maintenance. The system proposed may be a stepping stone to 5G technology.

2. Experimental Setup

The proposed system consists of a central station (CS), guiding medium and a Base station (BS). The CS act as the transmitter which transmit the data in the form of light. The light signal is produced by the continuous wave laser source having a frequency of 193.1 THz. The information is provided by the pseudo random signal generator with the help of a non return to zero (NRZ) device which helps to give the data in the form of digital signal to the light source. The data rate 6 Gbps is setup in the CS and a carrier signal is generated to carry the message signal to achieve long distance transmission. The carrier signal is generated with the help of signal generator. The figure 1 shows the setup arrangement in the central station for the generation of mmw. In the figure it is observed that the laser signal, signal generator, and NRZ out are given as the input to a mach zehnder modulator (MZM). In the MZM all the signal join together and due to the carrier suppression scheme used in the MZM the output signal from the modulator achieves frequency multiplication. The MZM used in the proposed system is LiNbO3 modulator which helps to increase the frequency of the input signal by its reflection process. The LiNbO3 is a crystal which will act as a mirror to reflect the light signal inside the device and performs stimulated emission from the voltage applied to the modulator.

The voltage given to the modulator to achieve sextupling frequency is 7 V hence the input signal is multiplied by 6 times. The carrier suppression scheme used in the LiNbO3 modulator helps to reduce the number of filters used in the traditional communication system. The bandpass filter is used in the most of the communication design to prevent unwanted signal get into the system to increase the signal quality.[10]

![Figure 1. Block diagram for the Central station](image-url)
As the voltage applied to the modulator the aforementioned technique will pass only the desired frequency carrier signal thus required frequency can be generated in the central station. The generated signal is verified by using an optical spectrum visualizer connected to the output of the LiNbO3 modulator and verifies the generated signal. The input given to the central station is 10 GHz and the output produce by the system is 60 GHz which refers that frequency sextupling is achieved in the transmitter section. [11]

![Figure 2. Transmission Medium](image)

The signal generated from the central station is having frequency multiplication of six from the given input and this signal is transmitted through an optical fiber. The optical fiber will act as a guiding medium and the fixation of fiber length is an important section in the proposed method. The information is transmitted for a distance of 50 km through single mode fiber then the output from the fiber is verified by using optical spectrum analyzer which is shown in figure 2. The result obtained from the central station and the signal received through the guiding medium is verified to prove that the power of the carrier signal is maintained throughout the 50 km fiber.[12]

![Figure 3 Base station mode-single](image)

The optical spectrum obtained in the visualizer is the range of frequencies contained in the signal. In the proposed system the both optical spectrum visualizer shows the similar output hence it is proved that through a 50 km fiber the carrier mmw has the ability to carry the message signal with better signal strength. In the base station a photodiode (PD) is used to convert the optical signal into electrical signal which given as the input to the different analyzers to prove that the quality of the signal obtained in the proposed system is better shown in figure 3. The result from the radio frequency (RF) analyzer and the eye diagram analyzer gives more novelty to the design for the generation of mmw from the input micro wave frequency,[13-15].
3. Result and Discussion

The mathematical analysis for the proposed setup is carried out by using the Bessel function. Let us consider cosine signal as the carrier wave form which is expressed as

\[ \cos (2\pi fct + \beta \sin (2\pi fmt)) = \cos(2\pi fct) \cos(\beta \sin (2\pi fmt)) - \sin(2\pi fct) \sin(\beta \sin (2\pi fmt)) \]  

(1)

The equation 1 can be written in the odd and even signal form by using the Bessel function identities.

\[ \sum_{n \ even} J_n(\beta) \cos(2\pi (f + nfm)t) \]  

(2)

The equation 2 shows the even order side band and

\[ \sum_{n \ odd} J_n(\beta) \cos(2\pi (f + nfm)t) \]  

(3)

The equation 3 shows odd order sideband. The odd order side band is neglected due to the less immunity to the noise which leads to distortion effect and attenuation losses hence the even order side bands are considered for the communication system.

In the proposed system the voltage applied is 7 V hence the carrier frequency increased with the help of modulator and thus undesired even order side bands are suppressed. The signal which is projected shown in figure 5 indicates the width of the spectrum to identify the information carrying capacity of the carrier signal. Hence the output voltage carrier frequency achieved is expressed as

\[ V_{out}(t) = \sum_{n \ even} J_n(\beta) \cos(2\pi (6f + nfm)t) \]  

(4)

The equation 4 shows the generated carrier frequency obtained from the support of optical spectrum visualizers results. From the above expression it is verified the carrier frequency is 6 times multiplied hence proves that the proposed system generate sextupling frequency with improved efficiency.[16-18]
The result plays the supporting role for the proposed system hence the optical spectrum visualizer output is shown in the figure 5. The spectrum output is taken from the base station and it proves that the optical spectrum output from the central station and the base station are same, hence the generated mmw is verified. As the modulator is having a carrier suppression scheme the undesired even order side bands are suppressed and the essential frequency is transmitted. The voltage applied in the modulator is 7 V hence by observing the optical spectrum the generated frequency band is identified.

Figure. 5. Optical Spectrum for 60 GHz mm wave

The horizontal line denotes frequency in Hertz (Hz) and the vertical line denote power in decibels in one milliwatt (dBm). The two projected line shows the optical mmw generated in the proposed system and other projected lines are the suppressed bands. The suppressed band has less power of -40 dBm which is not used for 50 km fiber length data transmission. The projected bandwidth has the power of -24 dBm which shows better performance through a 50 km optical fiber. As by the observation of power it is verified that the projected lines are having better strength to achieve long distance transmission. Then again go for more information from the graph it is identified that the frequency range from left side band to right side band is 193.8 THz to 193.2 THz, [19-21]. The difference between the two frequency band is 6 thus it proved that the system achieved sextupling by increasing the frequency to 60 GHz from 10 GHz input. The identification carried out by using the optical spectrum graph confirms that the carrier signal is 6 times multiplied and generated sextupling mmw. In the base station the optical spectrum is used in the output area of the fiber because the input
signal of the optical spectrum analyzer has to be a light signal. Then the carrier signal with data reached to
the base station is passed to the photo detector. In this mode the optical domain is changed to electrical
domain and it is then directed to the RF spectrum visualizer. The figure 6 shows the electrical spectrum
analyzer graph which gives support to the graph obtained by the optical spectrum visualize.

![RF Spectrum for the proposed system](image)

**Figure 6.** RF Spectrum for the proposed system

The carrier signal transmitted from the central station after a 50 km distance it needs to be proved
that the signal strength of the carrier signal is not affected by the parameters like propagation loss,
scattering loss and fading effect. To confirm this only first the received signal from the fiber is given to
the optical spectrum and then the signal is directed to the photodiode then to RF visualizer. In the optical
spectrum analyzer it is verified that the required mmw is achieved even though it has to be proven in the
electrical domain also. It is done with the help of RF spectrum analyzer in that visualizer it is observed
that in the frequency scale the graph is formed in the 60 GHz space. As per the optical spectrum analyzer
the RF is also verifies the graph between power and the frequency but it is in the electrical province. By
the two visualizer outputs the proposed system proves to be generated sextupling mmw.[22-24].

The carrier frequency generated is verified successfully by using the optical and RF spectrum
graph. The main objective of the carrier wave is to carry the information safely from the central station to
base station without any bit error. On the way to the receiver the message signal may suffer from
unwanted noise signal obtained before the message signal is converted into optical signal. The advantage
of optical fiber is it will restrict the cross talk and interference obtained due to noise signal.
When the fiber length increases the chances like fading effect may occur this effect will increase the loss of the data signal. The carrier signal is verified like that the quality of message signal also needs to be checked. The quality of the message signal is identified by using eye diagram analyzer shown in the figure 7. The excellence of the information signal is identified using the eye diagram. The parameter used to check the performance of the system is eye height in which the lower and upper band should be wide enough. If the graph shows wide opening of the eye structure then it is verified that the proposed system shows error free performance. In the design three visualizers like optical spectrum analyzer, RF analyzer and eye diagram analyzer are used to determine quality of the received signal in the base station which successfully proved that the system performs well in the communication technology for the generation of mmw.[25-26]
In a communication system the carrier and the message signal should perform equally then only the received signal considered as the better quality signal and can be used for different applications. If the both signal shows different signal strength then the new design for communication has no use. By keeping this as the basic concept an experiment is done between fiber length versus eye diagram analyzer in the proposed system. Here the fiber length is starting from 10 km to 60 km is provided and verifies the eye structures obtained. In the figure 8 (a) show the eye structure obtained when the fiber length is of 10 km. By observing the eye diagram it is identified that there is no distortion in the message signal. Then the fiber length is again increased to 20 km shown in the figure 8 (b) and it is observed that in the upper wave some thickness produced in the eye structure compare to figure 8 (a). When the fiber length increases to 40 km figure 8 (c) and to 50 km figure (d) the difference is clearly observed in the eye diagram structure. In the 50 km the wide opening of the eye diagram proves that the data loss is negligible and it can be reconstructed by using different decoding techniques. Then the fiber length increased to 60 km figure (e) a drastic change in the eye diagram is noticed due to fading effect of the generated mmw signal from the central station. Hence it is proved that the proposed system shows better performance in the fiber length of 50 km distance. To achieve more fiber length the system, need to be used one optical amplifier and to maintain the novelty of the proposed system the amplifier is removed. [27-30]

4. Conclusion

A scheme for the generation of frequency sextupling mmw is proposed with data rate of 6 Gbps by using a LiNbO3 modulator without an amplifier. This system solves the bandwidth deficiency in the present communication era and will act as a stepping stone for the 5G technology. The fiber length of 50 km is connected and the quality of the received signal shows better robustness. The model proposed is less expensive due to the absence of amplifier and reduced number of optical filters in the system. The various fiber length versus eye diagram visualizer output is verified which gives more evidence to support the performance of the system.
References

[1] Zihang Zhu et.al. 2015 A novel scheme for high quality 120 GHz optical millimeter wave generation without optical filter. Optics and Lasers Technology, 65: 29-35.

[2] Zhao et.al. 2017 Multi-user precoding and channel estimation for hybrid millimeter wave systems. IEEE Journal on Selected Areas in Communications, 35(7) :1576–1590.

[3] Yu, X, et.al. 2017 Coverage analysis for millimeter wave networks: The impact of directional antenna arrays. IEEE Journal on Selected Areas in Communications, 3(7): 1498–1512.

[4] Anand Prem P K et.al. 2019 A novel scheme for optical millimeter wave generation using LiNbO3 Mach Zehnder Modulator without Amplifier. Proceedings of the National Academy of Sciences, India- Section A: Physical Sciences, vol. 89(4), pp. 699-704.

[5] Anand Prem P K et.al 2019 A millimeter wave generation scheme based on frequency Coupling using LiNbO3 Mach Zehnder Modulator, National Academy Science Letters, vol. 42(5), pp. 401-406.

[6] Shahid Mumtaz; et.al. 2017 Millimeter Wave Communications Mobile Networks. IEEE Journal on Selected Areas in Communications, 35(9) : 1909-1935.

[7] Du, J et.al. 2017 How much spectrum is too much in millimeter wave wireless access. IEEE Journal on Selected Areas in Communications 35(7) : 1444–1458.

[8] Hongyao Chen; et.al. 2020 Study on millimeter-wave photonic generator scheme with tunable multiplication factors. Optik Journal 202 : 163690.

[9] Gazi Mahamud Hasan et.al. 2019 Energy efficient photonic millimeter-wave generation using cascaded polarization modulators. Optical and Quantum electronics 51(217)

[10] Zhu, S., Li, et.al. 2019 1×N hybrid radio frequency photonic splitter based on a dual-polarization dual-parallel Mach Zehnder modulator. Optical Communication 431 :10–13.

[11] P. Sabarish et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 623 012011

[12] M D Udayakumar et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 623 012018

[13] Subramanian, A & Udayakumar, M & Indragandhi, V. & Ramkumar, R.. 2019 Intelligent system to monitor and diagnose performance deviation in Industrial Equipment. IOP Conference Series: Materials Science and Engineering. 623. 012012. 10.1088/1757-899X/623/1/012012.

[14] A.Gnana Saravanana, R.Arul Jose P.Ebbby Darney P.Sabarish, 2020 Converter based distributed drive system with enhanced dynamic response https://doi.org/10.1016/j.matpr.2020.08.073.

[15] P.Sabarish,R.Karthick, A.Sindh, N.Sathiyanathan 2020 Investigation on performance of Solar Photovoltaic fed Hybrid Semi impedance source Converter”, https://doi.org/10.1016/j.matpr.2020.08.390.

[16] A.T.Sankara Subramanian, P.Meanalochini, S.Suba Bala Sathiya, G.Ram Prakash 2020 0A review on selection of soft magnetic materials for industrial drives”, https://doi.org/10.1016/j.matpr.2020.08.389.

[17] P Sabarish et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 937 012013.

[18] A T Sankara Subramanian et al 2020 IOP Conf. Ser.: Mater. Sci. Eng. 937 012028

[19] Subramanian, AT Sankara, P. Sabarish, and A. Nazar Ali. 2017 A power factor correction based canonical switching cell converter for VSI fed BLDC motor by using voltage follower technique." Electrical, Instrumentation and Communication Engineering (ICEICE), 2017 IEEE International Conference on. IEEE, 2017.

[20] P. Sabarish, A. T. Sankara Subramanian, S. Murugesan and V. Suresh Kumar 2020 A New Methodology of Arterial Blood Clot Removal Using Bio Molecular Devices for ATPase Nuclear Motors.” Biosc.Biotech.Res.Comm. Special Issue Vol 13 No (3) 2020 Pp-197-201.

[21] A. T. Sankara Subramanian, P. Sabarish, M. D.Udayakumar and T. Vishnu Kumar 2020 Performance Analysis of Various Photovoltaic Configurations Under Uniform Shading and Rapid Partial Shading Formations”, Biosc.Biotech.Res. Comm. Special Issue Vol 13 No (3) 2020 Pp-185-
[22] S.Vijayalakshmi, P.Sabarish, S.R.Paveethra, Dr.P.R.Sivaraman, Dr.V.Venkatesh, 2020 Exploration And Applications Of Electronic Balance For High Power Discharge Lamps At High Frequency through Power Factor Modification", International Journal Of Scientific & Technology Research Volume 9, Issue 02, February 2020 ISSN 2277-8616.

[23] A.Nazar Ali and R. Jayabharath 2014 Performance Enhancement of Hybrid Wind/Photo Voltaic System Using Z Source Inverter with Cuk-sepic Fused Converter." Research Journal of Applied Sciences, Engineering and Technology7.19 pp. 3964-3970.

[24] A Ali Nazar, R Jayabharath, MD Udayakumar 2014 ,An ANFIS Based Advanced MPPT Control of a Wind-Solar Hybrid Power Generation System,International review of modeling and simulations.vol.7, no. 4, pp. 638–643.

[25] Kalavalli, C., Sachinamreiss, G.N., Nazar Ali, A."Performance Enhancement of Boost Converter Fed Permanent Magnet Synchronous Machine"IOP Conference Series: Materials Science and Engineering, 2020, 937(1), 012015

[26] Udayakumar, M.D., Gowthaman, K.S., Prabhu, A., Nazar Ali, A. 2020 HERIC Inverter- A SEPIC based transformer-less converter design and simulation for isolated standalone PV system IOP Conference Series: Materials Science and Engineering, 2020, 937(1), 012031

[27] Vijayalakshmi, S., Sivaraman, P.R., Karthick, R., Nazar Ali, A. 2020 Implementation of a new Bi-Directional Switch multilevel Inverter for the reduction of harmonics"IOP Conference Series:Materials Science and Engineering, 2020, 937(1), 012026

[28] Sankara Subramanian, A.T., Priyadharshini, S., Palaniyappan, S., Nazar Ali, A.2020 A novel IOT based domestic automation system for load monitoring and efficient control"IOP Conference Series:Materials Science and Engineering, 2020, 937(1), 012028

[29] Anton Amala Praveen, A., Muthu Kumaran, M. Nazar Ali, A. 2020 Minimization of Power Factor Penalty Charges for Non-Linear Domestic Loads with IOT Technology"IOP Conference Series:Materials Science and Engineering, 2020, 937(1), 012011

[30] S.R.Paveethra, C.Kalavalli, S.Vijayalakshmi, Dr.A.Nazar Ali, D.Shyam 2020 Evaluation Of Voltage Stability Of Transmission Line With Contingency Analysis, International Journal of Scientific & Technology Research, Vol 9,issue 02, pp. 4018-22