ISSN 1330-3651(Print), ISSN 1848-6339 (Online)
UDC/UDK 681.7.067.5:621.376.5

INVESTIGATION OF ALL-OPTICAL INVERTER SYSTEM WITH NRZ AND RZ MODULATION FORMATS AT 100 Gbit/s

Pallavi Singh, D. K. Tripathi, N. K. Shukla, H. K. Dixit

Original scientific paper

The paper presents the comparative investigation on non-return-to-zero and return-to-zero modulation formats for optical inverter gate at 100 Gbit/s. Various performances as eye pattern, extinction ratio and bit error rate at different bit-rate are compared based on suitability of data formats. It indicates that return-to-zero pulses are distorted in a similar pattern, therefore bit error rate is better than non-return-to-zero format. The non-return-to-zero is more affected by non-linearity of semiconductor optical amplifier hence the bit error rate is degraded and extinction ratio is improved.

Keywords: *Bit error rate (BER), extinction ratio (ER), non-return-to-zero (NRZ), return-to-zero (RZ), semiconductor optical amplifier (SOA)*

Istraživanje sustava optičkih pretvarača s formatima NRZ i RZ modulacije kod 100 Gbit/s

Izvorni znanstveni članak

U radu se predstavlja komparativno istraživanje formata modulacije ne-vraćanje-na-nulu (non-return-to-zero) i vraćanje-na-nulu (return-to-zero) za ulazu optičkog pretvarača kod 100 Gbit/s. Uspoređuju se različite performanse kao što su dijagram oka, omjer gašenja i učestalost pogrešnih bitova kod različite učestalosti bitova na osnovu prikladnosti formata podataka. To pokazuje da su impulsi vraćanja na nulu promijenjeni po sličnom uzorku te je stoga učestalost pogrešnih bitova bolja od formata non-return-to-zero. Na format non-return-to-zero više djeluje nelinearnost optičkog pojačala poluvodiča te je stoga degradirana učestalost pogrešnih bitova, a poboljšan omjer gašenja (ekstinkcije).

Ključne riječi: *ne-vraćanje-na nulu (NRZ), omjer gašenja (ekstinkcije) (ER), optičko pojačalo poluvodiča (SOA), učestalost pogrešnih bitova (BER), vraćanje-na nulu (RZ)*

1 Introduction

The key elements in all-optical network for implementing various signal processing are optical logic gates. Nowadays optical technology has become a fundamental need to realize high speed signal processing. Today all-optical logic gates are most promising field for researchers to implement high speed optical signal processing. In the paper [1] author A. Bogoni et al. demonstrated 640 Gbit/s all-optical AND gate function using periodically poled lithium niobate waveguide structure operating between two synchronized optical time division multiplexed signals. The optical modulation formats is also an important parameter to optimize the system performances, as it can increase the speed of optical transmission systems. The main aim of modulation formats is for the reduction of non-linear impact and improvement of the spectral efficiency at high bit rate in optical systems. For wavelength division multiplexing (WDM) systems the NRZ is affected by non-linearity of the optical fibre but RZ is affected by dispersion, due to high modulation bandwidth [2]. In papers [3, 4] RZ and NRZ modulation formats have been investigated on different criteria. In 1999, C. Caspar et al. experimentally investigated that NRZ suffers from nonlinear signal distortion and RZ allows simple linear dispersion compensation. Therefore to design a network NRZ modulation format makes it complicated [5]. In [6], authors concluded that NRZ pulse shape is superior to RZ, for systems which are limited by amplified spontaneous emission noise, fiber chromatic dispersion, self-phase modulation and also for duo-binary transmission systems.

The incoming digital information represents the approach by the modulation formats for each optical carrier. The speed and capacity of optical signal processing should not be confined to its cost and complexity. For bit rate above 10 Gbit/s, the optical signal-to-noise ratio should ideally scale up by the same amount for the bit error rate (BER) to remain unchanged. All optical logic gates are based on cross gain modulation (XGM), cross phase modulation (XPM), four wave mixing (FWM) in semiconductor optical amplifier (SOA) [7 ÷ 9]. The design discussed here is a resultant of XGM in SOA and phase modulation in MZI. For XGM two optical signals of different wavelengths lying within the bandwidth of SOA pass through it. Due to the stimulated process in SOA, the minority carrier concentrations are depleted through the pump signal. Hence, the minority carrier concentration is diminished, the pump signal will not be amplified, but it will be depleted. The high energy to the low energy state is a cross talk phenomenon which depends upon the spontaneous emission in SOA.

Phase modulation is produced by introducing the data pulse in MZI by 2×2 coupler which creates a phase shift of π/2 in data pulse travelling through upper and lower arm of interferometer. After passing through both the arm of MZI again it is fed into 2×2 coupler to create a phase shift of π/2. Therefore the total phase shift at T-port will become π and data will be cancelled.

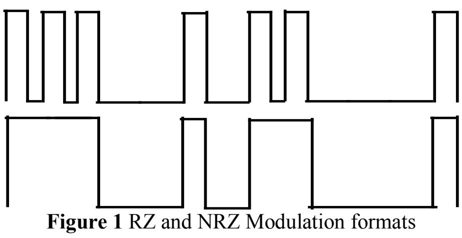


Figure 1 RZ and NRZ Modulation formats

Fig. 1 shows commonly used RZ and NRZ modulation formats in optical as well as digital systems. In RZ, the fraction of bit interval is occupied for '1' bit and for ‘0’ bit no pulse is used, as in NRZ. In optical systems, bit interval occupied by pulse is variable, which means the power is transferred only for fraction of bit period. In digital systems, it means only half of the bit interval is occupied. It is used to describe the solution where the pulse occupies only a small fraction of bit interval. The RZ signal spectrum is broader than NRZ because it suffers from nonlinear signal distortion for high bit rate above 10 Gbit/s. The RZ modulation format is resistant to self-phase modulation (SPM) and chromatic dispersion, as all pulses are distorted in the same way unlike NRZ, degrading the pattern effect. NRZ is the simplest modulation format, therefore it is commonly used in optical communication systems. As the name mentioned for NRZ i.e. non-return-to-zero, the optical power will not return to zero in consecutive ‘1’. NRZ occupies a smaller band-width, about half of the RZ format which makes it superior in optical communication systems. There are certain problems which occur in both RZ and NRZ. When a string of zeros occurs, the receiver is unable to differentiate between the string of 0’s or no transition. The NRZ modulated pulses travelling through optical fibre will undergo the effect of XGM which includes the amplitude distortion penalty. Due to the XGM the eye pattern will be degraded. The investigation is done on XGM effect in inverter system for different modulation formats.

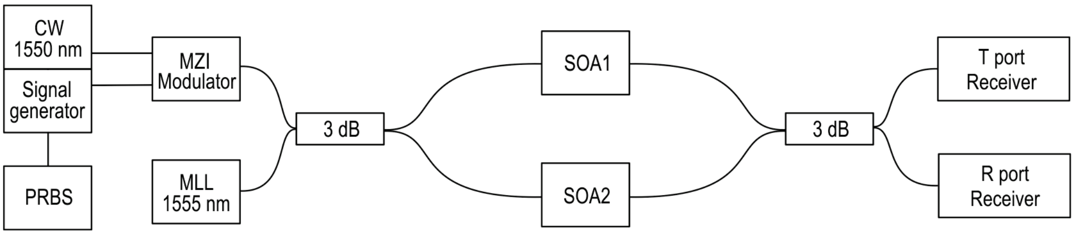


Figure 2 Schematic diagram of Inverter gate layout and principal of operation

2 Operation principal

The design of given inverter gate, as in Fig. 2, consists of a symmetrical Mach-Zhender Interferometer (MZI) where the two SOAs are placed at the upper and lower arm of MZI [10, 11]. The optical data (1111110000001000011) is fed in the upper arm of first 3dB coupler to perform Boolean inverter operation. Mode lock laser (MLL) is used to generate a continuous clock pulse which is fed into the lower arm of first 3 dB coupler. The phase shift of π/2 is produced between upper and lower arm of data pulse travelling through it, as it is fed into the first 3 dB coupler. When SOA is operated under the gain saturation condition, clock and data of different wavelengths are injected. The available optical gain is distributed between the two wavelengths depending upon their relative photon densities. Thereby, the clock pulse is compressed, giving the inverse effect on the gain, available to the data wavelength. After passing through SOAs these saturated signals are fed into the second 3 dB coupler, again the phase shift of π/2 is created. Therefore, the total phase shift will become π at T-port for data pulse. Hence the data pulse will be cancelled at T-port and only clock pulse with compressed form will give the inverter operation.

3 Results and discussion

In the simulation, the data stream of 100 Gbit/s bit rate is taken to prove the principal of inversion operation for different modulation formats such as RZ and NRZ. Mode lock laser of frequency 10 GHz operating at 1555 nm with optical power of $1{,}0\times10^{-3}$ W at 0,1 ps clock pulse is taken. Probe pulse was formed by 100 Gbit/s, 2^7-1 Pseudorandom binary sequence (PRBS) pattern generated with 0,05 W at 1550 nm. The electrically generated pulse is modulated in RZ and NRZ formats to achieve good results. Both clock and data pulses pass through first 3 dB coupler and propagate through SOAs. The confinement factor, line width enhancement factor and injection efficiency are set at 0,3; 5,0 and 1,0, respectively. To achieve cross gain modulation in SOA, the pump current is set at 7,0 A. The length, width and depth of SOAs are $5{,}0\times10^{-4}$, $3{,}0\times10^{-6}$ and $1{,}5\times10^{-7}$ meter, respectively.

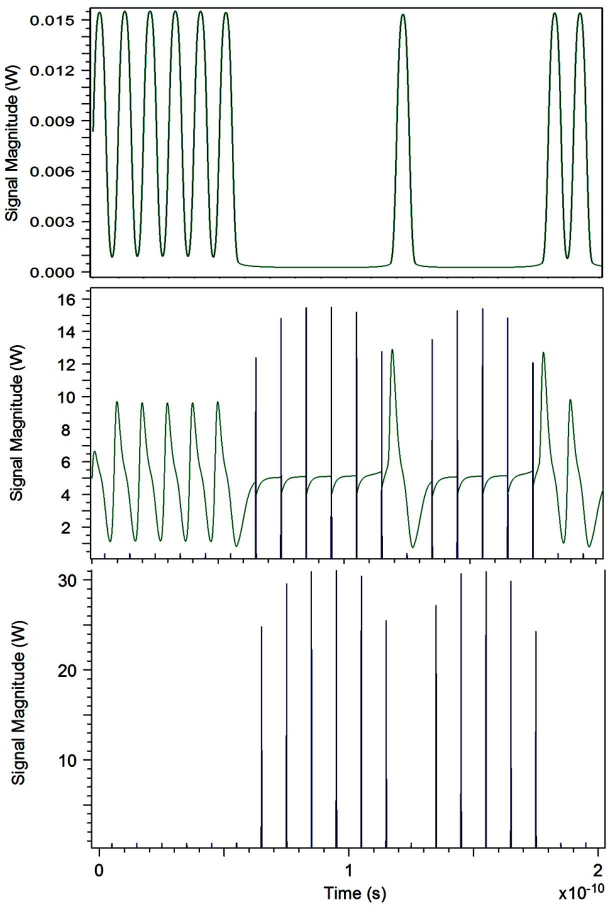


Figure 3 Data produced through CW laser, RZ saturated pulse after passing through SOA and resultant inverted pulse at T-port

In RZ modulation format, clock pulse and data pulse are synchronized such that they pass through SOAs. For each data pulse there is a clock pulse which separately saturates it, to achieve a good bit error rate. The time shift of a data pulse arises from the shift of its carrier frequency due to the collision with a clock pulse. So the resultant pulse at the transmission port is compressed wherever the data pulse is present as in Fig. 3.

In NRZ modulation format, the pulse width is greater than RZ, so the energy is saturated in each pulse and will become more than RZ. After passing through SOA, there will be XGM and the resultant pulse is compressed, taking the energy of next pulse. Therefore, inverted pulse of high power is obtained at T-port because output threshold decision level for pulse 1's and 0's are high compared to RZ pulse as shown in Fig. 4. The effect of XGM during collision is not only to distort the pulse amplitude but also to vary the arrival time of the pulse at T-port. This contributes to the total timing jitter defined as the standard deviation of the time shift of all pulses.

Fig. 5 shows the eye pattern of RZ and NRZ modulation formats showing the degraded eye pattern of NRZ. The shape of received bit pattern is affected by non-linearity of SOA i.e. XGM and FWM. It is also influenced by bit value of its neighbourhood. Therefore, in NRZ the bit pattern is distorted compared to RZ.

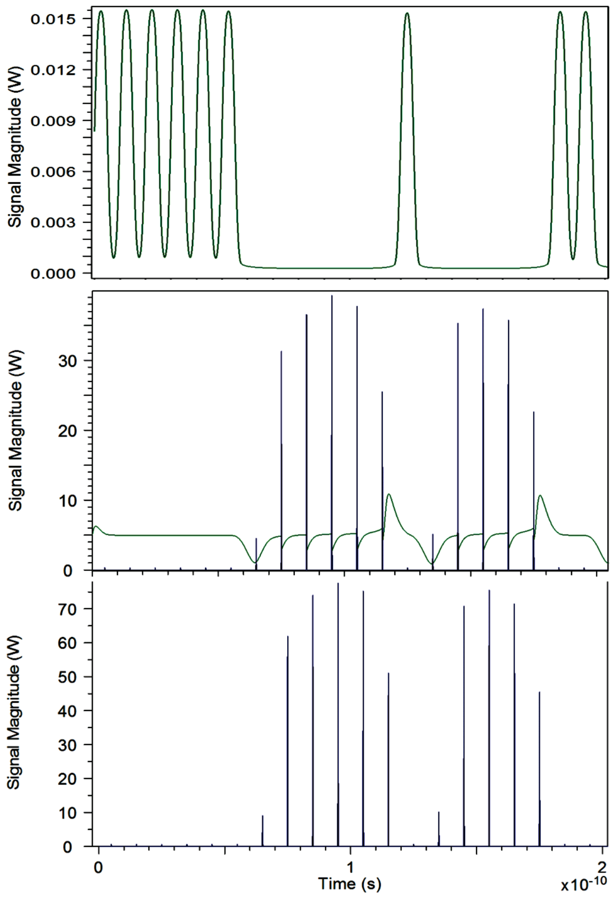


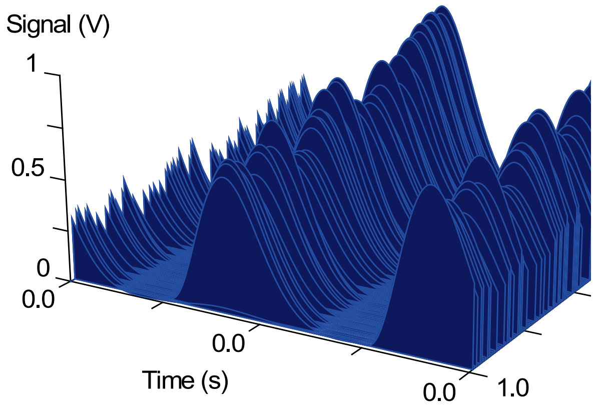
Figure 4 Data produced through CW laser, NRZ pulse after passing through SOA and resultant inverted pulse at T-port

In order to assess the performance of inverting operation the extinction ratio (*ER*) and bit error rate (*BER*) are evaluated. Extinction ratio is defined as the ratio of minimum value of peak power of ones to maximum value of peak power of zeros at transmitted port [12].

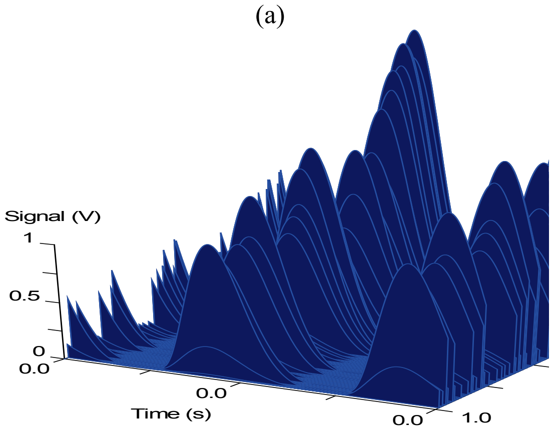
$$ER = 10\lg\frac{\text{minimum value of } P_{1,\,\text{Tran}}}{\text{maximum value of } P_{0,\,\text{Tran}}},\ \text{dB} \tag{1}$$

where $P_{1,\text{Tran}}$ − Peak power of ones at Transmission port, $P_{0,\text{Tran}}$ − Peak power of zeros at Transmission port.

The *BER* is defined as the probability of an error occurring per transported bit. The benchmark for *BER* is 10^{-9} to 10^{-12}, with the use of forward error correcting (FEC) code. In the above case lower rate may be possible since the Gaussian noise will affect the transmission system.



(a)



(b)

Figure 5 Eye pattern for (a) RZ format (b) NRZ format

The two distributions which govern the spread of upper and lower bars of the eye are given by mean value v_0 and v_1 with width of σ_0 and σ_1, respectively.

$$BER = \frac{1}{4}\left(erf\left[\frac{v_1 - v_{\text{level}}}{\sigma_1\sqrt{2}}\right] + \left[\frac{v_0 - v_{\text{level}}}{\sigma_0\sqrt{2}}\right]\right), \tag{2}$$

where v_{level} specify the threshold decision level which is given as

$$v_{\text{level}} = \frac{v_1\sigma_0 - v_0\sigma_1}{\sigma_0 + \sigma_1}. \tag{3}$$

Figs. 6 and 7 show the variation of ER and BER at different data wavelengths for three different bit-rates i.e. 100 Gbit/s, 110 Gbit/s and 120 Gbit/s. The extinction ratio for RZ modulation format at 100 Gbit/s, for data wavelength at 1550 nm, is degraded to 13,62 dB. This is because the energy saturated in each pulse will be relatively less than NRZ, but eye pattern will be good because the Gaussian noise is more in NRZ compared to RZ. The BER for RZ and NRZ at 100 Gbit/s, 1550 nm are 10^{-10} and $.08\times10^{-3}$ respectively.

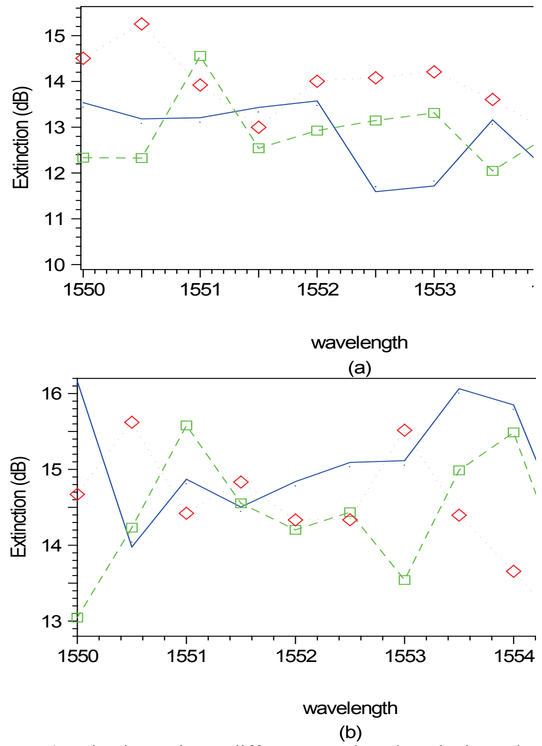


Figure 6 Extinction ratios at different wavelengths. The legends are given as 100 Gbit/s as blue, 110 Gbit/s as green, 120 Gbit/s red for (a) RZ (b) NRZ format.

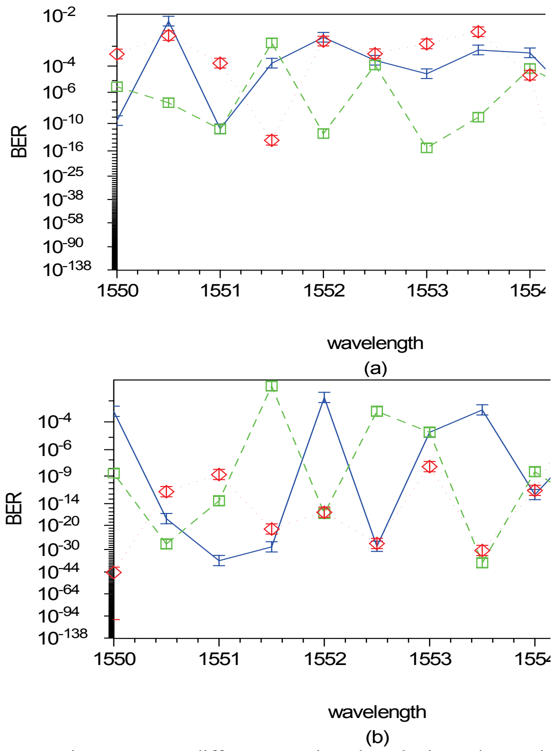


Figure 7 Bit error rate at different wavelengths. The legends are given as 100 Gbit/s as blue, 110 Gbit/s as green, 120 Gbit/s as red for (a) RZ (b) NRZ format.

4 Conclusion

To design an optical gate, the choice of clock and modulation formats are an important parameter. The NRZ is affected by the pattern effect of its neighbourhood bits and also depends upon the non-linearity of SOA. Therefore, saturated pulse power is high in NRZ that gives good result of ER i.e. 16,23 dB than RZ format. In RZ format the pulses are distorted in a similar pattern giving a good eye pattern and *BER* i.e. 10^{-10}.

5 References

[1] Bogoni, A.; Wu, X.; Bakhtiari, Z.; Nuccio, S.; Willner, A. E. 640 Gbits/s photonic logic gates. // Opt. Lett. 35, (2010), pp. 3955-3957.

[2] Hayee, M. I.; Willner, A. E. Versus RZ in 10-40 Gb/s Dispersion-Managed WDM Transmission System. // IEEE Photon. Technol. Lett. 11, 8(1999), pp. 991-993.

[3] Kaur, J.; Sharma, N. Effects of Amplified Spontaneous Emission (ASE) on NRZ, RZ and CSRZ Modulation Formats in Single Channel Light-wave System. // ETNCC. (2011), pp. 61-64.

[4] Mauro, Y.; Lobanov, S.; Raghavan, S. Impact of Modulation Format on the Performance of Fiber Optic Communication Systems with Transmitter-Based Electronic Dispersion Compensation. // OFC/NFOEC. (2007), pp. 1-3.

[5] Caspar, C.; Foisel, H. M.; Gladisch, A.; Hanik, N.; Kuppers, F. And Ludwig, R. RZ Versus NRZ Modulation Format for Dispersion Compensated SMF-Based 10 Gb/s Transmission with More Than 100-km Amplifier Spacing. // Photon. Technol. Lett. 11, 4, (1999), pp. 481-483.

[6] Chien, C.; Lyubomirsky, I. Comparison of RZ versus NRZ Pulse Shapes for Optical Duobinary Transmission. // Journal of Lightwave Technol. 25, 10 (2007), pp. 2953-2958.

[7] Stubkjaer, K. E. Semiconductor optical amplifier-based all-optical gates for high-speed optical processing. // IEEE, J. Sel. Top. Quantum Electron. 6, 6(2000), pp. 1428-1435.

[8] Kim, S. H.; Kim, J. H.; Son, C. W.; Kim, G. Implementation of All-Optical Logic AND using XGM based on Semiconductor optical amplifier. // COIN. (2006), pp. 247-249.

[9] Xu, J.; Zhang, X.; Dong, J.; Liu, D.; Huang, D. Ultrafast all-optical AND gates based on Cascaded SOAs with assistance of optical filters. // Electronics Lett. 43, 10(2007), pp. 585-586.

[10] Singh, P.; Dixit, H. K.; Tripathi, D. K.; Mehra, R. Design and analysis of all-optical inverter using SOA based Mach-Zhender Interoferometer. // Elsever-Optik, 124, (2013), pp. 1926-1929.

[11] Singh, P.; Tripathi, D. K.; Jaiswal. S.; Dixit, H. K. Design of all-optical buffer and OR gate using SOA-MZI. // Opt. Quant. Electron. DOI 10.1007/s11082-013-9856-0.

[12] Houbavlis, T.; Zoiros, K. E.; Kanellos, G. and Tsekrekos, C. Performance analysis of ultrafastall-optical Boolean XOR gate using semiconductor optical amplifier-based Mach-Zehnder Interferometer. // Optics Communications 232, (2004), pp. 179-199.

Authors' addresses

Pallavi Singh *(corresponding author)*
Department of Electronics and Communication, University of Allahabad, Allahabad-211002, India
E-mail: singh.pallavi73@gmail.com

Devendra Kumar Tripathi
Department of Electronics and Communication, University of Allahabad, Allahabad-211002, India
E-mail: dekt@rediffmail.com

Narendra Kumar Shukla
Department of Electronics and Communication, University of Allahabad, Allahabad-211002, India
E-mail: nksjkiapt@gmail.com

Hemant Kumar Dixit
Department of Electronics and Communication, University of Allahabad, Allahabad-211002, India
E-mail: hkdixit@gmail.com