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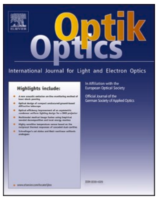

The performance of millimeter-wave over fiber using electro absorption modulator and avalenche photodiode

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ABSTRACT

In this paper, a parallel MZM and a quadrupling frequency technique are used to produce a 72 GHz mm-wave. The determined optical sideband suppression ratio (OSSR) is 71 decibels. This mm-wave signal's performance is compared to that of two optical modulators, the Mach Zehnder Modulator (MZM) and the Electro Absorption Modulator (EAM) as well as two different kinds of photodiodes, the Avalanche Photodiode (APD) and the PIN-PD. When using the EAM modulator, the maximum Q factor for 80 km is almost 20, but when using MZM, it is only 2.3. The performance of the generated mm-wave was then investigated using two different types of PD, PIN and APD, as optical receivers to achieve the best result in terms of signal quality. When compared to PIN-PD, APD improves the power of the received 72 GHz signal by 35%. The system's ability to carry a higher data rate is tested by successfully varying the bit rate up to 10 Gb/s over a distance of 20 km.

1. Introduction

A crucial solution is to switch carriers at lower radio frequencies all the way up to mm-wave carriersacarriers at lower radio frequencies all the way up to mm-wave due to the enormous growth in the number of wireless communication users and the bandwidth needed per subscriber. One of its limitations is that the research sector must use higher frequencies due to the demand for more bandwidth in network backhaul and for various applications by subscribers. The ability to provide a high bandwidth in wireless communication systems and achieve high-speed operation has led to mm-wave frequencies emerging as a solution for increasing the power of RoF technology beyond 5 G [1]. Radio over Fiber, or RoF, is a method of transmission that involves modulating an optical pulse with an RF signal before transmitting it over a broadband network. It can consume a lot of capacity, which allows it to handle more customers than conventional wireless technologies. Millimeter waves are used by 5 G to transmit signals, and it has benefits including fast data speeds, less interrupted communications, dependability, and effectiveness. Compared to the frequency band that is often utilized for transmission, 5 G millimeter-wave frequencies oscillations have a higher number. Thus, combining the characteristics of mm-wave frequencies with those of fibre systems, which provide a massive data rate and capacity, would result in improved systems capable of meeting the demands of future wireless communication systems [2,3]. Thus, integrating the features of mm-wave frequencies and those of fiber systems, which deliver a massive data rate and capacity, would lead to improved systems to meet the demand from wireless communication systems [3,4]. The two main operations in a millimeter-wave communication system are

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downlink data modulation and mm-wave generation [2]. Many methods for generating higher frequencies have recently been reported. Electronic devices with a higher frequency, such as a local oscillator (LO), are more expensive and more difficult to produce. A localized oscillation is required to realise frequency-tupling in order to achieve mm-wave utilizing exterior modulating approach. We are well aware that a localized oscillation with high frequencies cost more and takes longer to make. Always a believed to contribute with a lower frequency can be used to generate mm-waves owing to a frequency-tupler with an ultrasonic proportional gain. As a result, a frequency-tuple technique with a frequency multiplication aspect may be a suitable solution for generating mm-waves with a low input frequency local oscillator [7]. Low overtones and a steady amplitude should be produced by the specific frequency. Heat, power, as well as structural instability are all important elements in durability. The terminal voltage of the oscillation should be sufficient to operate succeeding hardware levels, like integrators or harmonic multiplication, efficiently. Modal latency variations never occur with single-mode fibre, also described as essential or mono-mode fibers since it only allows one phase to transmit. Single-mode cables are perfect for long-haul as well as higher density networks since they can handle broad transmission bandwidth (such >40 GHz). The transmitter is not transmitted with DSB, only the sidebands. Both the carriers as well as one subcarrier are eliminated by SSB. SSB is superior, but it costs more to create. It is simpler to accept, though. Whenever the approximate position of the disturbance in the spectral domain is recognized, a frequency response can be beneficial. The bandpass filter diminishes vibrations beyond the specified range while allowing harmonics inside the designated period to escape.

In this paper, a mm-waves at 72 GHz based on carrier suppression is generated with high quality performance. 2.5 Gb/s is modulated with an obtained 72 GHz signal to study the performance of the obtained signal. Whereis, To achieve the best modulated mm-wave performance at 72 GHz at BS.

The following is how this paper is structured. Section II provides a synopsis of some related work. Section III mathematically and graphically describes the proposed scheme's principle, while Section V provides simulation design and analysis of the generated mm-waves at higher bands of mm-waves. The generated 72 GHz mm-wave signals are then measured over various distances over single-mode fibre (SMF) links. When APD is replaced by the PIN-PD, the performance of 72 GHz is investigated. The performance of the obtained signal is then evaluated at various bit rates. Section VI is complete.

2. Related work

External modulation generates stable, high-frequency, high-purity mm-wave signals while lowering system costs (EM) optical generation has a lot of potential [1]. In 1992, O'Reilly proposed using an external modulator to create mm-wave signals. The signal was created by biassing a MZM to obstruct even-order optical sidebands [5].

Different EM modulation techniques have been used to produce mm-waves, each with a unique resistance to fibre dispersion, [4,5]. Due to its advantages, OCS has been discovered to be preferred [8]. It can produce RF signals with low bandwidth requirements for RF signals, high receiver sensitivity, low spectral occupancy, and a mall power penalty during long-distance transmission [3,5]. Additionally, signals carried by OCS mm-wave Dual-tone optical sidebands are transmitted over chromatic fibre, and the sidebands' not fading-affected [6]. The following techniques for producing mm-waves while suppressing the optical carrier have been shown to work. In [9], an experiment with radio over fibre was carried out (RoF). This is accomplished by using the least amount of transmission bias with two cascaded Mach-Zehnder modulators. As a result of their experiment, a signal with an electrical frequency of 34,125 gigahertz was produced, which was visible very close to the frequency multiplied by four. The obtained electrical spectrum contains harmonic components with orders ranging from 0 to 4, which are arranged ascendingly. The fourth-order harmonic is favoured over the first three due to carrier suppression. A signal propagation technique where the energy fundamentally connected to the frequency band is not conveyed. Three MZM create issues [10] utilises an optical phase modulator to accelerate an electrical signal. Two second-order optical sidebands were initially selected. A mm-wave signal was produced four times faster than the input local oscillator by beating two second-order sidebands at a photodetector. This was perfect. A 15-GHz optical modulator is used to generate 60-GHz mm-wave signals in this system. This technique produces mm-wave signals that can be tuned with an optical filter. This method will complicate and increase the costs of the system [11,12] demonstrate that frequency quadrupling with a Mach-Zehnder modulator (MZM) produces mm-wave signals. Strategy has been developed. The frequency of an electromagnetic beam is controlled via a Mach-Zehnder modulation [17]. There are two broadband diffraction limbs made from the source wavelength. A phase difference is created for the waveform flowing via that forearm if a voltage is used to one of them. A diffraction pattern divides a laser beam into two halves, which are later reassembled by another diffraction grating. The secondary diffraction pattern will return the laser with an effectiveness ranging from 0% to 100% based on the relative speed that the light has obtained along the two routes. To generate optical mm-wave signals, a dual-electrode dual-parallel integrated Mach-Zehnder modulator is used [13]. (MZM). Because it is made up of three MZMs with dual electrodes, it can be assembled without the use of any electrical or optical filters. The proposed strategy's performance is evaluated using both simulation and experimental validation. The frequency of the input signal has been determined to be 9 GHz RF drive signal. It has been discovered that optical sideband suppression (OSSR) of 35 dB is possible. The RFSSR of the 36 GHz produced mm-wave is 30 decibels. According to reference [14], an integrated dual-parallel MZM [17], rather than an optical filter, can be utilised to operate a high-quality quadruple frequency mm-wave signal. When a 15 GHz signal is fed into an RF local oscillator, it produces a 60 GHz Mm-wave (LO). The Hartley oscillators may produce vibrations up to 30 MHz in the RF (Radio-Frequency) band. Even after 60 kilometres, the transmission system remains faultless [15] proposes and experimentally validates a method for producing frequency-quadrupled microwave signals with a 360-degree phase shift. Odd-order sidebands can be suppressed by biassing two DD-MZMs at the maximum transmission point. The experiment's frequency range is 30–42.4 GHz. The suggested method could be implemented in a system that analyses signals from broadband arrays. In fact, 23.9 dB OSSR was achieved.

When the extinction ratio is set to infinity, The proposed parallel MZM configuration quadruples frequency with an OSSR of 42.07

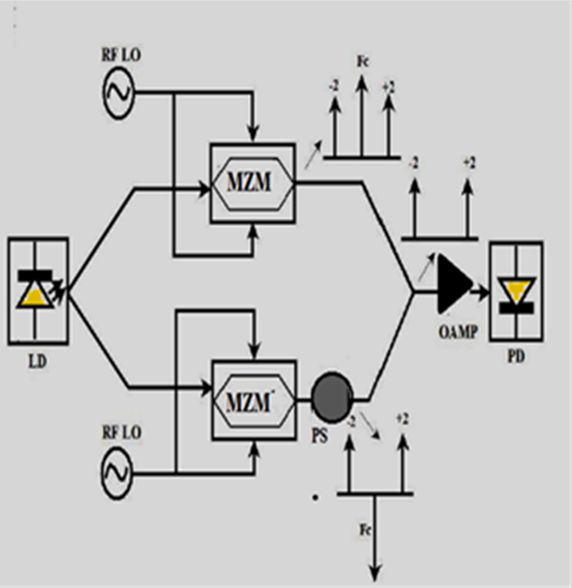


Fig. 1. Schematic diagram of generating mm-wave using quadrupling technique.

dB and an RFSSR of 36 dB(16). A strong, constant stream of a specific, essentially pure wavelength is produced by the CW laser. A very brief, strong discharge of illumination, lasting approximately 1/100,000,000 of a moment, is produced by the pulsed laser. Scanners that produce illumination in the form of light signal instead of continuously are characterized as pulsed lasers (light flashes). Although it offers a brief description of a larger variety of pulse-generating diodes, the phrase is much frequently utilized Q-switched beams, that representative sample nanosecond flashes. To suppress the carrier, the smallest current was used to bias the MZMs at the transmission point. In our example, both MZMs are driven by quadrature and in-phase signals to produce even order sidebands with pages and are biassed at the maximum transmission point. The 180-degree phase shift and MZM output are combined into a single signal via an optical coupler. Only second-order side bands are present at the coupler's output, causing the photodetector's frequency to quadruple and the OSSR and RFSSR values to rise. The researchers used a 6 GHz RF input drive signal and cascaded intensity and phase modulators to generate 36 GHz mm-waves [16]. Only the lower OSSR is possible due to the lower RFSSR between the desired frequency sextupling [7] mm-wave signal and other undesirable RF components. This is due to ineffective suppression of undesirable optical sidebands [14] proposes a method for sextupling the frequency of mm waves without using an optical filter. The 3.5 GHz radiation pattern, where contemporary 5 G runs, enables larger ability and less delay. For next-generation communication, established mmWave technologies can be used to obtain even wider bandwidth. Enormous bandwidth or even better connectivity are made possible by combining 5 G and mmWave to truly experience 5 G. Researchers presented yet another method for producing frequency sextupling in [15]. In this case, a fixed-wavelength notch filter was combined with a polarisation modulator [18]. The researchers in [16] proposed frequency sextupling as a method for producing mm-waves. The first MZM was chosen because it had the lowest transmission required to suppress the optical carrier. The even-order optical harmonics are generated by the second MZM, which is chosen based on the most available information. The suppression of high-order optical harmonics, which are derived from first-order optical harmonics, eliminates the GOBF between two MZMs. As a result, a microwave input frequency of 10 GHz is used to generate 60 GHz, which drives the MZMs with a 36 dB RFSSR while carrying the data signal. However, the obtained electrical signal is about − 50 dBm, whereas the received optical power signal is about − 40 dBm. In reference [19] By adjusting the RF drive voltage and polarisation angle of the DP-PolM, the frequency 12-tuples mm-wave is obtained with an OSSR of 37.76 dB and RFSSR of 31.67 dB. Also considered and presented is how nonideal parameters affect the OSSR, RFSSR, and BER. In [20], two Filterless mm-wave generators are being investigated. There were two approaches taken. A dual-parallel Mach-Zehnder modulator generates a six-order optical harmonic (DP-MZM). Second, two intensity modulators and 12 tuples are used to generate a 36-tuple optical harmonic mm-wave signal. 1.75–3.25 GHz RF driving produced 63–117 GHz mm-wave signals. More than 28 dB and 23 dB, respectively, have been measured for the OSSR and RFSSR. A BER of 10(−9) was attained over a 20 km SMF distance. Single-mode fibre can transmit signals up to 10 km away without losing quality because to its design. It is perfect for every long-distance broadcast because of this capability.

In this work, a single Parallel MZMs is used for the first time to generate 72 GHz carrier suppression with high optical sideband suppression without the need for a filter at receiver. The frequency of an optical pulse is controlled via a Mach-Zehnder modulation. There are two broadband diffraction arms made from the source wavelength. A phase difference is created for the waveform flowing via that branch if a charge is supplied to one of them. To achieve the best performance of a modulated mm-wave at BS, the performance of the obtained signal is then examined EAM and MZM are the two types of optical modulation used in this context. A semiconductor device designated an electro-absorption modulation (EAM) can be employed to change an infrared laser's brightness by applying an electrical signal towards it. When an exterior electrostatic attraction is supplied, a transistor object's absorbance equation models, which is how an electro-absorption modulation (EAM) function. Photon-assisted tunnelling from the oxide to the conducting group is made possible by the electrical field's tilting of the semiconductor's carriers. APD is used simultaneously to boost the signal's received power, producing superior outcomes to PIN-PD. Since it is more sensitive than PIN, the APD's key benefit is that it is more sensitive overall. A considerably stronger selectivity is provided by the explosion activity, which several times improves the diode's strength. Nevertheless, a greater working voltage is necessary for an APD.

3. Principle of the proposed design

A schematic diagram of the frequency quadrupling method of producing mm-waves is shown in Fig. 1. To begin,The upper and lower MZM are organised in a dual parallel configuration [21] is injected with a CW laser having a the following finite spectral width:

$$E(t) = E_o \cos\omega_c t \tag{1}$$

E_o is the amplitude and ω_c light's angular frequency.
$E_0(t) = E\ of MZM_{lupper}(t) + \text{E of } MZM_{lower}(t)$.
$= \frac{E_0}{4}\cos\omega_c t * \left\{ \left[J_0(m) + 2\sum_{n=1}^{\infty} J_{2n}(-1)^n \cos(2n\omega_m t) \right] + \left[J_0(m) + 2\sum_{n=1}^{\infty} J_{2n}\cos(2n\omega_m t) \right] e^{j\pi} \right\}$.
The upper MZM electrodes are both driven by RF LO.

$$V_{rf}(t) = V_{rf}\cos\omega_m t \tag{2}$$

RF LO drives the lower MZM

$$V_{rf}(t) = V_{rf}\sin\omega_m t \tag{3}$$

At the MZM's Maximum Transmission Point, both MZMs are biassed. Additionally, a 90-degree The RF-driving signals to each MZM electrode are phase-shifted as part of the operation of an RF local oscillator to drive upper and lower MZMs. The transmitted signal as well as a regional oscillator's modulated signal are the sources of the processor (LO). The message with the middle wavelength is the result. The RF value is modulated by the specific frequency during combining, as well as the output waveform is subsequently low-pass filtered.

Some of a group of arithmetic operations that were methodically generated while looking into the values to each of Kepler's planetary kinetic theory is described as a Bessel variable, also referred as a cylindrical feature. Eq. (3) can be expressed as using the Bessel function of the first kind.

$$EofMZM_{lower}(t) = \frac{E_0}{4}\, cos\omega_c t\omega_c t * j_0\,(m) + 2\sum_{n=1}^{\propto} J_{2n}\cos(2n\,\omega_m t)e^{j\pi} \tag{4}$$

Equation depicts the optical output of the upper MZM (4). Order terms and a major carrier are also available as options. In a similar vein, the synthesis of lower MZM can be explained as follows:

$$EofMZM_{lower} = \frac{E_0}{4}\cos\omega_c t * [\cos(msin\omega_m t)] \tag{5}$$

The first kind of Bessel function can be used to solve the following equation:

$$EofMZM_{lower}(t) = \frac{E_0}{4} cos\omega_c t * j_0\,(m) + 2\sum_{n=1}^{\propto} J_{2n}\cos(2n\,\omega_m t)e^{j\pi} \tag{6}$$

This equation states that the even order sideband and carrier are output by the lower MZM. by giving the lower MZM output a 180o phase shift. The optical couple then combines the output of both MZMs, as shown below:

$$E_0(t) = EofMZM_{lupper}(t) + EofMZM_{lower}(t) = \frac{E_0}{4}\cos\omega_c t * \tag{7}$$

This equation can be reduced to

$$\frac{E_0}{4}\boldsymbol{cos}\omega_c t[J_0(m)\cos(2\omega_m t]$$

Using the trigonometric relationship

$$E_0 = J_2(m)[+\cos(\omega_c - 2\omega_m t)][j_0(m) + 2] + j_0(m) + \frac{E_0}{4}\boldsymbol{cos}\omega_c t * j_0(m)\sum_{n=1}^{\propto} J_{2n}\cos(2n\omega_m t)e^{j\pi} \tag{9}$$

The output of the optical coupler is entirely second-order sidebands aforementioned equation. The photocurrent produced when two-order sidebands are beaten together is denoted as follows:

$$\mathrm{I(0.t)} = \Re|E_0(t)|^2 \tag{10}$$

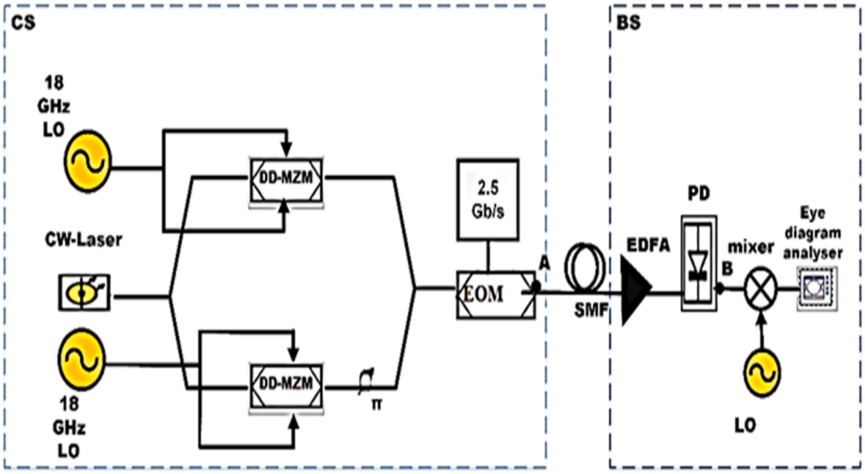


Fig. 2. Simulation set up design for generating and data transmission of 72 GHz.

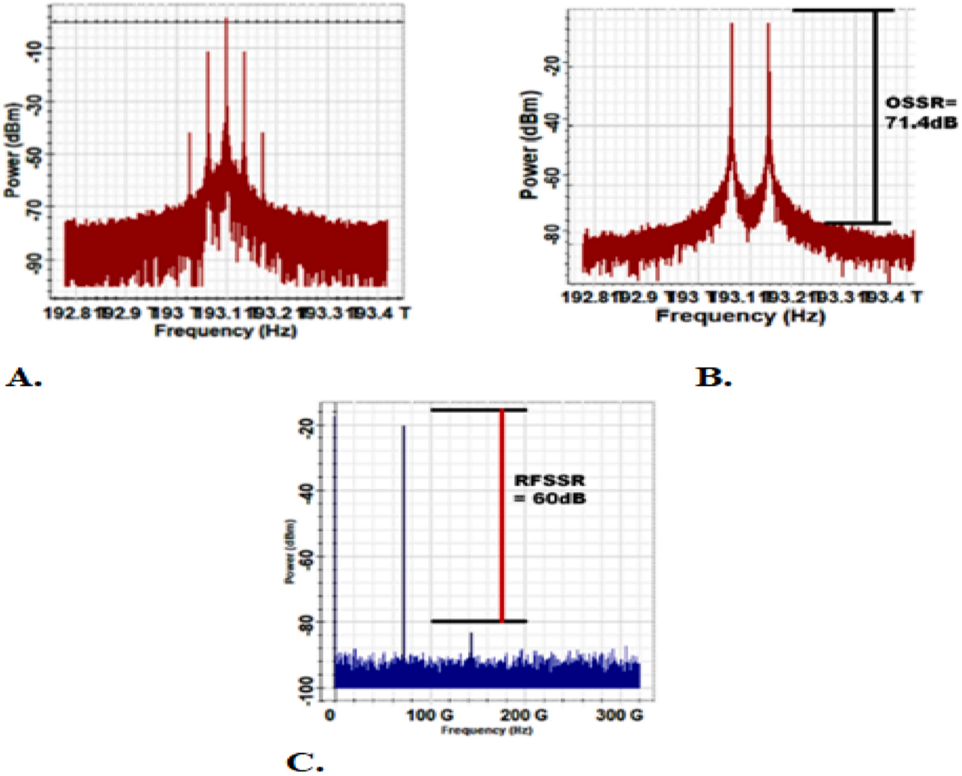


Fig. 3. A. Obtained mm-wave at the output of optical coupler. B. Obtained mm-wave at the output of optical coupler C. Obtained mm-wave at RF domain.

$$\mathrm{I}(0.\mathrm{t}) = \Re|E_0(t).E_0{}^*(t)| \tag{11}$$

$\Re$photodetector sensitivity $E_0{}^*(t)$: conjugating 11 simplified:

$$\mathbf{I}(\mathbf{0},\mathbf{t}) = E_0{}^2 J_2{}^2(\mathbf{m})[1+\cos 4\omega_m t]$$

The aforementioned equation demonstrates that the detected photocurrent only consists of the desired mm-wave signal at 4 m t. Equation (12) demonstrates that the signal at 4 GHz, the desired MM-Wave signal, is the only component of the detected photocurrent at the receiver. Since no optical filtering is required, this scheme is filterless, extremely stable, and tunable.

Table 1
Simulation set up parameters for generating of 72 GHz mm-wave signal.

Symbol	Parameter	Value
CW-laser	Optical signal frequency	193.1 THz
	Optical power signal	0 dBm
	Spectral width	10 MHz
LO	Radio frequency	18 GHz
MZM	Bias voltage	0 V
	Switching bias voltage	4 V
	RF voltage	4 V
PIN-PD	Responsivity	1 A/w
	Parameter	
SMF	Range	(0–100) Km

4. Simulation setup and result

To generate and analyse 72 GHz downlink transmission performance, we use the OPTSYSTEM 16 software. The OptiSystem 16.0 Devices Collection now contains the Phi-OTDR and Phi-OTDR Intelligence officer modules. These parts can be employed to detect the Rayleigh back-reflected signals of a fibre undergoing one or more oscillations at various points or to detect simultaneous oscillations. The simulation experiment first generates mm-waves at 72 GHz. Examine the mm-performance waves with MZM modulation. The experiment is then conducted once more to assess how well this wave performs when modulated with data using EAM. To determine how much the system can handle, the performance of the system is assessed using a range of bit rates.

4.1. Generating mm-Wave At 72 GHz

The simulation configuration used to generate 72 GHz the quadrupling technique is shown in Fig. 2.

The table displays the setup for parameter simulation.

1. A light signal with a Light with a spectral width A continuous-wave laser source injects 10 MHz into MZMs. The initial sensor system with widespread adoption was the argon laser. It is a continuous-wave pulse that glows at the frequencies of 488 nm & 514 nm, respectively. With a 90° phase shift, 18 GHz powers both the upper and lower MZMs. Both MZMs receive a 4 V switching bias voltage.

193 GHz optical mm-wave is shown in Fig. 3. According to Figure, the In the optical domain, the value found for mm-OSSR waves is 71.4 dB (3-B). The desired mm-wave frequency of 72 GHz with an RFSSR of 60 dB is shown in Fig. (3-C). As a result, high mm-wave cleanliness and low optical carrier and harmonic suppression reduce impairment brought on by fibre dispersion. Unlike superfast or pulsed diodes, which create a pulsed laser pointer, sustained laser beams (CW lasers) generate a continuously laser pointer. Regular CW beams, continuous wave optical components, wavelength-tunable continuous wave lasers, and quasi – CW lasers are the optical components that are all available from Spectra-Physics. Consequently, the finding in this work enhances the finding in reference [22]. Using the same technique, the obtained OSSR was 42 dB in and the obtained RFSSR was 32 dB, implying that generating mm-wave signals improves the obtained OSSR and RFSSR by approximately 44%. Moreover, this system is tunable while we can generate different frequencies by tuning the input frequency generated at LO. For example, 60 GHz is obtained in the following Figure by tuning the input frequency to 15 GHz Figures show the superior signal quality obtained, avoiding the need for an electrical filter at the receiver.

mm-wave is resistant to fiber-induced chromatic dispersion, which gives it the ability to be transmitted over a longer fiber distance.

4.2. Downlink data transmission

The system is simulated with OPTISYSTEM 17 to test the quality of optical mm-wave over SMF, as shown in Fig. (2). To test signal quality, the mm-wave is modulated with a baseband signal using two optical modulators (QF). MZM data is first used to modulate the mm-wave signal. To modulate the mm-wave signal, the same simulation setup and an EAM optical modulator are used. The simulation parameters in Table 1 are identical, but some components have additional parameters. Two types of PD are used to test the efficiency of mm-wave downlink transmission (PIN-PD and APD). As a result, the simulation setup is run with PIN PD first, followed by APD, to see how the performance of the signal can be improved.

4.3. The performance of obtained 72 GHz when using PIN – PD as photodetection

The mm-wave will then be generated and 2.5 Gb/s of data will be modulated using MZM. Following that, the electrical domain mm-wave will be extracted using SMF and PIN-PD. The same procedures are used to modulate the mm-wave with EAM at 2.5 Gb/s as shown in Fig. 2. To test the effectiveness of modulated mm-wave signals using MZM and EAM sent over various SMF distances, both systems are simulated. As fibre length increases, the maximum Q factor and received signal power decrease as a result of fibre characteristics like attention and dispersion. They affect how well signals perform when sent over longer distances.

When EAM is used for optical data modulation, the highest Q factor for 40 km is 51, and when MZM is used, the highest Q factor for 40 km is 17.2. The maximum Q factor for a MZM design is 10, whereas the maximum Q factor for an EAM-based 80 km design is 38.2.

Table 2
The compare between the performances of received of 72 GHz with different optical modulators (MZM and EAM) under two types of PDs (PIN-PD and APD).

	PD-PIN				APD			
EOM	EAM		M2M		EAM		M2M	
Obtained Results	Max Q Factor	Received Signal Power	Max Q Factor	Received Signal Power	Max Q Factor	Received Signal Power	Max Q Factor	Received Signal Power
20 KM	40	-22	20	-32	40	28	21	25
40 KM	51	-32	16.1	-42	60	18	28	12
8 KM	38	-48	10	-58	38	8	18	-6

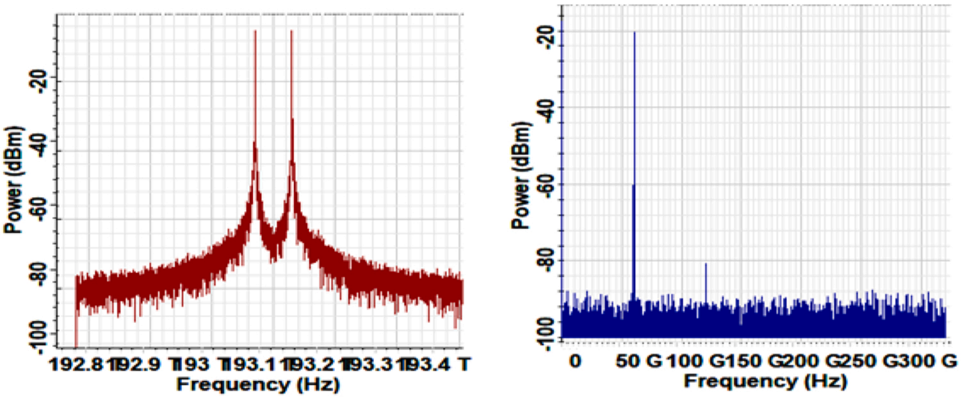
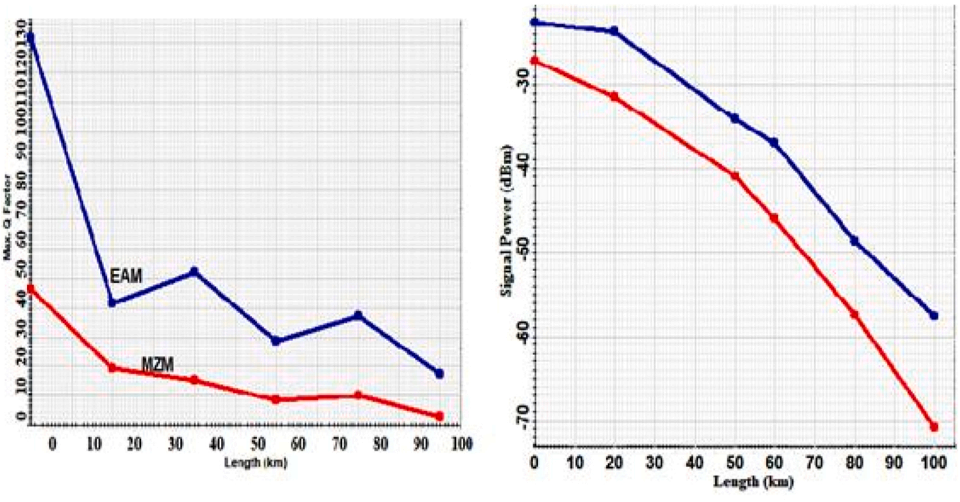


Fig. 4. A. Optical 60 GHz B. Obtained mm-wave at 60 GHz.



A. Max Q factor over different SMF length

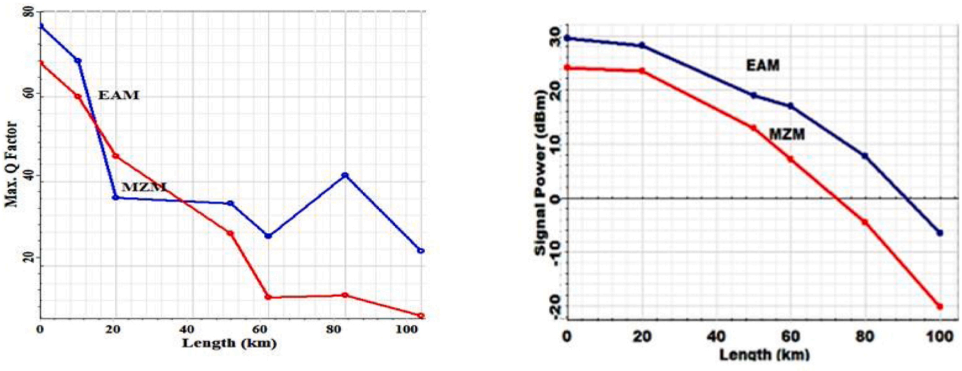
B. Recieved power over different SMF length

Fig. 5. Performance of 72 GHz mm-wave when PD is PIN-PD.

Fig. 1 depicts the received signal power at 72 GHz mm-wave over various SMF lengths. (4–5. B). Over 20 km of fibre, 72 GHz received power is − 18 dBm, and mm-wave power is − 48 dBm. The received signal was − 38 dBm 67system used MZM for optical data modulation over 20 km and − 58 over 80 km. The outcome was displayed in Table 2.

4.4. The performance of obtained 72 GHz when using APD as photodetection

Then, mm-wave modulation is studied, but this time with APD -PD. The modulated mm-wave in two scenarios are sent to be received by APD to extract 72 GHz mm-wave signal in different SMF ranges. Fig. 6 shows the performance result of exhausting systems.



A. Max Q factor with different fibre lengths **B. Signal power with different fibre lengths**

Fig. 6. Performance of 72 GHz mm-wave when PD is APD.

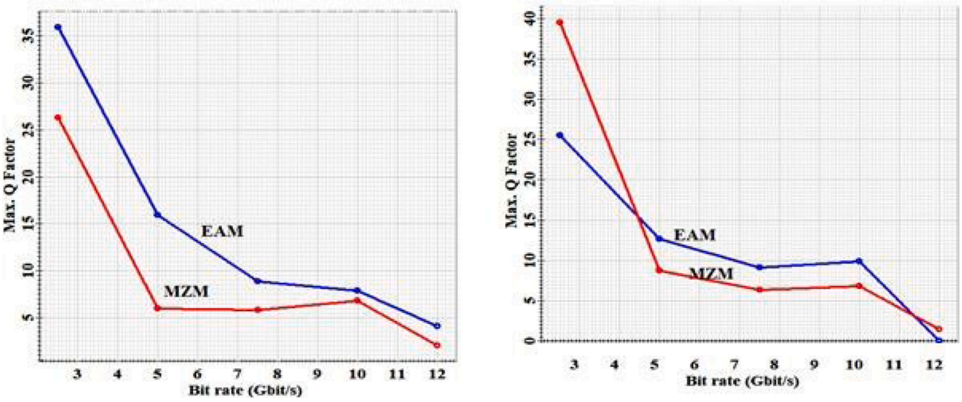


Fig. 7. The performance of 72 GHz with different Bit rates. A. PD is PIN-PD B. PD is APD.

It is found that, in general, the received signal power is better than the first system where PIN-PD is used. Max-Q is a system that makes gameplay computers silent as well as smaller. The Max-Q innovation could be exactly whatever you're searching for if you're searching for a gaming console as well as desire one with a thin form or a long-lasting battery. It is true that both curves (max Q factor and received signal power) decrease in increasing fiber length, but that, as maintained previously, is expected because of the characteristics of the fiberThe maximum Q factor for a signal obtained at different fibre Fig. 6: Lengths A. The maximum Q factor of an EAM at 20 km is 40 while at the same fibre length, the maximum Q factor is 21. When the system is using EAM, the maximum Q factor at 80 km is 39, while in a different scenario, the maximum Q factor is 18.1. When the system uses EAM as a data modulator, the maximum Q factor at 100 km is 17.1, whereas it is 8.02 when the system uses MZM. Modulated mm-wave signal power over different fibre lengths is represents in Figs. (4–6) B.The system uses EAM, the received power at 20 km is found to be 29 dBm, while when the system uses MZM, it is found to be 26 dBm. When using EAM at 80 km, the received signal power is six dBm, and when using MZM, it is − 5 dBm. When using EAM, the received signal power at 100 km drops to − 11 dBm and, in another case, to − 20 dBm. The curve shows that in the first scenario (MZM), the electrical power received from modulated millimetre waves is a little less than what is obtained in the second scenario (EAM). However, the results show that the proposed system performs well over 100 km when APD is used as photo detection at the receiver.

Furthermore, according to the results, the mm-wave performance obtained using EAM outperforms the mm-wave performance obtained using MZM. In terms of PD, the proposed system works well with both types of PD that have already been implemented to extract the mm-wave signal for ROF technology. The main limitation of PIN PDs is that their receiver performance is severely limited by thermal noise when compared to APD, which is preferred for long-distance links; APD is used, which provides a current gain due to its impact ionisation process [23] [24]. However, the effect of APD is clearly visible in received electrical powers, as shown in Fig. 6. B. Table 2 summarized the obtained result. It shows that, the performance of obtained 72 GHz is in high quality according to obtained max Q factor and received signal power in all scenarios. However the performance of obtained signal when EAM is implemented as data optical modulator is better than the performance of obtained signal when MZM is used for about 10%. Additionally using APD as photodectction improved the received signal power for about 35% compared when the used phtotdiode is PIN-PD.

5. Investigate the performance Of 72 GHz with different bit rates

The generated 72 GHz mm-wave performance using this design is also measured by varying the Bit rate at the input data of EAM and MZM. The simulation was set up using the proposed design over 20 km SMF lengths. The simulation result shows that the proposed system can process and send in different bit rates. According to the obtained result, the system can successfully work up to 10 GB/s. For 20 km, the Max Q factor of received 10 GB/s is 10 when the system uses EAM and 9 when the system uses MZM.

6. Conclusion

The research presented in this paper shows that 72 GHz can be produced using quadrupling techniques with high-quality performance. An 18 GHz driving signal can produce mm-wave signals at 72 GHz with an optical carrier suppression ratio (OSSR) of more than 71 dB. High optical carrier suppression and harmonics are used to reduce chromatic dispersion-related impairment. In contrast to MZM optical modulator, The results of this study demonstrated that using an EAM optical modulator to modulate mm-wave with data results in the production of modulated mm-wave of high quality that can be used for downlink transmission. APD as PD also enhances the obtained 72 GHz signal performance in comparison to PIN-PD. This technique can successfully generate a signal with a BER of 10 Gb/s over a distance of 20 km.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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