Research Article

A 60 GHz RoF generation system based on optical beat of narrowband Bragg filters

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Abstract
Radio over fiber is considered as a very promising technology that will indisputably compete as a viable solution for the distribution of current and future broadband wireless communication systems. In this paper, we propose a new millimeter-wave generation system: the 60 GHz system which is based on two narrowband Bragg filters forming with the coupler a *Y* system. The millimeter wave is obtained by the optical beat technique detection of two optical waves. The frequency interval between the two waves generated by the Bragg filters gives the 60 GHz millimeter wave. The simulation results demonstrate that an optimal BER less than 10^{-9} for different values of flow rate and a good quality factor *Q* can be reached by using Bragg filters with a very narrow band. In addition, we simulate the 60 GHz system for various lengths of optical fiber. The eye diagram remains clear and open for fiber lengths that reach 50 km.

Keywords Narrowband Bragg filter · Radio over fiber · Beat · BER

1 Introduction

To preempt the saturation of the 2.4 or the 5 GHz unlicensed bands used by Wi-Fi technologies and to increase the connection speed, the industrials are heading toward the unlicensed millimeter-wave band (mmW) that is limited in the interval from 57 to 66 GHz. The unlicensed millimeter-wave band offers large channels of 2.16 GHz bandwidth with high authorized emitted powers allowing advanced integration into radio terminals. However, the 60 GHz technology poses the problem of propagation losses, which limits the typical signal transmission distance to 60 GHz that varies from a few meters to several tens of meters.

To extend the coverage area, fiber-over-the-air (RoF) technology has been the subject of much scientific research over the last decade for the generation and optical transmission of RF signals. The RoF consists to transport the information over optical fiber by modulating the light source with the radio signal. Two types of modulation can be used: a direct modulation with the radio signal or an external modulation with intermediate frequency. Radio-over-fiber technology thus combines the advantages of fiber communication (very wide bandwidth, immunity to electromagnetic interference and low losses) [1, 2] along with radio communication.

RoF technology is used in several applications similar to fiber to the home (FTTH) [3–5], mobile communication [6–8] and wireless broadband systems [9–13]. Multiple studies with various methods have also recently been proposed [14–17]. Among the most recent studies for the generation of frequencies close to 60 GHz [18–21] is the use of frequency-division orthogonal multiplexing (OFDM, multi-carrier modulation) proved by a RoF tunnel

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certificate operating two wireless radio links [22]. This millimeter wave is generated by the gain-switching laser that is a result of the beating of two uncorrelated optical tones [23] on the one hand or by using Mach–Zehnder modulators (MZM) [24, 25] on the other.

The contribution provided by this paper is based on a miniaturized optical system that generates millimeter waves without electrical-to-optical (EO) conversion or optical-to-electrical (OE) conversion. The proposed system is a *Y*-shaped coupler with two inputs, each having a very high-bandwidth Bragg filter (the two bands are slightly different). Both inputs of the couplers will lead to a single output [26].

In this paper, we propose a new all-optical system to generate the 60 GHz millimeter-wave band, based on the beat of the wavelengths reflected by a narrowband Bragg filters.

The optical beat achieved by Bragg filters shows performance by comparing with other recently used techniques for the generation of millimeter carriers such as laser beats [27]. Narrowband Bragg filters can give well-defined frequencies, the thing that gives good results in terms of quality factor and BER. On the other hand, the proposed system is an all-optical system; the optical devices replace the electronic components especially the E/O or O/E converter used in other 60 GHz millimeter systems which use the optoelectronic oscillator [28].

The frequency interval of the coupled spectra generates a 60 GHz signal, with flow rates of 5 Gbit/s and 10 Gbit/s, for a BER less than 10^{-9} and distances up to 50 km.

2 Generation of radio frequency signals on optical fiber by optical beat detection

The technique of microwave generation by optical beat detection is based on photodetection of the mixture of two optical waves whose frequency interval is equal to the desired frequency as shown in Fig. 1.

If two lasers, respectively, emitting the frequency λ_1 and $\lambda_1 + \Delta\lambda$, are used with a respective optical power P_1 and P_2, the photodetector receives a continuous power proportional to the sum of the optical powers and a microwave power proportional to $\sqrt{P_1 P_2}$.

$$I_{PD} = \sigma_{PD}\left\{ \left(P_1 P_2\right) + 2\sqrt{\left(P_1 P_2\right)}\cos\left(2f_{RF}t + \phi_2(t) - \phi_1(t)\right) \right\}$$

with σ_{PD} being the sensitivity of the photodetector and ϕ_1 and ϕ_2 the respective phases of lasers 1 and 2.

The 60 GHz millimeter-wave system proposed in this paper is based on the optical beat technique that replaces the lasers with a narrowband Bragg filters which will be slave filters with a master laser. The Bragg filters each hang on one of the sidebands of the master laser.

3 Narrowband Bragg filter

Bragg reflectors have been the subject of development of many applications in the field of optical communication systems. Bragg gratings (BGs) are used to provide narrow

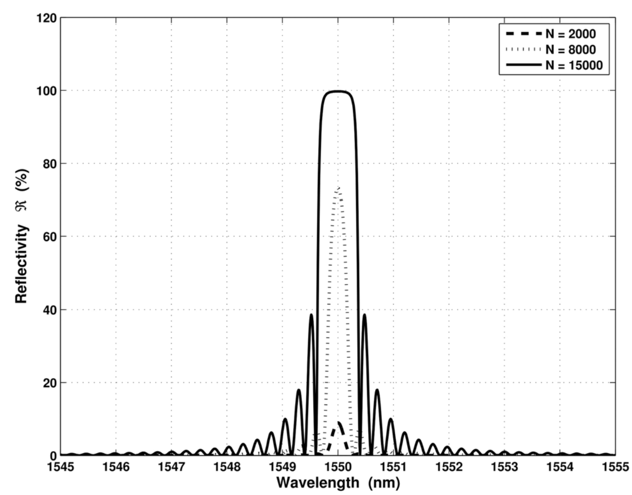


Fig. 2 Reflectivity curves versus wavelength for different numbers of period *N*

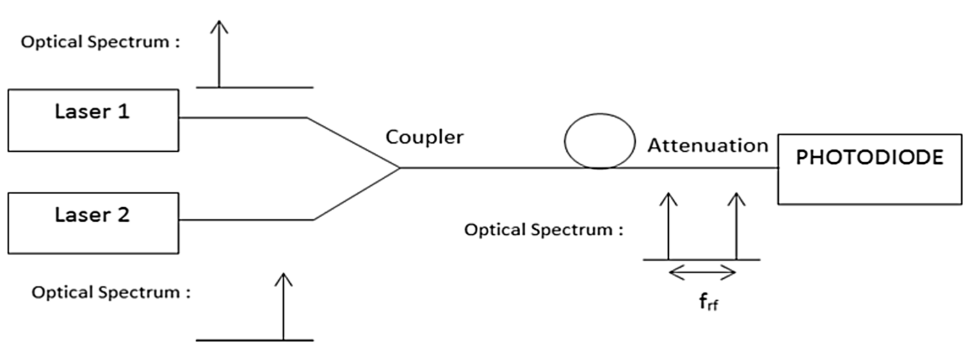


Fig. 1 Generation and transmission of microwave carrier by optical beat detection

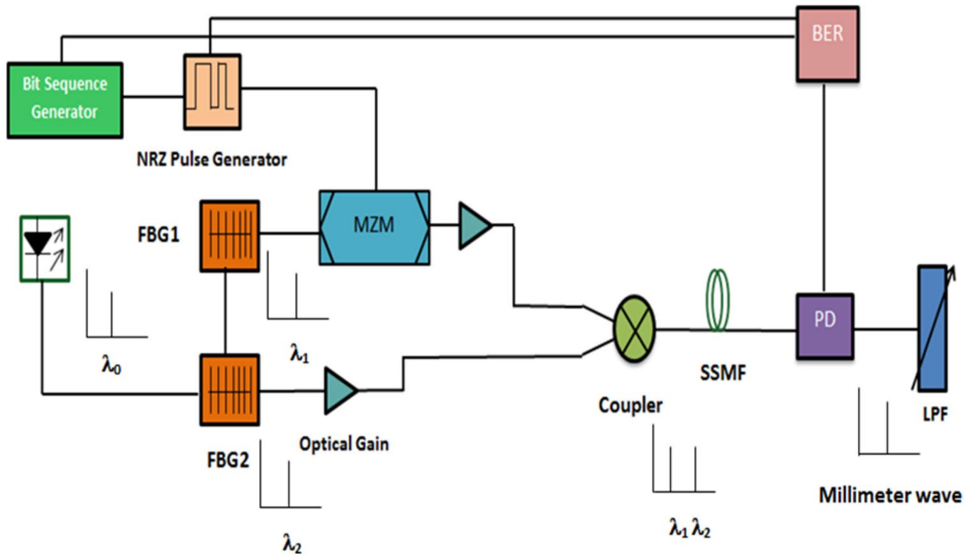


Fig. 3 Principle diagram of the proposed system for 60 GHz mm-wave generation

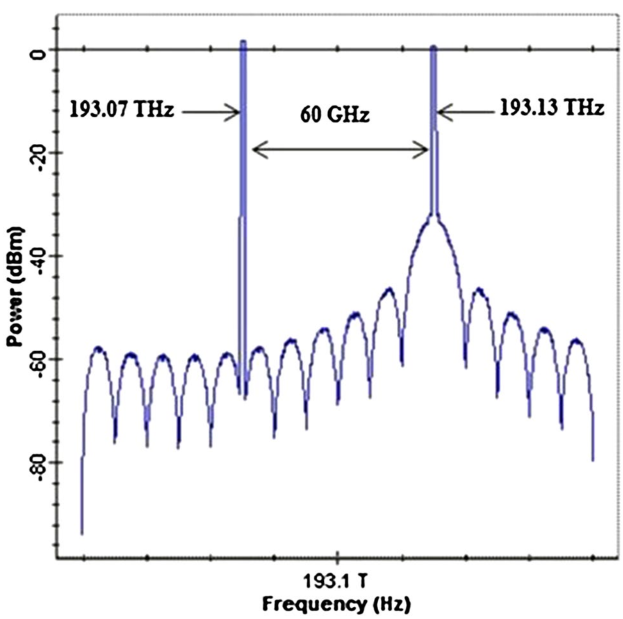


Fig. 4 Optical spectrum of beat of bands reflected by the FBGs

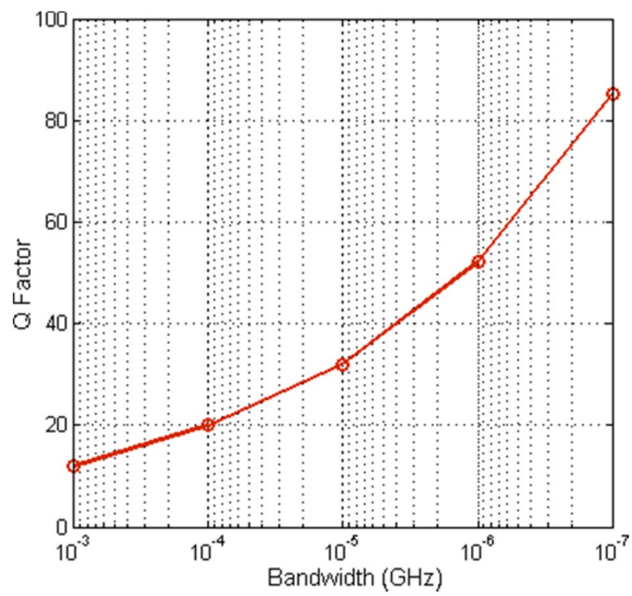
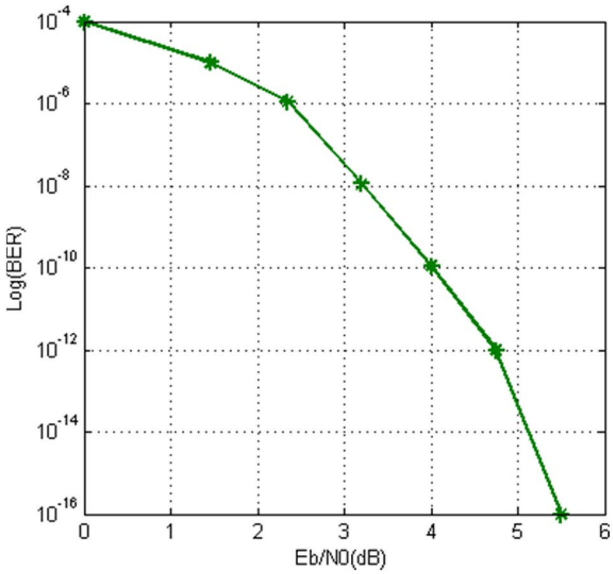


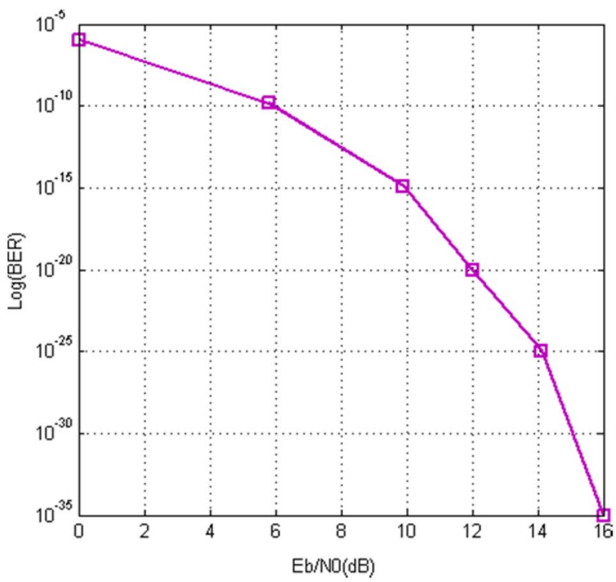
Fig. 5 Q curve versus the width of the reflected bands of the FBGs

spectrum filters, couplers, mirrors, sockets and sensing elements that define the required basic functions. Another area for the use of the Bragg filters is that of wavelength multiplexers and demultiplexers that make in-line optical filters, particularly band-pass filters and wavelength-specific reflectors.

Several researches have been carried out in the field of narrowband Bragg filters, among these latter are the narrowband Bragg filters fabricated with (in designates the place of fabrication) Ti:$LiNbO_3$ with weak modulation index which was the subject of our previous work [29–33]. The technique consists of modulating the index profile by micro-structuring an upper layer deposited on the propagation channel (optical fiber or waveguide) in order to realize optical filters with very narrow bandwidths. Figure 2 represents a transmission spectrum of the reflectivity versus wavelength of a narrowband Bragg filter fabricated on lithium niobate with low index modulation. The reflective band of the filter is very narrow (< 1 nm) with a reflectivity about 100% for a number period of 15,000. This filter is the main element of our 60 GHZ millimeter-wave generation proposed system, as we will see in the next paragraphs. As the reflected bands filter are very narrow, the system is more efficient.



(a)



(b)

Fig. 6 BER curves versus signal-to-noise ratio for 10^{-7} GHz and 10^{-8} GHz reflected bands, respectively

4 Model description

Figure 3 shows the proposed system for 60 GHz mm-wave which consists of two narrowband Bragg filters, each of them reflecting a defined frequency band; the light source is externally modulated with a Mach–Zehnder modulator (MZM); both the reflected signals by the Bragg filters will be coupled by an optical coupler that consists of two waveguides arranged side by side where the coupling of light is effectuated (see Fig. 4). The role of the coupler is to split or combine the optical signals. The generation of 60 GHz mm-wave is achieved by optical the beat detection technique already described in previous paragraphs. The simulation is performed using the OptiSystem 7.0 software.

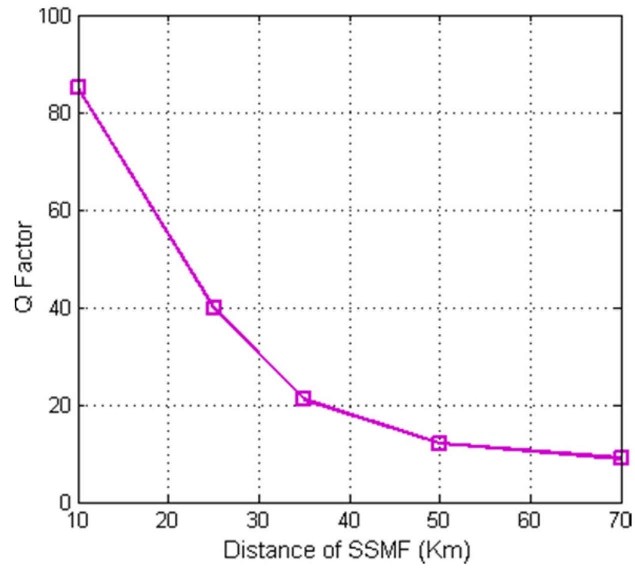


Fig. 7 *Q* curve versus the width of the reflected bands of the FBGs

5 Simulation results and discussion

5.1 Effect of reflected band of the Bragg filters on quality factor (*Q*) and BER for 5 Gbit/s

In this section, we demonstrate that the choice of the width of the reflected bands of the Bragg filters influences on the quality factor. In Fig. 5, we have the quality factor curve as a function of the width of the reflected bands of the FBGs, for a rate of 5 Gbit/s and a fiber length of 10 km. As we can see, by decreasing the width of the reflected band of the FBGs, the *Q* increases. For a width of 10^{-7} GHz, the *Q* reaches the value 85 with a BER of 2.23×10^{-23}.

To demonstrate the width's impact of reflected bands of the Bragg filters, we plotted the BER versus the signal-to-noise ratio (*S/N*) for different values of reflected bandwidth. Figure 6a shows that for a value of 10^{-7} GHz of the width of the reflected bands, the BER can reach 10^{-16} with a signal-to-noise ratio of 5.5. The BER can be improved by decreasing the width of the Bragg filters reflected bands, as shown in Fig. 6b for a width of the 10^{-8} GHz; the BER can achieve a value of 10^{-35} for a *S/N* about 16 dBm. The choice of the widths of the reflected bands can improve the performances of the simulations. The reflected bands of Bragg filters must be very narrow to give better results.

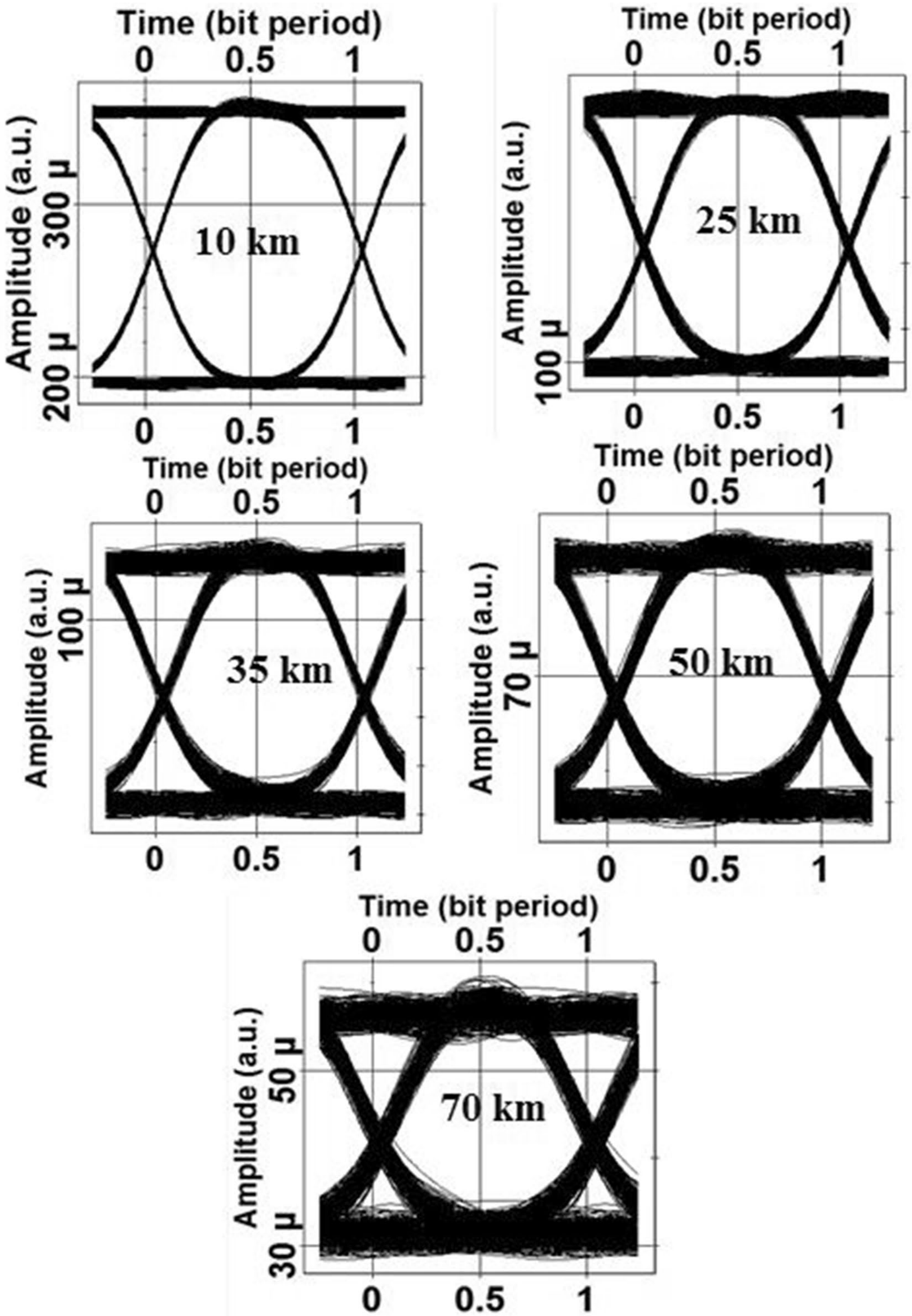


Fig. 8 Eye diagram of 60 GHZ millimeter wave generated for 5 Gbit/s for different lengths of SSMF

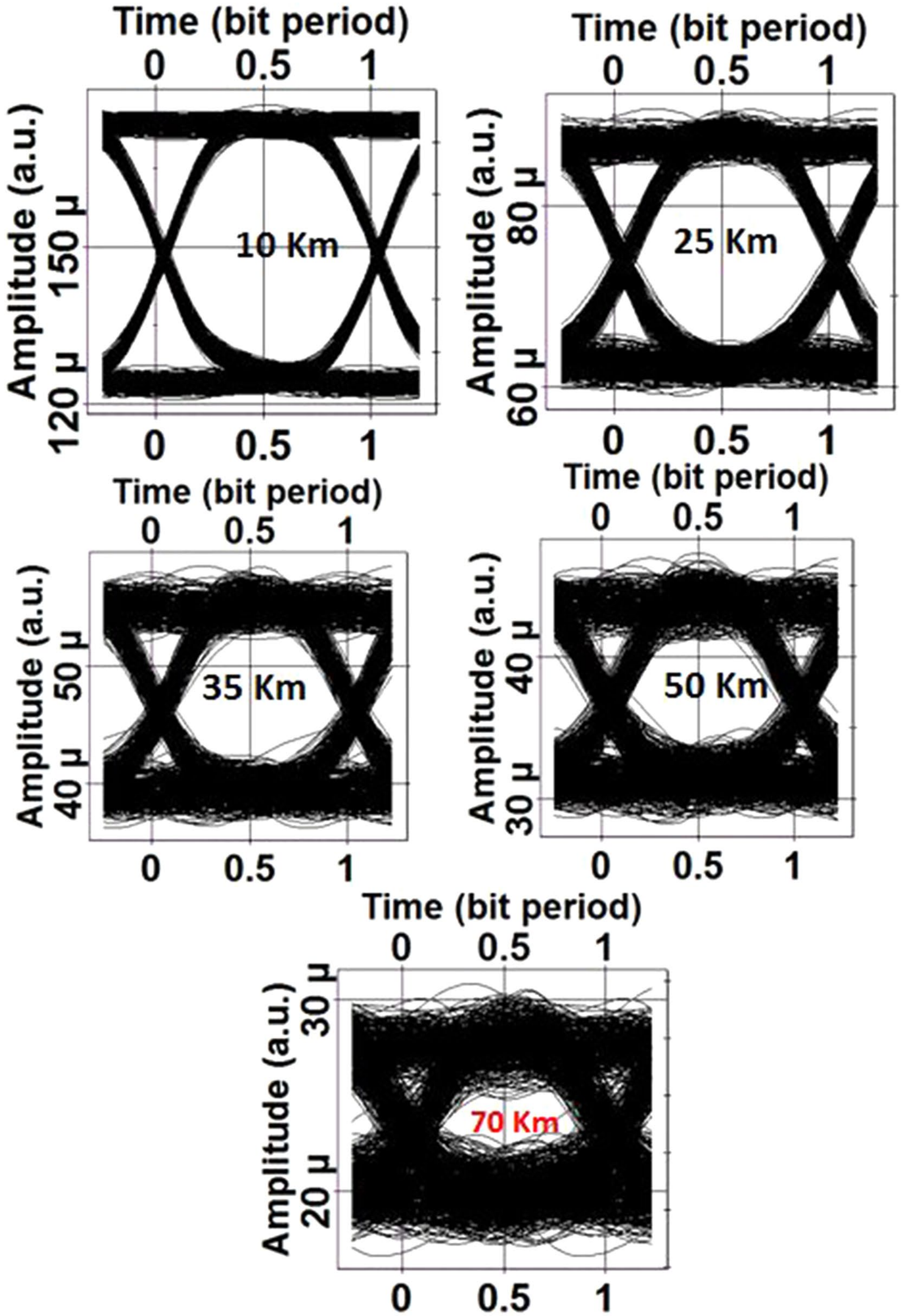


Fig. 9 Eye diagram of 60 GHz millimeter wave generated for 10 Gbit/s for different lengths of SSMF

5.2 Eye diagram for 5 Gbit/s and 10 Gbit/s for different SSMF lengths

To demonstrate the influence of the length of the SSMF on the transmission, we simulate the *Q* factor for different values of optical fiber length. Figure 7 shows that by increasing the length of the optical fiber, from 10 to 70 km the quality factor *Q* decreases. The quality factor drops from 85.22 to 9.53 with a BER of 7.6973×10^{-9}.

We simulated the transmission for different lengths of SSMF for a Bragg filter reflected band of 10^{-7} GHz and a flow rate of 5 Gbit/s. Figure 8 shows that the eye diagrams of 60 GHz signal versus the optical fiber length are very clear and open for 10 km, 25 km and 35 km. The clarity of the eye diagram decreases with the increase in length. For a length of 70 km, the eye diagram remains open but less clear.

To demonstrate the performance of the proposed system for high flow rates, we simulated the transmission for 10 Gbit/s. As shown in Fig. 9, the eye diagram remains clear up to 50 km. By increasing the length of the SSMF, the transmission starts to degrade; for a fiber length of 70 km, the eye diagram is almost closed with a BER of 0.67×10^{-7}.

6 Conclusion

In this paper, we have attempted to demonstrate the generation and transmission of a 60 GHz mm-wave signal based on narrowband Bragg filters. The millimeter wave is obtained by optical beat of the coupled narrow bands generated by the Bragg filters. The simulation results show the improvement in the BER and the quality factor *Q* for 5 Gbit/s and 10 Gbit/s flow rates also for a length of fiber link up to 50 km.

The system proposed in this paper can be used in several RoF applications: ADSL, cellular communications, wireless systems, etc.

Compliance with ethical standards

Conflict of interest The author(s) declare that they have no competing interests

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