

Designing Optical Beam Filter And Detector Based On Photonic Crystals Structure By FMCW method

Reza Khodadadi *, Parviz Amiri **

*(Department of Electrical Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran.)

** (Electrical and Computer engineering Department, Shahid Rajaee Teacher Training University, Tehran, Iran.)

ABSTRACT

In this study designing and simulation of laser range finder has been studied by FMCW method that a set based on one-dimensional photonic crystals structure as mid-pass filter and beam detector has been replaces and designed. The material of Silicon (Si) and Germanium (Ge) has been considered and gained by transfer matrix method (TMM) of light detector with too narrow band width, about 5 nanometers. Also by using of defect effect and apodization of refraction coefficient profile, wave length bound of optical detector from (630 nm – 645 nm) becomes controllable. So measuring ranges is by choosing transmitter's laser type and it depends on the wave length of transmitted beam and proportionate to it, error percentage of system is decreased.

Keywords - Range finder, Frequency Modulation of Continuous Wave (FMCW), detector, photonic crystals

I. INTRODUCTION

Since there are different technics in measuring distances as time of flight (TOF), frequency modulation of continuous wave (FMCW) and phase change, it is possible to measure in each condition by continuous spectrum of signal or pulse transmission [3,4]. In this research, we will study distance measuring by frequency modulation of continuous wave (FMCW). As we know, using the technics of continuous wave (CW) or laser, one after another, is applied for average distances [1, 3, 4]. Diagram block of distance measuring system by modulation of continuous wave has been shown in figure (1). On the other hand, applying laser, one after another, is not possible and because of recognizing beam reflector from far distances, laser with relatively high power is needed. So in this condition parameters such as cost, dimension and heat stability of system are introduced [5, 6]. Using high power laser with wave repeat or wave continuity is impossible and one of the reasons for measuring distances that are more than one kilometer by laser pulse transmission is the amount of transmitted beam power. On the

other hand, applying laser, one after another, is not possible and because of recognizing beam reflector from far distances, laser with relatively high power is needed; so in this condition parameters such as cost, dimension and heat stability of system are introduced [5, 6]. Using high power laser with wave repeat or wave continuity is impossible and one of the reasons for measuring distances that are more than one kilometer by laser pulse transmission is the amount of transmitted beam power.

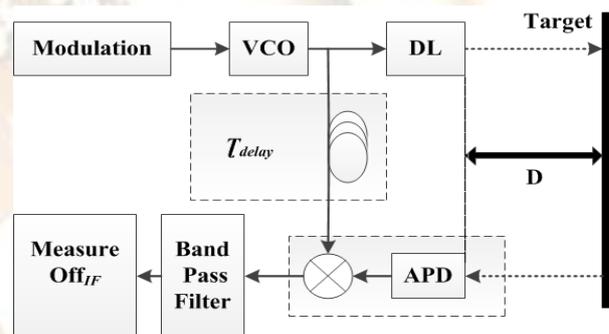


Fig. 1. One sample of diagram block of distance measuring system

According to FMCW method structure, commuting time of conversion is differentiated to frequency and by this way measuring becomes easy for short and average distances. Therefore in this process, laser in continuous state of CW is used and mentioned state is useable in low powers, so as mentioned before, it's applicable for low distances [4, 5, 6]. Since the amount of measuring error and accuracy of system is considered in this condition, for receiving the transmitted beam we should provide condition in a way that can detect transmitted beam. Also since we have some limitations in increasing band width of modulation wave frequency (linear function of system) [1, 4], if we limit received and transmitted wave length in a special band width by offering a structure based on photonic crystals, we could record the amount of distance or measured changes by detecting received wave length, Figure (2), [5, 6, 7].

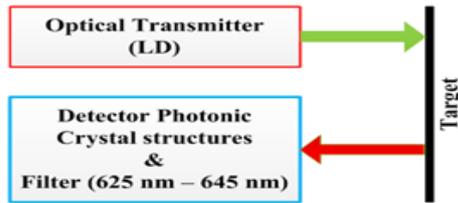


Fig. 2. The block of how beam is received in designed structure

II. FUNCTION OF FMCW METHOD AND INTRODUCING STRUCTURE

In FMCW method, laser power of frequency modulated with sloped surface or sinus wave is done by PRI (Pulse Repetition Interval) alternation period [2, 4]. In this paper transmitted signal $f_e(t)$ and received signal $f_r(t)$ with minimum (f_{min}) and maximum (f_{max}) modulation frequency in band width bound has been called B that received signal after returning from a time delay is t_d that we can observe frequency difference of beat in both signals as $f_{IF} = f_c(t) - f_r(t)$, Figure (3).

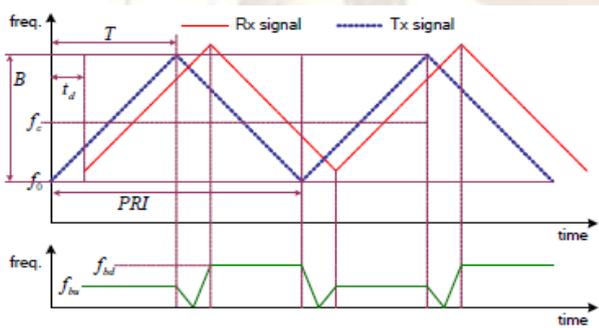


Fig. 3. Specifications of received and transmitted signal and their difference

In conditions that purpose is assumed fixed, we can measure summation difference and received and transmitted frequencies difference according to(1) equation that parameter d is the amount of measured distance and parameter V, purpose speed (movable).In this way, acceptable ambiguity bound is $CT/2$ [4,5,6].

$$f_r = \frac{|f_{bu} + f_{bd}|}{2} \quad (1)$$

$$f_d = \frac{|f_{bu} - f_{bd}|}{2} \quad (2)$$

$$d = \frac{c.T.f_r}{2.B} \quad (3)$$

Approximate amount of distance measuring is calculated by equation (4) and if purpose is no t fixed, by equation (5) speed measuring is provided.

$$d = \frac{c.PIR.F_a}{4.\Delta F} \quad (4)$$

$$V = \frac{c.f_d}{4.f_c} \quad (5)$$

III. FUNCTION OF FMCW METHOD AND INTRODUCING STRUCTURE

For measuring and comparing minimum and maximum distance, in two following states, we study how wave is transmitted and then we consider resulted comparisons as follows:

- a) Triangle and sawtooth wave with $f_m = 2$ KHz
 - b) Triangle and sawtooth wave with $f_m = 1$ KHz
- Then after studying each case, quantitative comparison is done between two states.

First state: triangle and sawtooth wave with $f_m = 2$ KHz

In this state by exerting modulation signal of triangle and sawtooth wave with $PIR = 0.0005$ in bound of 4 KHz minimum and 60 KHz maximum, We can study condition by (6) and (7) equations that mentioned signals difference (Frequency Beat) is observed in (4) and (5) figures.

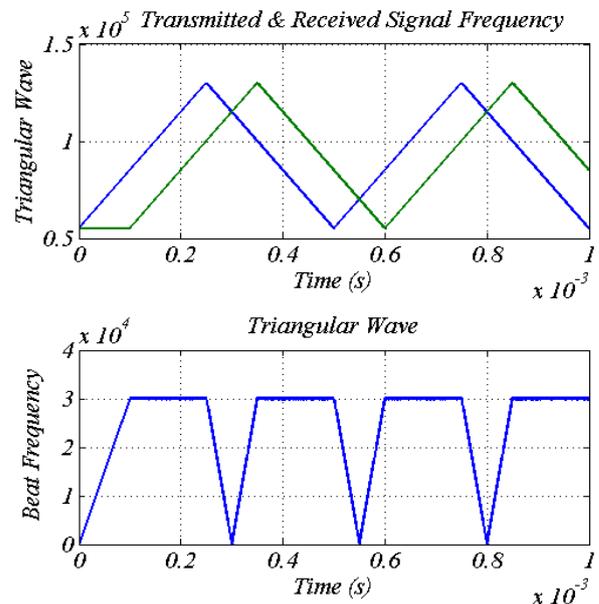


Fig. 4. Transmitted and received triangle signal with $f_m = 2$ KHz with delay (above figure) - two signals difference (following figure)

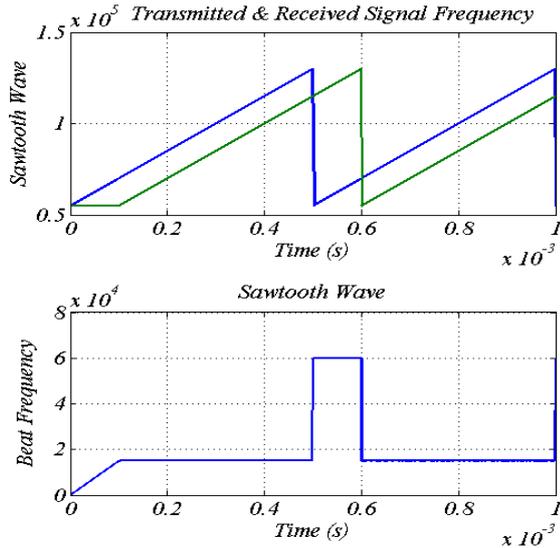


Fig. 5. Transmitted and received sawtooth signal with $f_m = 2$ KHz with delay (above figure) – two signals difference (following figure)

$$F_{a(\min)} = \frac{4.B.d_{\min}}{c.PIR} = 4\text{KHz} \quad (6)$$

$$F_{a(\max)} = \frac{4.B.d_{\max}}{c.PIR} = 60\text{KHz} \quad (7)$$

So we can study the results of minimum and maximum measuring amounts of distances from 2m to 30m have been considered in figure (6) for both triangle and sawtooth wave in a condition that $PIR = 0.0005$ and observe done calculations.

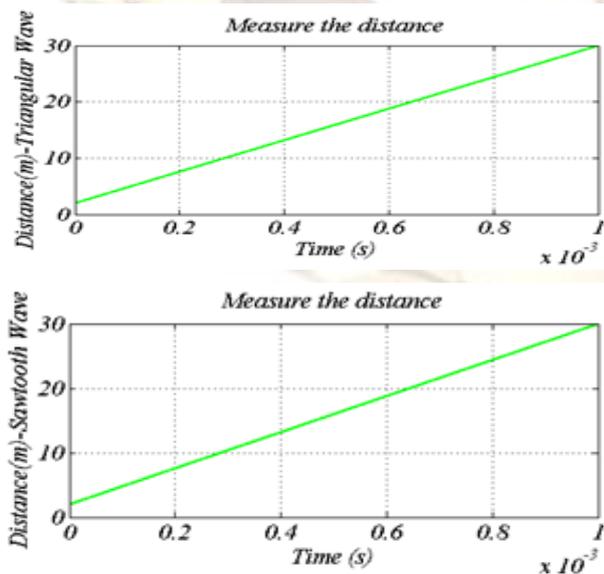


Fig. 6. Minimum and maximum distance with $PIR=0.0005$ of triangle wave (above figure) – sawtooth wave (following figure)

Second state: Triangle and sawtooth wave with $f_m = 1$ KHz

In this state according to mentioned conditions, by exerting modulation signal of triangle and sawtooth wave with $PIR = 0.0001$ in bound of 4 KHz minimum and 60 KHz maximum, we can study existed signals difference (Beat Frequency) and observe them in (7) and (8) figures [1, 2, 4].

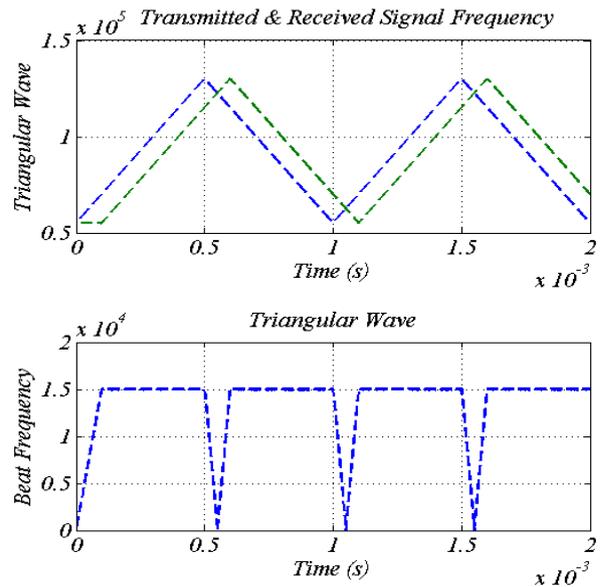


Fig. 7. Transmitted and received triangle signal with $f_m = 1$ KHz with delay (above figure) – two signals difference (following figure)

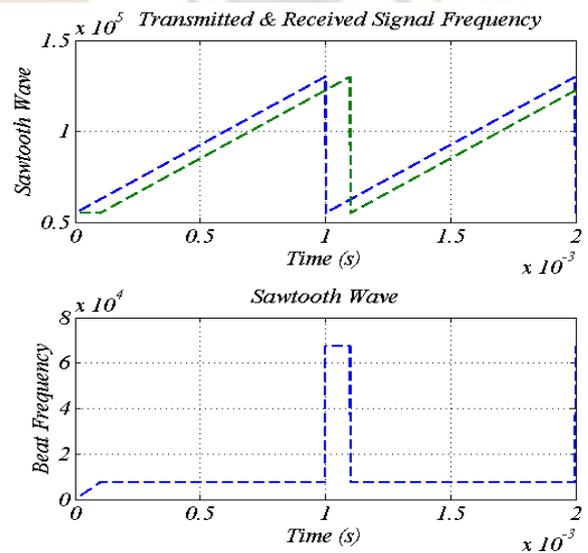


Fig. 8. Transmitted and received sawtooth signal with $f_m = 1$ KHz with delay (above figure) – two signals difference (following figure)

By observing distance amounts change in figure (9), we can see increase in distance measure from minimum amount of 4m to maximum amount of 60m and consider gained results with PIR=0.001 and compare with figure (6).

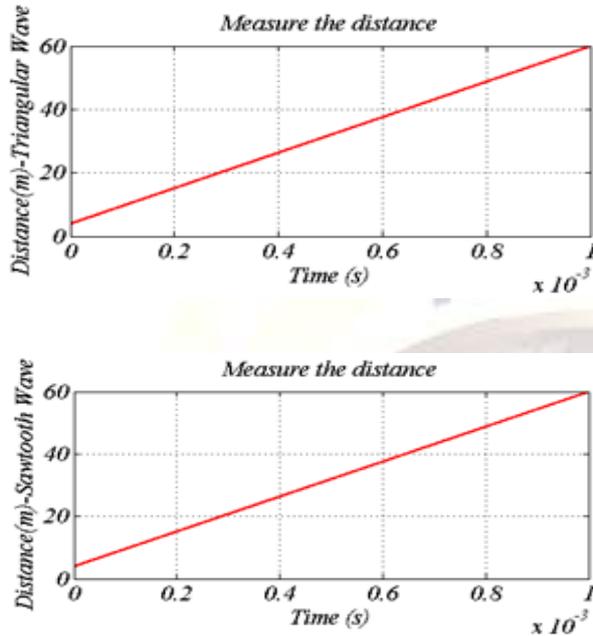


Fig. 9. Minimum and maximum distance with PIR= 0.001 of triangle wave (above figure) –

sawtooth wave (following figure)

Therefore we can conclude that one of the methods of increasing measure of maximum and minimum amounts is distance bound of frequency decrease of f_m modulation wave that enforcing this condition has limitation and because of having linear function, we can't increase PIR more than limit amount [6]. So as we observe in figure (9), to increase distance measure bound from minimum amount of 4m to maximum amount of 60m, conditions are provided in a way that by exerting triangle or sawtooth wave with 1 KHz alternation period, we can gain considered results. So according to identical conditions of minimum and maximum modulation frequency in each two triangle and sawtooth signal, we can conclude that by increasing the amount of alternation period of modulation signal (PIR), measureable distance is increased and in fact, according to equation (8) this condition has reverse relation with frequency modulation of considered wave (triangle or sawtooth wave) [5, 10].

$$T = \frac{1}{f_m} = PIR \uparrow \Rightarrow d \uparrow \quad (8)$$

Now according to the function of system against PIR changes, we study

wave figure of received and transmitted mixed signal with modulation wave frequency of $f_m = 2$ KHz and analyze simulation results to observe input beam to considered mid-pass filter.

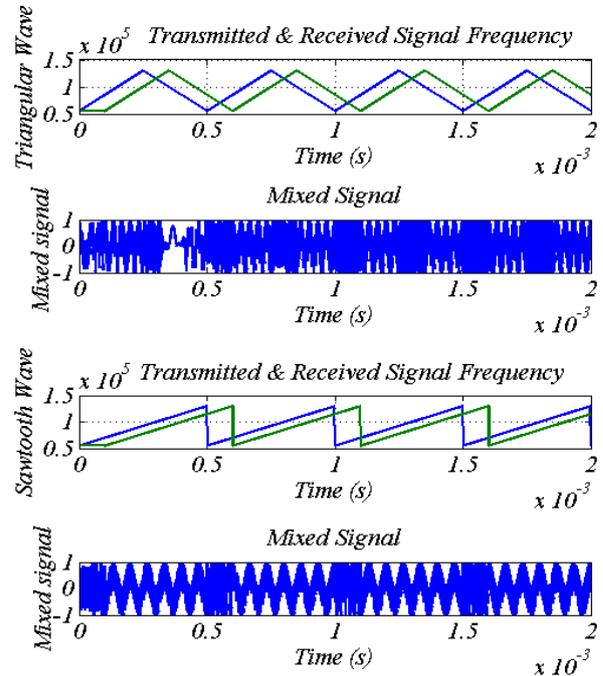
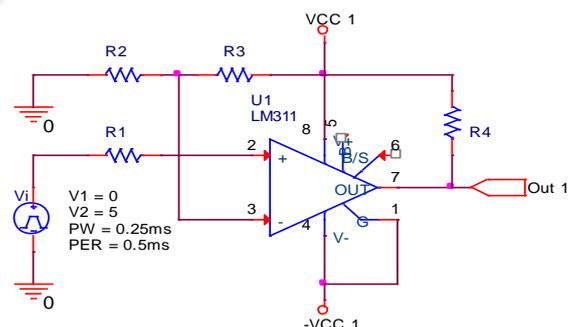


Fig. 10. Wave figure of mixed signal in two states (triangle – sawtooth) with modulation frequency of 2 KHz

Since in distance measuring of system structure, APD is used to detect received and transmitted mixed signal [3, 4], in this condition by applying a mid-pass filter design considered band width and to measure distance, exert output final signal to one microcontroller (AVR). So in this study, first we offer performed design in circuit level and then explain the structure of suggested optical deflector by photonic crystals.

IV. DESIGNING IN CIRCUIT LEVEL

According to the block diagram of figure (1) in this design, circuit in figure (11) has been used as VCO unit for making 2 KHz triangle wave oscillator in controllable bound with 3 volt minimum and 7 volt maximum.



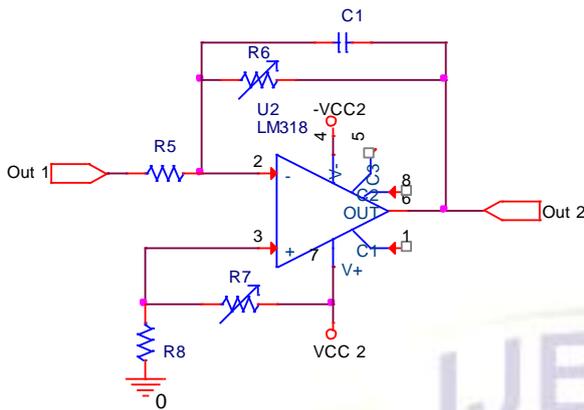


Fig.11. Triangle wave producer circuits with 2 KHz frequency

Working procedure of above circuit is at this way: first we should produce one slope signal for frequency modulation, in this design, we have used comparator ICs of LM311 model for producing TTL square pulse and complex circuit of LM318 model for making triangle wave producer.

So it's necessary to regulate voltage level of this pulse in a way that necessary slopes for triangle wave would be accessible, by changing suggested volume of R7 in sample design, we can change the amount of output offset level and control it. Also resistance amount of R6 variable is chosen so big that by increase in fixed time value of integration system, smooth triangle wave is made (or by choosing C2 variable condenser, we can increase capacity amount).

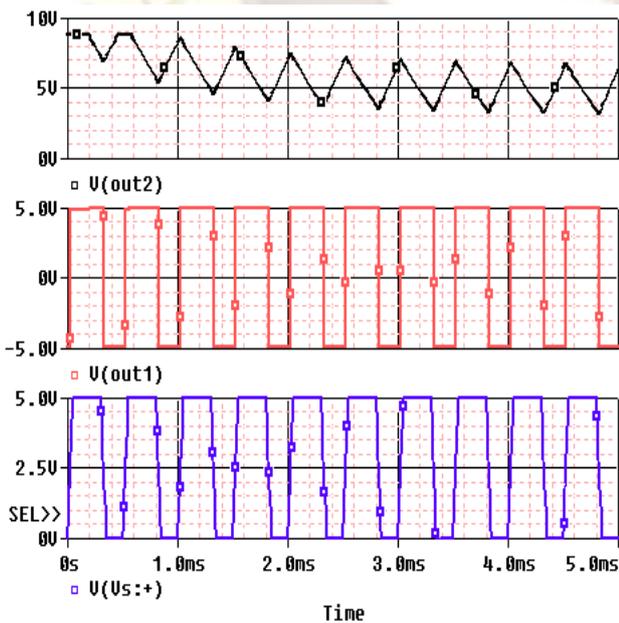


Fig. 12. Input - output pulse simulation signals, out1 and out2 of circuit of figure (11)

Therefore existing equations of this circuit are studied and analyzed as follows:

$$V_-(U1) = \frac{VCC1}{2}, V_+(U1) = V_{in} \quad (9)$$

$$\text{if } \rightarrow V_{in} > \frac{VCC1}{2} \Rightarrow V_o(U1) \approx VCC1 \quad (10)$$

$$\text{if } \rightarrow V_{in} < \frac{VCC1}{2} \Rightarrow V_o(U1) = V_1(U1) = -VCC1 \quad (11)$$

$$\begin{aligned} \text{SignalRamp} &\rightarrow \pm \frac{2 \times (V_{max} - V_{min})VCC1}{T_r} \\ &= \pm \frac{2 \times 4}{0.5 \times 10^{-3}} = 16000 \text{ V/s} \end{aligned} \quad (12)$$

$$V_{o(dc)}(U2) = V_+ \left(1 + \frac{R_6}{R_5} \right) = V_{dc}(\text{Ramp}) = 5 \quad (13)$$

$$\begin{aligned} V_{o(dc)}(U2) &= \frac{-1}{RC} \int V_i(t) dt \\ \Rightarrow \frac{VCC1}{R_5 \cdot C_1} &= 16000 \Rightarrow R_5 \cdot C_1 = \frac{VCC1}{16000} \end{aligned} \quad (14)$$

According to mentioned materials, in transmitting continuous wave modulation signal we can study the difference between simulations of range finder with two different states and compare the difference between these two states of MC1648 complex circuit.

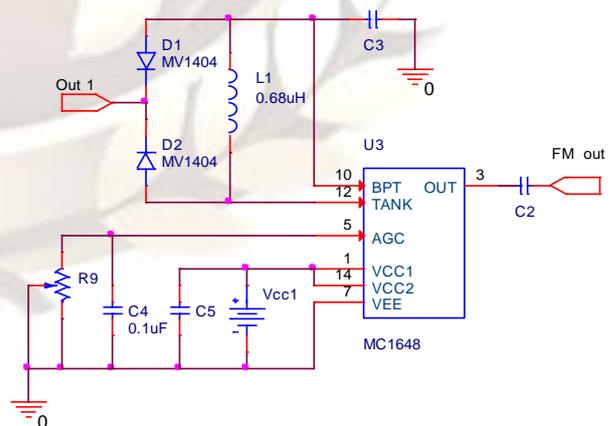


Fig. 13. VCO oscillator circuit by using of MC1648

Down complex circuit is a voltage controllable oscillator (VCO) in linear function bound of 55 MHz to 130 MHz.

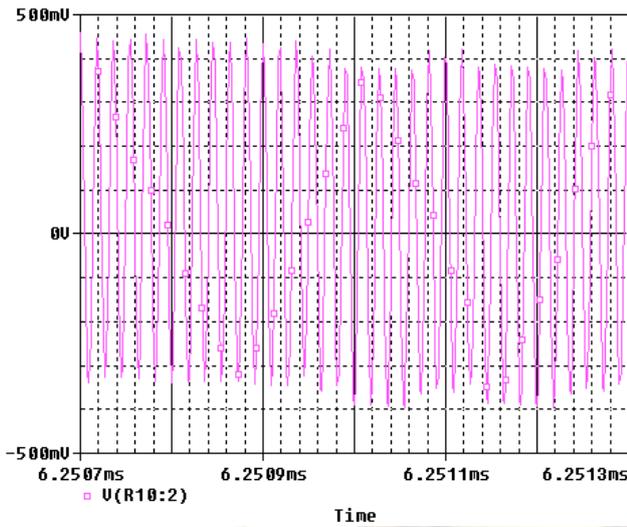


Fig. 14. Output signal of VCO oscillator

According to above conditions , we can make the driver of transmitted beam by stimulation of MC1648 complex circuit. So according to complex circuit data sheet,we select circuit elements proportionate to designing method to have $Q_L > 100$ maximum.

$$f_{\min} = \frac{1}{2\pi\sqrt{L(C_D(\max) + C_S)}} \quad (15)$$

Now according to mentioned conditions and oscillator signal production , we exert resulted output to a laser driver circuit . Applied laser diode of this design is SLD1132VS that in wave length bound is minimum 625 nm to maximum 645 nm that in normal condition and in normal temperature has 635 nm wave length with output power of $P_o = 3$ mW.

In this level ,through driver circuit of figure (15) ,wave length is transmitted by choosing laser transmitter that in this paper , SLD1132VS laser diode with normal wave length of 635 nm has been used for designing simulation part.As we know , oscillation extent for modulation of laser current is considered 10% of the amount of fixed current [6].

So laser current oscillates as 7 mA around 60 mA. In offered driver circuit we have used a differentiated reinforcement to control current by APC circuit , the duty of APC circuit is converting diode current to control current. So circuit form and related equations of laser diode function are as follows.

$$I_B(Q6) = I_{PIN} \quad (16)$$

$$I_C(Q3) = \frac{2V_{CC1} - 2V_{BE} - h_{fe}(Q6).I_{PIN}}{R_{10}} \quad (17)$$

$$I_{LD} = \frac{I_C(Q3)}{2} = \frac{V_{CC1} - V_{BE} - h_{fe}(Q6).I_{PIN}}{R_{C1}} \quad (18)$$

$$\frac{V_{FM}}{I_{LD}} = 2 \times \left[\frac{(R_E + h_{ie}(Q1))}{1 + h_{fe}} + R_E \right] = \frac{0.4(V/mA)}{7} \quad (19)$$

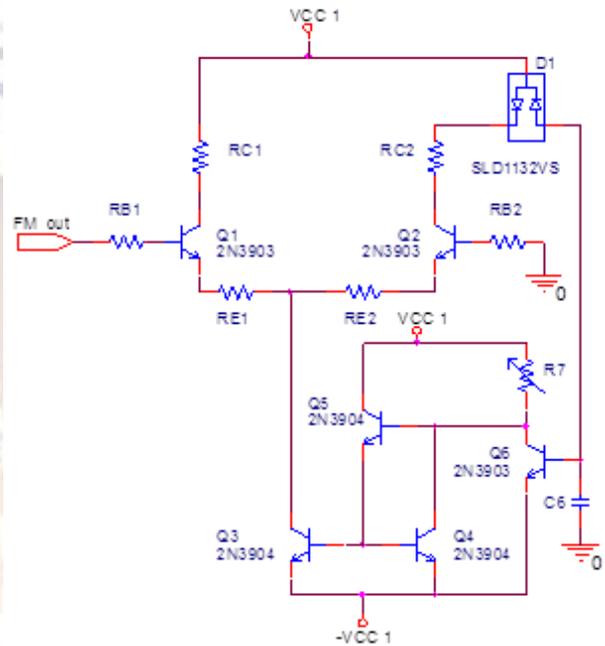


Fig. 15. SLD1132VS laser driver circuit

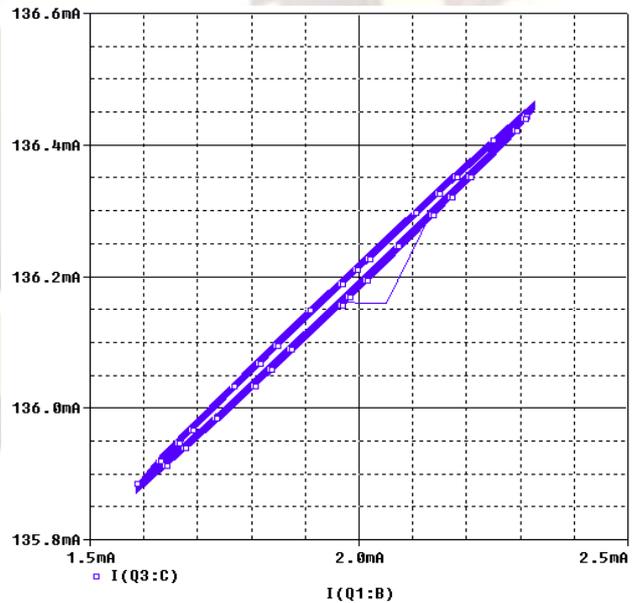


Fig. 16. Characteristic of simulated laser driver circuit gain

R_E resistances have been added to increase the bound of circuit linear function that for large

amounts of $2R_E \cdot I_{RE}$, in comparison with V_T linear bound it continues till this amount:

$$2R_E \cdot I_{RE} = |V_{FM}| \quad (20)$$

In this level by using of APD detector through receiving reflected beam, detection is done according to figure (1) block and then in acceptable band. In this level by using of APD detector through receiving reflected beam, detection is done according to figure(1) block and then in acceptable band width of 30 KHZ, according to figure (17) circuit, designed mid-pass filter is controlled. Since APD detector output signal is a mixed frequency harmonics that should pass through a filter to gain differentiated signal. For eliminating dc surface of mixer output signal, according to following figure we can use a third rank up-pass filter.

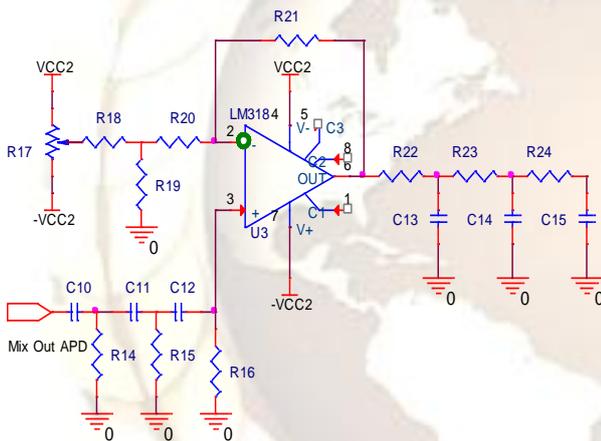


Fig. 17. Characteristic of simulated laser driver circuit gain

According to this condition, we have used an up-pass filter with high resistance amount in mixer output. Then it has been used an OP_Amp for buffering and correcting dc surface. So this condition leads to the separation of two down-pass and up-pass filters and omits loading effect on each other. Now after buffering, again it has used a third rank down-pass filter that eliminates existed high signals of spectrum. At this way, the output of filter is differentiated signal that should be reinforced. Mid-pass filter has $3 \text{ KHZ} < \text{PB} < 60 \text{ KHZ}$ passing band.

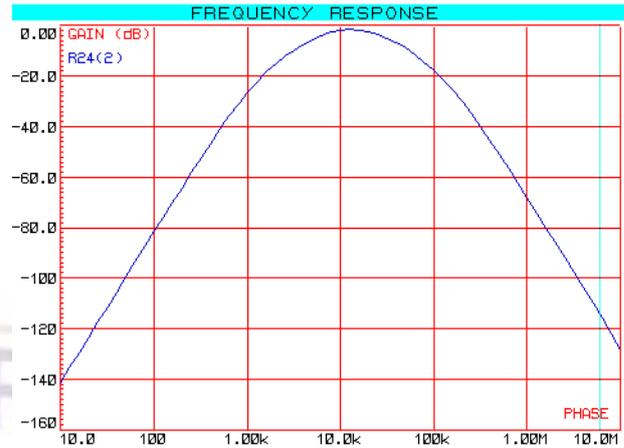


Fig. 18. Gain bound of mid-pass filter output

Now we turn to offer a suggested structure of continuous photonic crystals of Germanium and Silicon and according to offered explanations on detection, we study and simulate the conditions of this design and new function of structure through APD [8, 9].

In fact, the purpose of this paper is to offer an optical detector based on photonic crystals that has a combination of received beam and mid-pass filter block in wave length bound (625 nm – 645 nm) jointly, therefore we explain the characteristics of simulated filter completely.

V. OPTICAL FILTER AND DETECTOR DESIGNING

According to the general structure of optical receivers, that has been shown in figure (19) by considering all introduced noise resources, we have used defect exerting technic to periodic network to study applied filter and detector results [2, 9]. So by using of transfer matrix method or TMM we study the response of considered filter frequency in wave length bound with (625 nm – 645 nm) band width.

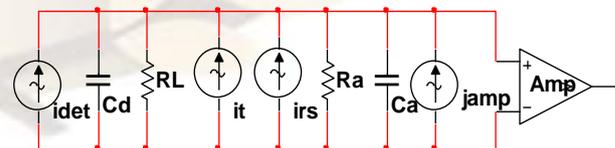


Fig. 19. Characteristic General structure of optical receivers

According to the effect of reinforcing input layer that contains (jamp current source, C_a capacitor and R_a resistance), in circuit of optical receivers (APD), we should consider quantum noise (i_{rs}) and thermal noise (i_t) in circuits and compare optical detector capacitor (C_d) and received optical detector

current (i_{det}) proportionate to R_L load resistance. In this structure, we have used 203 layers symmetrically from left to right first and last layers have been had Silicon and Germanium crystal with $n_{Si}= 3.45$ and $n_{Ge}= 4$ refraction coefficients, figure (20).

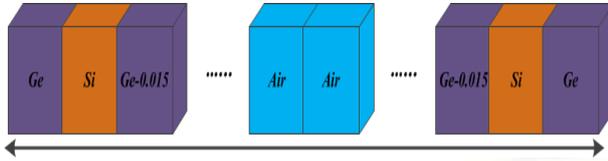


Fig. 20. 203- layer structure with air distance and apodization effect of refraction coefficient profile

In order to exert defect in mid layer, we have used air distance with $n_{air}= 1$ refraction coefficient (air distance has been considered in 102th layer) and apodization effect of refraction coefficient profile in optical filter behavior. Therefore in second to 101th layers, from left to right respectively with 0.015 steps, refraction coefficients are decreased till 102th layer with 1 refraction coefficient.

So from 103th layer to 202th layer, refraction coefficient is added with 0.015 steps conversely till finally in 203th layer Si and Ge crystal are used, so the total number of all layers is 203 layers. Also in this suggested sample, we use apodization method of refraction coefficient profile (Graded Index) to get desired band width [2, 8].

VI. EQUATIONS AND SIMULATION RESULTS

Performed simulation results are based on identical layers width ($d_l=10$ nm) and numerical modeling and have been used transfer matrix method (TMM). So conditions in TE mode and mathematical equations are studied as follows:

$$M = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} = D_0^{-1} \left[\prod_{i=1}^N D_i P_i D_i^{-1} \right] D_S \quad (21)$$

$$D_l = \begin{bmatrix} 1 & 1 \\ n_l \cos \theta_l & -n_l \cos \theta_l \end{bmatrix} \quad (22)$$

In this state, band width amounts are calculated through the calculation of D dynamic matrix and P spreading matrix in boundary conditions and TE mode by supposing θ_l as input wave angle and d_l as identical distance between two consecutive layers.

$$P_l = \begin{bmatrix} e^{-i\phi_l} & 0 \\ 0 & e^{-i\phi_l} \end{bmatrix} \quad (23)$$

$$\phi_l = k_{lx} d \quad (24)$$

$$k_{lx} = n_l \frac{\omega}{c} \cos \theta_l, l = 0, 1, 2, \dots, N, S_l \quad (25)$$

$$d_l = x_l - x_{l-1}, l = 0, 1, 2, 3, \dots, N \quad (26)$$

So by identifying the amounts of electric field matrix and A_0, B_0, A_s, B_s coefficients as first and last layer, we can observe and conclude transmission and reflection diagrams of signal.

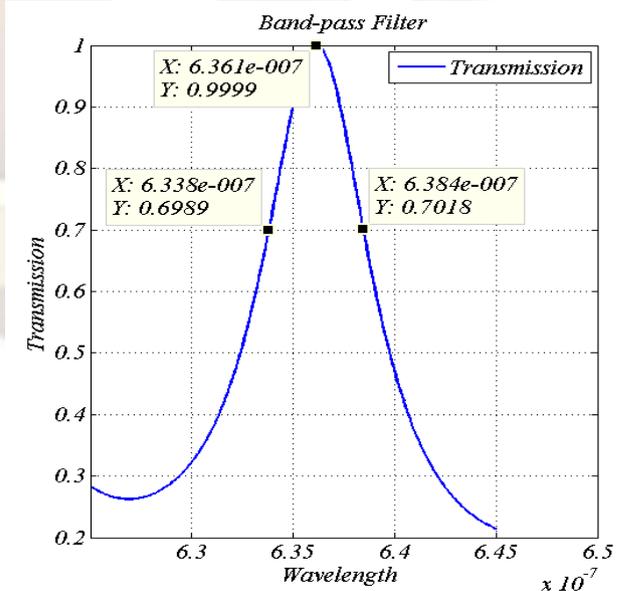
$$\begin{bmatrix} A_0 \\ B_0 \end{bmatrix} = M \begin{bmatrix} A_s \\ B_s \end{bmatrix} \quad (27)$$

$$T = \frac{n_s \cos \theta_s}{n_0 \cos \theta_0} \left| \frac{1}{m_{11}} \right|^2 \quad (28)$$

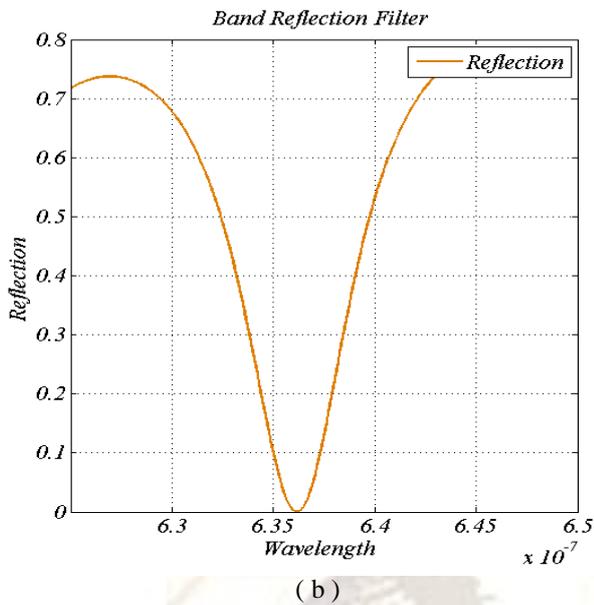
Since $\theta_0 = 0$ is input wave angle in first layer, $\theta_s = 0$, input wave angle in last layer, n_0 , refraction coefficient of first layer and n_s refraction of last layer, so band width amount of designed optical detector is measured and analyzed by equation (29).

$$T = \frac{n_s}{n_0} \left| \frac{1}{m_{11}} \right|^2 \quad (29)$$

Gained results of optical detector simulation are observed and studied in (21) and (22) figures. In this state we can receive transmitted beam in wave length band width bound of 630 nm to 645 nm and make distance measurement conditions possible by using of an optical converter to digital signal.



(a)



(b)

Fig. 21. Characteristic of optical detector output by using of apodization method of refraction coefficient profile – (a) transmission , (b) reflection

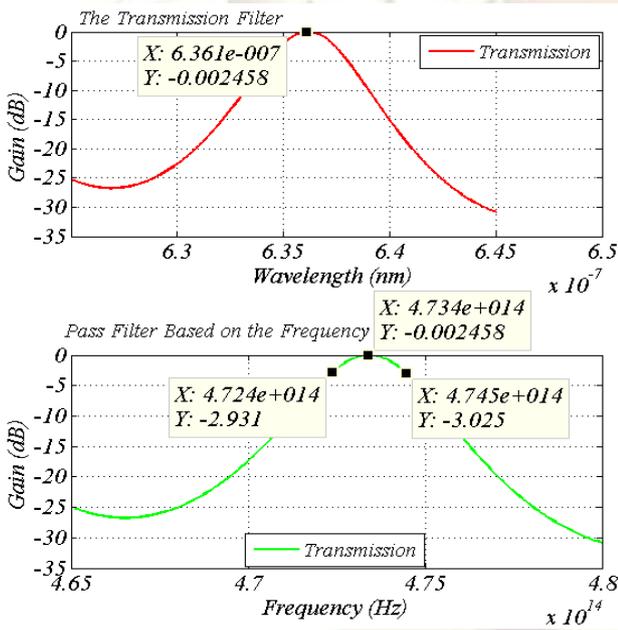


Fig. 22. Characteristic of optical detector output gain in terms of wave length(above figure) –in terms of frequency (following figure)

Now if there is change in layers width, there will be disorder in structure detector receiving bound. In order to prove this claim if we increase the width of layers($d_1=30$) identically, we will have frequency shift and beam receiving bound plurality and will not have beam receiving in 636 nm wave length or 473 GHz central frequency, suitably,so signal detector wave length is out of our design and it's not acceptable,figure (23).

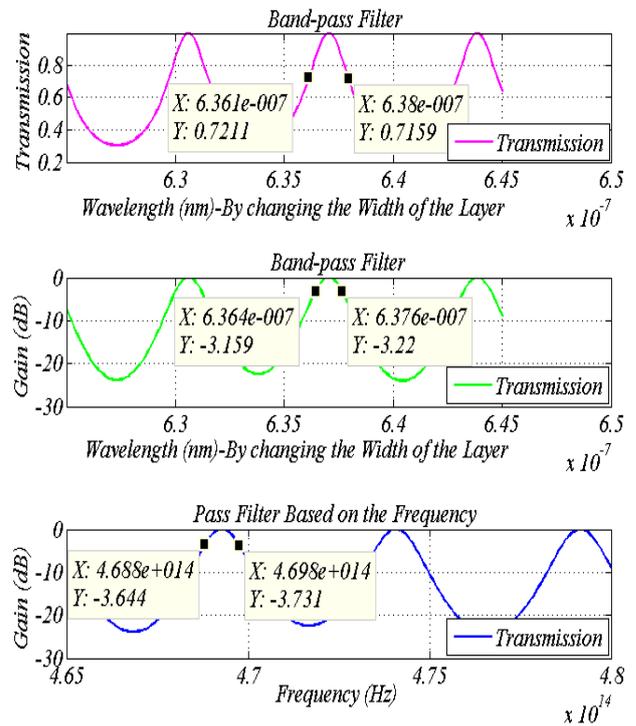


Fig. 23. Frequency response change of structure by the effect of layers width increase in identical amount ($dL1= dL2= 30$ nm)

In this level , in order to observe the function of passing beam from offered structure output and detector , we should suppose that mixed beam of figure (10) has been exerted to the suggested structure, in this way we analyze the output of designed detector , gained results are observed in figure (24).

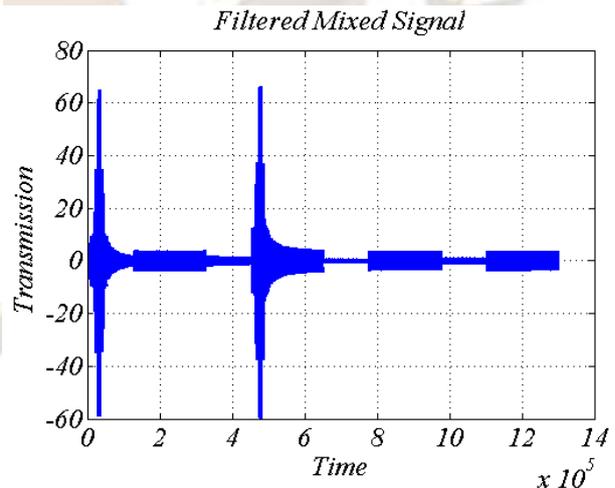


Fig. 24. Received beam figure of crystal detector So by receiving beam in designed structure bound , we can control system operation in this wave length and perform distance pulses count through exertion to an optical beam convertor to electric signal.

VII. COMPARISON OF APD OF S3884 MODEL BY DESIGNED PHOTONIC CRYSTAL STRUCTURE

According to the characteristics of APD optical receiver data sheet and offered third rank mid- pass filter in this design , received wave length in maximum peak is 800 nanometers. Since the wave length of selected laser receiver is 635 nanometers in peak amount , designed detector has been predicted in a way that has been set in nearest bound to laser transmitter wave length . Some differences of this detector with designed one dimensional photonic crystal structure are studied and observed in following table.

Table 1. The difference between a photonic crystal structure detector model

Type of detector	Photonic crystals	APD (S3884)
Spectral response range λ (nm)	630 to 645	400 to 1000
Cut-Off frequency (fc)	473 (Thz)	400 (Mhz)
Peak sensitivity wavelength λ_p (nm)	636	800
Type Filter	Method TMM	Circuit
Detector bandwidth filter	4.724 THz < PB < 4.745 THz	3 KHz < PB < 60 KHz
Type of Transmitter	Laser	Laser

VIII. CONCLUSION

In this study designing method of one optical beam filter and detector sample has been studied in wave length bound of 630 nm to 645 nm based on Germanium and Silicon photonic crystals structure. As it was observed , to measure longer distances by FMCW method , we should decrease the band width amount of continuous modulation wave or have the maximum amount of measurement by PIR increase.

Since there is limitation in B decrease or increase in alternation period of wave , that`s enough to provide condition in a way that transmitted beam is created in special wave length to perform detection in considered bound in opposite point and finally measure unknown distance through optical convertors to digital ones. So we can receive desirable result and maximum operation of received beam in maximum 473 GHz frequency proportionate to 636 nm designed wavelength maximum. Also we can use this detector in a condition which it has been set in front of optical beam transmitter

directly, so transmitted wave length will have identical beam receiving bound.

REFERENCES

- [1] Toshiya Mitomo ,Member, IEEE , Naoko Ono, Hiroaki Hoshino , Yoshiaki Yoshihara, Member , IEEE ,Osamu Watanabe, Member , IEEE, and Ichiro Seto , Member , IEEE “A 77 GHz 90 nm CMOS Transceiver for FMCW Radar Applications ” , IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 45, NO. 4, APRIL (2010).
- [2] Jian-Bo Chen , Yan Shen , Wei-Xi Zhou , Yu-Xiang Zheng, HaiBin Zhao and Liang-Yao Chen “Comparison Study of the Band-gap Structure of a 1D - Photonic Crystal by Using TMM and FDTD Analyses”, Journal Of the Korean Physical Society, Vol.58, No.4, April(2011)
- [3] Eugin Hyun , and Jong-Hun Lee “ Method to Improve Range and Velocity Error Using Deinterleaving and Frequency Interpolation for Automotive FMCW Radars”, International Journal of Signal Processing , Image Processing and Pattern Recognition Vol. 2, No. 2, June (2009).
- [4] Shahram Mohammad Nejad, Saeed Olyaei “Comparison of TOF, FMCW and Phase-Shift Laser Range Finding Methods by Simulation and Measurement”, Quarterly Journal of Technology & Education Vol .1 , No.1 Autumn (2006).
- [5] D. Dupuy, M . Lescure, M. Cousineau, “A FMCW Laser Range-Finder Based on a Delay Line Technique ” , IEEE Instrumentation and Measurement Technology Conference Budapest , Hungary, May 21-23, (2001).
- [6] Mohammad Nejad S. and Mirsaedi H. , “ Altitude measurement using laser beam reflected from water surface”, International Journal of Engineering Science , Vol. 1, No.1, (2005).
- [7] Leonhard Reindl , Member , IEEE , Clemens C. W. Ruppel, Senior Member , IEEE, Stefan Berek, Ulrich Knauer , Associate Member , IEEE , Martin Vossiek, Member, IEEE, Patric Heide, Senior Member , IEEE, and Lutz Oréans , “Design, Fabrication, and Application of Precise SAW Delay Lines Used in an FMCW Radar System ” , IEEE TRANSACTION ON MICROWAVE THEORY AND TECHNIQUES, VOL. 49, NO.4, APRIL (2001).

- [8] Lu Xiaodong , Han Peide, Quan Yujun ,Ran Qijiang, Gao Lipeng , Zeng Fanping , Zhao Chunhua , Yu Jinzhong “Optical response of high-order band gap in onedimensional photonic crystal applying in-plane integration ” , Optics Communications 277 (2007).
- [9] Safwat W. Z. Mahmoud, Moustafa F. Ahmed and M. A.Kaid “ Synthesis of Multilayer and Waveguide Filters for use in Optical Communication Systems”, Egypt. J. Solids, Vol. (28), No. (1), (2005).
- [10] Peter K.C.Chan,W.Jin,Senior Member,IEEE,J.M.Gong and M. S.Demokan, Senior Member , IEEE “ Multiplexing of Fiber Bragg Grating Sensors Using an FMCW Technique”,IEEE PHOTONICS Technology Letters,Vol.11,No.11,November(1999).

Authors' information



Reza Khodadadi was born in Tehran , Iran, in 1975.He received the B.Sc. and M.Sc degrees in electrical engineering , electronics , Islamic Azad University , Karaj branch , Karaj , Iran and Islamic Azad University , Ahar , Iran , in 2000 and 2012 , respectively. His research interests include Strengthening the Optical Sensors, Photonic Crystals, Laser,Wireless Networks, LNA,Audio Mixers ,RF Application , Signal Processing and Artificial Intelligence. Mr. khodadadi is a lecturer in Islamic Azad University, Karaj Branch, Karaj, Iran.



Parviz Amiri

Received B.S degree in electrical engineering from University of Mazandaran in 1994 and M.S Degree in electrical engineering From Khajeh NasirToosi(KNTU) University in 1997, and PHD degree in electrical engineering from Tarbiat Modares university in 2009 Tehran, Iran, He is currently research in electronic circuit designing in industries and university. His primary research interest is in RF and power electronic circuits, with focus on high efficient and high linear power circuit design. He is currently with the Department of Electrical Engineering at Shahid Rajaei teacher training University in Tehran, Iran.